Rapid Ecological Restoration for Aggregate Sites (RERAS)

Replication of Mature Hardwood Forests

Final Report

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1.0. EXECUTIVE SUMMARY

1.1. This Final Report summarizes the major research findings of the RERAS project, which TOARC has been funding since 2017 and has now concluded. We discovered that translocating topsoil and woody debris from a mature "donor" deciduous forest, requiring removal in preparation for quarrying, to nearby afforested lands rapidly advances the state of understorey succession at recipient sites. The degree of advancement was remarkable at 40-80 year-old conifer plantations featuring canopy gaps.

1.2. Major institutions are motivated to expand land covered by forests to combat climate change and biodiversity loss, but critics point to planted stands that exacerbate both crises. Improving afforestation by directing plantations towards high ecological similarity with outcomes of natural succession offers hope but faces challenges, including management preferences for planting coniferous stands in otherwise deciduous ecoregions.

1.3. We hypothesized that vegetation communities resembling the understorey of old natural deciduous stands can rapidly assemble at locations of younger successional age, provided managers distribute "living mulch" (topsoil and surface litter) extracted from a suitable donor stand experiencing advanced succession. We further hypothesized that such translocations will produce stronger similarity to the target (donor) forest where managers replicate "refuge" habitat structures on top of the living mulch layer, using translocated deciduous woody debris and ground-shading techniques.

1.4. We conducted experimental translocations in Clearview Township, Ontario, applying donor materials from mature, unplanted *Acer saccharum* (sugar maple) forest located near Duntroon that an aggregates producer must clear to prepare for their licensed quarry expansion. The experiment would have been impossible without logistical assistance and access to study sites provided by Walker Aggregates, Clearview Nursery and Clearview Township. Recipient sites for the living mulch were lands fewer than ten kilometers from the donor forest and on likely successional trajectories toward typical Niagara Escarpment forest. Each site started its trajectory at different points in the past including a former gravel pit undergoing passive rehabilitation since the late 1990s and planted stands established around 1940, 1985, and 2015. The youngest planted stand is comprised of diverse native deciduous and coniferous trees whereas the two older stands are typical silvicultural plantation forests, planted with mixed pines and spruces. We translocated living mulch to new locations within the larger sugar maple stand containing the donor forest, to determine the effectiveness of the translocation techniques when recipient habitat is optimal for the biodiversity within the living mulch. As each recipient site represents a stage or "sere" of forest succession (albeit modified by people), the locations are labelled and discussed as S1 (gravel pit), S2 (young plantation), S3 (middle-aged plantation), S4 (old plantation) and S5 (old-growth deciduous forest).

1.5. In order to determine the effectiveness of living-mulch addition for changing recipient ecosystems to resemble target forests more closely, we compared the species compositions of ground-layer vegetation communities emerging from "blocks" of deposited living mulch to vegetation growing at nearby not-treated (NT) areas of each site. To determine roles that recipient-site habitat conditions play in determining translocation outcomes, we left one quadrant of each recipient block alone (LM) but modified the remainder. We first distributed additional large woody debris items harvested from the donor forest (mainly fallen limbs, trunks and stumps), then installed a shade-cloth shelter (SS) in one quadrant, planted a shrub cluster (SC) of dogwood saplings in another, and left the third with just the extra woody debris (WD). Contrasting LM vs. NT tests the effect of translocating just living mulch.

Contrasting WD vs. LM tests additional benefits from arranging woody debris refuge structures on top of the living mulch. Contrasting SS and SC vs. WD tests further gains from installing non-living and living sources of ground shading, respectively. As a complementary test, we measured the percentage of ground covered by woody debris throughout all sites and treatments and evaluated how vegetation responded to this quantity directly.

1.6. We carried out extensive sampling of vegetation communities (our preferred indicator of ecosystem response) throughout the donor forest and recipient sites beginning in May 2018 (7 months post-translocation) and concluding September 2021. The most appropriate set of quantitative data for our statistical analyses represents “early-season” understorey communities from 2018-2020 (including spring ephemerals) and “late-season” communities from 2018-2019. Follow-up field visits in late summer 2020 and 2021 enabled qualitative site evaluations including photographs. We focused our analyses on the number and identities of plant species occurring on small patches of ground throughout each treatment and site, calculating the degree of compositional similarity between samples from recipient sites and samples from the donor forest using the Jaccard definition. We used linear model analyses to investigate the effects of habitat treatments within each recipient sere on this calculated “Community Similarity” metric. We complemented this approach using non-parametric ordination analyses (DCA, CCA) that tracked the roles of each individual species in influencing multivariate similarity.

1.7. The results from both analytical approaches point to similar conclusions. The calculated Community Similarity values were significantly greater for the vegetation sampled from living-mulch blocks than not-treated areas but degrees of difference varied among seres. We calculated similarity scores comparing different areas within the donor forest to each other and took the mean value as a “bar” representing maximum scores likely at recipient areas producing vegetation compositionally equivalent to the donor forest. Vegetation emerging from living mulch at S5 expressed this target score, indicating that our specific translocation methods produce vegetation extremely similar to the donor-forest community when optimal habitat features exist at the recipient site.

1.8. Not-treated areas of the former gravel pit (S1) and the recently afforested field (S2) supported vegetation communities differing strongly from each other and from the donor forest. The donor-similarity scores for these areas, based on early-season sampling, were values approximately 15% and 13% of the target bar, respectively. Recipient-block quadrants receiving no additional habitat modifications at these sites produced communities with donor-similarity scores 45% and 36% the target value. Combinations of additional woody debris and shade shelters produced respective scores 52% and 54% the value of the maximum-similarity target. The shade shelters alongside woody debris at S2 produced a statistically significant jump in the similarity score compared to the effect of woody debris alone. Not-treated areas of both conifer plantations expressed similarity scores 21% the target value but skyrocketed to scores 64% and 73% the target value, respectively, following living mulch translocation to S3 and S4. At the middle-aged plantation (S3), assembling the additional woody debris structures produced a score 75% the target value, representing a statistically significant increase over living-mulch only.

1.9. The late-season vegetation samples exhibited similar patterns to the early-season ones except less pronounced, e.g. some habitat modifications that produced significant effects on the early-season species composition did not influence the late-season community. Analyzing donor-similarity at not-treated areas and recipient blocks in response to percent ground cover by woody debris indicated that our treatments tended to double or triple woody debris cover previously present and achieve average levels resembling the donor forest. Importantly, similarity to the donor-forest plant community increased significantly with woody debris cover at S2 and S3 recipient blocks. Results predict that establishing 45-55% woody debris cover over living mulch patches should yield the greatest vegetation similarity to the donor forest: 75% the target value, in the case of a middle-aged conifer plantation.

1.10. Results from ordination analyses incorporating early-season and late-season samples confirm that not-treated areas of the relatively open recipient sites (S1-S2) support vegetation communities quite distinct from each other and the donor forest. Not-treated and treated areas of the mature, unplanted forest (S5) support communities highly similar to the donor forest. Not-treated areas of the conifer plantations support compositions halfway between the open sites and S5. Against this backdrop, living-mulch recipient blocks at S1 and S2 produced vegetation communities shown in ordination space as moderately displaced from communities occupying the not-treated areas and nearer to the position of the donor forest. Areas under shade shelters supported communities occupying ordination space even closer to the donor forest, by a small margin. Some of the increased similarity was due to exclusion of old-field weeds otherwise dominating much of the open sites.

1.11. Vegetation samples from living-mulch blocks at conifer plantations S3-S4, in contrast, occupied ordination space immediately adjacent to the donor forest, indicating near-equivalence in terms of species composition. The middle-aged plantation community was especially similar to the donor forest: peak abundances of several native herbs considered iconic of Ontario’s heritage deciduous (e.g. trilliums, wild leeks, wild ginger, Jack-in-the-pulpit) occurring at equally at S3 and the donor forest. The ordination analyses demonstrated that the amount of woody debris ground cover contributed significantly to compositional turnover that headed in the direction of donor-forest vegetation communities.

1.12. Cumulatively, results from the RERAS project show that translocating living mulch from a mature, unplanted deciduous forest to lands at earlier positions along a forest succession can rapidly advance aspects of the successional stage exhibited by recipient sites. Applying living mulch can make understorey vegetation communities compositionally similar to late-successional donor forests, opposing the major criticism that afforestation is unable to achieve such similarity. Appropriate sources for living mulch may be rare but, where available, they offer substantial opportunities to improve the outcomes of the various tree-planting initiatives pledge and ongoing worldwide. Extractive industries including aggregates production must collaborate with afforestation managers to help realize these opportunities, including producing reliable research to guide industry-scale applications in different regions.

1.13. Aggregate producers may successfully translocate living mulch they generate during extraction to help meet onsite rehabilitation or mitigation needs but our results demonstrate that the greatest return-on-investment for the natural capital inherent in living mulch biodiversity requires translocating the material to locations already experiencing moderate-to-heavy canopy cover. Our most surprising finding was that coniferous plantations aged 40-80 years are fully capable of functioning as “nurse” canopy for the deciduous-forest communities that emerge. This is likely because such plantations feature canopy gaps wherein succession toward deciduous forest is ongoing, albeit slowly. The critical implication of this finding is that aggregate producers with living mulch resources available right now do not need to wait decades for present-day afforestation efforts to reach maturity. Rather, they may collaborate with managers of existing conifer plantations to achieve truly rapid positive ecological changes, by improving expanses of existing mature and maturing plantations that are otherwise “green deserts” with respect to native woodland biodiversity.

1.14. Targeting materials to the most suitable sites will provide greatest bang-for-buck given the scarcity of living mulch resources and the value of their inherent biodiversity. Fortunately, results from our habitat “refuge structure” treatments offer insight for converting less-suitable sites to ones capable of supporting target vegetation. One of the most reliable methods will be to ensure appropriate sized clearings and canopy gaps prior to living-mulch deposition, then oversee establishment of variable but generally high ground cover (45-55%) by deciduous woody debris at varying stages of decomposition. Constructing sources of artificial shade can improve outcomes modestly at more open sites, when applied at the small scale we tested. Creative strategies for imposing artificial shade at larger scales may provide effective new methods for accelerating woodland succession at open locations such as former extraction sites requiring rehabilitation.

1.15. Extending the lessons learned from the RERAS project to forest management broadly is likely to help managers of living-mulch sources network with managers of the most suitable recipient sites to realize fully the biodiversity value inherent to living mulch. This is not to say that treated lands can necessarily function as perfect ecological replacements for the converted forests; important distinctions will remain. Rather, converting forests when necessary combined with strategic translocation programs will benefit regional forest biodiversity and functioning, more so than status quo methods of clearing woodlands but stockpiling living-mulch components under conditions that prevent them from living for long. Applying the RERAS findings will ultimately help the aggregates industry more fully achieve its longstanding objective of sustainably providing essential mineral resources, by maximizing ecological compatibility between extraction operations and the surrounding environment.

2.0. INTRODUCTION

2.1. Forests are essential

Impacts of climate change and the current mass extinction event that is eroding global biodiversity have forced the world to wake up to its crucial reliance on forests [1]. Lands covered by closed canopies of mature trees produce oxygen, sequester carbon dioxide, and provide critical habitat for diverse flora, fauna and soil communities. The interactions among species and their woody, shaded environment drive numerous ecosystem processes (i.e. related to the cycling of materials, like nutrients through food webs) that ultimately provide people with important fibers, fuels, foods and livelihoods [2].

Destruction of forests worldwide has contributed to major biodiversity declines by removing the specialized habitat conditions that plants, animals and fungi are adapted to and require – the open environments remaining after forest clearcutting, for example, are intolerable for the large components or forest communities that are shade-dependent during early development [3]. Emissions from burning forests to establish agriculture, and of course fossil fuels and multiple sources, have changed the Earth's relationship with solar radiation to a point that climate warming is ongoing and will continue, alongside skyrocketing levels of temporal variability exhibited by many climate factors (e.g. extreme weather events). This trend would likely slow and reverse if sufficient carbon dioxide could be extracted from the atmosphere and stored – a possibility if enough land that is presently not forested can be commandeered to support the growth of tall trees [4].

Global efforts to fight climate change emphasize the need for countries to halt and reverse deforestation, including by restoring forests in the midst of impact and by establishing new forests on lands that may once have supported woodland but more recently experienced conversion to uses such as agriculture [5,6]. Efforts in the former category are generally termed "reforestation" while those in the latter classify as "afforestation"[7]. World leaders and financial institutions have made significant commitments to support implementation of major programs to restore and create forests, such as the United Nations declaring the current decade a "Decade On Ecological Restoration" and the US $19 billion pledge by over 100 countries at this year's 26th Conference of the Parties, in Glasgow, to enhance forest protection. Unfortunately, inadequate commitments do not hamper afforestation's capacity to improve the biosphere nearly so badly as unsuitable management practices, which are unable to meet objectives of whole-ecosystem restoration.

2.2. Problems with plantations

Part of the problem comes from viewing the climate and biodiversity crises independently rather than as to sides of the same coin. Planted forests sometimes come at the expense of other ecosystems that are just as valuable as forests, or more so, with respect to supporting ecosystem processes that everyone relies on (e.g. natural grasslands or savannas planted with trees stop providing critical habitat to native species including pollinators)[8]. Even on historically forested lands where future forests make "ecological sense" – i.e. where natural succession is likely to generate new forest cover eventually, if left to its own devices – conventional forest-creation practices (e.g. plantation forestry) often fails to establish diverse, healthy ecosystems because management goals focus on the "crop" of trees [9]. The greatest deficiencies relate to the forest understorey: tall shrubs and small trees that often produce sporadic, intermediate woody layers and especially the vegetation communities that develop on the forest floor. In most forest types, including those that dominated southern Ontario and much of eastern North America prior to

European settlement (e.g. sugar maple stands), ground-layer vegetation comprises the largest fraction of plant biodiversity and directly services faunal and fungal components, contributing collectively to forest health (e.g. resistance and resilience in the face of extreme weather events or pest outbreaks)[10].

The major fault with many plantation-style forests established in historically forest-dominated regions such as southern Ontario is that, although the planted trees may grow tall and healthily, the plantation floors do not support vegetation communities that bear any resemblance to the understoreys of forests in the same region that developed via natural succession only [11]. Successional forests generally host plant communities rich with native herbs (e.g. wildflowers, sedges), shrubs, vines and saplings long-adapted to shade and other habitat conditions produced by the region's dominant trees (e.g. accumulated piles of maple leaf litter and fallen logs or trunks). Plantation understoreys, in contrast, often appear completely barren of herbaceous cover, until closer inspection reveals a handful of scattered species [12]. These generally include exotics (i.e. introduced from outside of Ontario), which can sometimes become invasive (e.g. some plantations appear to have no patch of floor not covered by dog-strangling vine). Planted forests may therefore appear to meet environmental goals related to carbon capture but fail to support biodiversity and ecological functioning associated with mature unplanted forests, lending their label as "green deserts" by critics [9].

The reasons for large ecological discrepancies between planted forests and those arising solely from succession can be complex and vary among regions and management paradigms [13]. A key factor relates to the common goal of achieving closed canopy by trees (with desirable traits) over a much shorter timespan than would normally be required for succession to play out. In temperate deciduous regions like southern Ontario, where slow-growing hardwood trees dominated historically, achieving relatively fast canopy closure (including trees harvestable for various ends) usually means planting coniferous (softwood) trees [14]. The species used historically (and in forest-product oriented industries still) were often exotic (e.g. Norway spruce, Scots Pine) or native but with only minor roles within the mostly deciduous pre-settlement forests (e.g. red pine).

Such plantings are successful because foresters choose tree species that are well suited to the local soil and climate conditions but the understorey habitat conditions they generate pose several stringent challenges to ground-layer plants and animals that evolved in deciduous forests. Thick layers of shed conifer needles rather than broadleaves characterize plantation floors, providing distinctly harsh growth substrates for most plants (e.g. absence of nutrients, slow to decompose, acidic). The structure of coniferous plantation canopies (and their consequent ground-shading properties) also differs from deciduous stands, most notably in spring, as does the character of woody debris habitats that accumulate on the ground. The woody structure of planted stands also differs from mature unplanted ones, even in cases where managers plant native deciduous trees rather than conifers, as plantations tend to be highly homogenous with respect to tree ages and spacing (e.g. a single cohort of trees planted in rows at the same time).

A final layer of difficulty facing succession in many plantations is that even should ground-layer habitat conditions develop that are suitable for the rich communities of native herbs found in mature deciduous forests, the capacity of such species to successfully immigrate to plantations may be exceedingly low. Species producing canopy and sub-canopy layers in deciduous forests can often dispersal over long distances relatively quickly due to wind, bird and mammal-assistance but characteristic ground-layer flora (e.g. wild ginger, leeks and trilliums) require ants and face multiple constraints expanding their populations [15]. Such species may therefore never have the opportunity to colonize plantations that are distant or disconnected from mature deciduous forests, even where the ground-layer habitat conditions are suitable (e.g. at older conifer plantations where planted stock was harvested and “volunteer” hardwoods established through succession).

2.3. Road to solutions?

Our previous research on plantation succession (the TOARC-sponsored “Afforested Environments Study) showed that such suitable-but-unoccupied habitat does emerge in coniferous and mixed Ontario plantations approximately 50-70 years after planting [16]. Indicator plants – wild ginger and leek root material that we translocated from mature deciduous forests to experimental plantation sites not previously occupied by these herbs – demonstrated the potential to enhance biodiversity at older plantations exists. The superior responses at plantations amended with fresh soil from the “home” deciduous forests, however, suggested that improvements to ground-layer habitat conditions at plantations would likely be required, alongside assisting immigration, to achieve forest communities and functions resembling the deciduous “target” ecosystem.

We designed and carried out the present study (the “RERAS” project) to discover whether managers could utilize resources uniquely available to extractive industries to advance succession within planted forests towards a state better resembling mature unplanted forests within the same region. Overcoming successional challenges related to the structure of plantation canopies may be achievable over the long-term through education of forest planners and managers but we hypothesized that a relatively rapid solution may be achievable with respect to understorey biodiversity via collaboration with aggregates producers needing to clear patches of unplanted forest where they are developing new mineral resources.

2.3.1.. The “living mulch” transplantation hypothesis

Specifically, the upper layers of forest floor in mature deciduous stands requiring clearing may serve as source for a “living mulch” capable of helping many understorey species overcome immigration and habitat constraints at planted forests, if translocated directly in bulk to appropriate recipient sites and distributed throughout the ground layer. Comprised of surface leaf litter, woody debris and underlying topsoil that contains nutrients and diverse organisms (ranging from plant seeds and living roots to symbiotic fungi, bacteria and invertebrate communities), such living mulch could substantially enhance the biodiversity and functioning of recipient planted forests by producing ecological communities similar to those occupying unplanted forests. The benefits of such an outcome would depend on the degree of similarity achieved but are likely to include locally increased population abundances for native woodland herbs and increased support to the pollinators and food webs these service. Over time, sub-canopy and canopy layers would likewise increasingly resemble unplanted forests and perform similar ecological functions, including carbon sequestration.

Our understanding from the Afforested Environments Study suggests that such successful outcomes of living mulch applications are only likely where appropriate habitat conditions at recipient sites exist, e.g. related to the amount of ground shading or accumulations of coarse woody debris. Habitat features and properties at recipient sites should not diverge far from the conditions that most organisms within the living mulch can tolerate but managers may be able to direct materials appropriate environments either by selecting sites exhibiting suitable habitats, engineering conditions at recipient sites to be more hospitable to understorey biodiversity, or both at once. Our hypothesis about the potential utility to afforestation of living mulch from developing aggregates production sites is somewhat inspired by successful applications of a similar approach to surface-mine reclamations in Australia and New Zealand (termed Vegetation Direct Transfer) [17,18] as well as to mined lands around Sudbury, Ontario [19]. Direct translocations of forest topsoil have been rare in southern Ontario, however, and never studied rigorously (to our knowledge) such that ecologists can confidently predict which successional stages or conditions at afforested sites are capable of “accepting” versus “rejecting” the forest ecosystem “transplantation surgery” we propose.

2.4. RERAS objectives and general method

One main objective of the RERAS project was therefore to determine how lands at different early stages of forest development respond to living mulch, with respect to their capacity to produce “target” forest-floor plant communities (i.e. ones that are compositionally similar to the ground-layer of the mature unplanted forest providing the living mulch). The second objective was to determine whether physically altering recipient sites to more closely resemble target habitat conditions (e.g. by increasing availability of shade and woody debris) can enhance the degree of vegetation similarity achieved by living mulch translocation.

As described in the Methods section, we initiated an experiment in 2017 capable of meeting these objectives and testing the utility of forest-floor translocations and habitat mimicry to enhance the outcomes of afforestation. The experiment grew from our collaboration with an aggregates producer, Walker Aggregates, whose licensed expansion of their Duntroon quarry (in Clearview Township, Ontario) provided an ideal opportunity to access and distribute living mulch and additional woody debris from the floor of a mature unplanted sugar maple forest (i.e. capping the section of Niagara Escarpment to be quarried). We likewise worked with Walker Industries’ collaborator Clearview Nursery to translocate the materials from the maple forest to recipient locations including a former gravel pit owned by Clearview Nursery that represented land at a very early stage of succession. Although not planted with trees, this former pit lies surrounded by Niagara Escarpment deciduous forest and supports some patches of early-successional tree species including poplars, cherries and cedars. Like other extraction sites, however, much of the ground is dry, rocky, and largely barren of vegetation, and elsewhere supporting herbs typical of meadows or fallow agricultural fields rather than forests. Representing the earliest stage (or “sere”) of succession among our experimental recipient locations, we refer to this Clearview Nursery Pit as S1.

Stands of planted trees at progressively later stages of succession within a few kilometers of the Duntroon Quarry “donor” forest (site “D”) provided three additional opportunities to test how translocating living mulch may alter the understorey species composition of afforested sites. Stands established around 2015 using a high diversity of native hardwood species provide site S2, corresponding approximately to the “stand initiation” stage of forest succession, when trees are abundant but a closed canopy is still decades away and ground between trees is dominated by “old field” herbs and aggressive grasses (including many exotics). Stands of older conifers (primarily mixtures of white pine, white spruce and red pine), established around 1985 on portions of the Duntroon Quarry property that will not be extracted, provide site S3. The ecology of this location corresponds to the beginning of the “understorey re-initiation” stage of forest development, when gaps begin forming in an otherwise dense canopy of young trees but the understorey is largely devoid of herbaceous vegetation.

An even older plantation of similar conifers, owned by Clearview Township and established around 1940, serves as site S4, corresponding to the later end of the “understorey re-initiation” stage. Much of the original conifer canopy cover has died back or become harvested but “volunteer” hardwoods similar to portions of the surrounding Niagara Escarpment forest have filled in many of the gaps. Strong legacies of the planted canopy remain however, especially in the properties of litter and woody debris on the plantation floor, and the sparse vegetation comprising the ground layer.

Mature unplanted sugar maple forest contiguous with the patch to be cleared but located on at a section of the Duntroon Quarry that will not be impacted by the expanding extraction zone provides the latest-stage recipient site, S5. As an unplanted rather than afforested site, S5 primarily functions as an experimental control for testing how vegetation residing in the living mulch responds to the shock of transplantation itself, independent of how suitable or unsuitable new habitat conditions may be. If the method of translocating living mulch is essentially sound (i.e. the physical activity of excavating and depositing topsoil only minimally damages viability of the species within it) then recipient habitat conditions will be the chief determinant of outcomes. Translocating living mulch from site D+ to S5 and finding that the emergent communities at S5 are compositionally very similar to those at D+ would demonstrate this.

2.5. Testing the hypotheses

The main test of whether earlier stages of succession respond to living mulch application by increasing in similarity to mature forests with respect to their understorey is to compare treated and untreated areas at each recipient site (S1-S4) to the plant communities occupying site D. We further investigated whether different strategies for mimicking habitat features of the donor forest at each recipient site could increase the effectiveness of living mulch translocations in eliciting compositional change. This required making various comparisons among up to five different treatment levels at each recipient site. We compared the donor forest understorey to Not Treated (NT) areas throughout S1-S5 and to adjacent areas where we translocated Living Mulch (LM); additionally, we evaluated plant communities within subsections of the LM areas where we overlaid additional habitat changes. These include sections that received additional accumulations of Woody Debris (WD) extracted from the donor forest, and areas that received both extra woody debris and a planted Shrub Cluster (SC) to increase ground shading. Finally, at the earliest-stage sites where minimal canopy cover was present (S1 and S2), we built Shade-cloth Shelters (SS) as a potentially more reliable source of ground shading at some locations that also received living mulch and woody debris.

If depositing additional accumulations of woody debris improves outcomes of living mulch translocations then areas receiving treatment level “+LM+WD” should produce ground-layer communities that are more highly similar to the donor forest understorey than are areas treated with just “+LM”. If planting shrub clusters or erecting artificial shade shelters can produce even greater “similarity gains” then “+LM+WD” areas should exhibit weaker similarity to the donor forest than “+LM+WD+SC” or “+LM+WD+SS” areas, respectively. Alternatively, if translocating living mulch and mimicking habitat features has no capacity to increase community similarity to the donor forest at a recipient site then plant communities in the treated areas should not express any greater similarity to the donor forest than the NT areas of that site.

2.6. Benefits from new knowledge

Discovering that translocating living mulch from mature unplanted forests to young planted stands or successional lands can cause recipient sites to represent closely the understorey biodiversity of donor sites would provide proof of principle that an occasional by-product of the aggregates industry may have outsized value in helping to meet goals of forest creation and restoration, if applied strategically. Learning which combinations of natural and engineered habitat conditions at recipient sites lend to greater and lesser levels of donor-similarity would guide managers in using living mulch efficiently by preparing suitable habitats and directing resources to locations most likely to "accept" the ecosystem transplantation successfully. Implications of following the lessons include likely improvements to the overall efficacy of forest management in fighting both climate change and biodiversity loss via restoration and afforestation programs. Aggregate producers stand to benefit indirectly, as suppliers of a rare resource with high value in helping to resolve global problems. They also stand to benefit directly, as any improved ability to direct early-successional lands towards greater resemblance of mature unplanted forests will be likely to increase success of industry-related activities aimed at rehabilitating extraction sites or restoring forests and setting them aside to mitigating impacts of new developments (e.g. "biodiversity offsets").

3.0. METHODS

3.1. Study sites: Donor forest and recipient seres

Our living mulch translocation experiment utilized six separate (though in some cases adjacent) locations within fewer than 10 km of each other, all located on lands along the Niagara Escarpment near Collingwood, Ontario. Natural succession there tends to produce deciduous forests dominated by sugar maple trees, over the course of centuries, but much of the landscape presently supports agriculture as well as some former fields converted to tree plantations. The plantations mostly feature mixed conifers (pines and spruces) planted to combat soil erosion in the mid and late 20th century then managed for forest health in a manner yielding light timber harvests (e.g. selection or row thinning every 15-30 years). A few limestone quarries have long been active on the Escarpment a few kilometers west of the town of Duntroon, including the Walker Aggregates property we had access to for our experiment, whereas several smaller gravel pits dot the wider landscape. Some of the pits are active, others rehabilitated and a few have been undergoing spontaneous succession for decades without rehabilitation – including the Clearview Nursery Pit we had access to for our experiment.

In December 2019, we submitted our Interim Report to TOARC. This document (available via TOARC's website) presented thorough descriptions of the six study sites, including the methods used to select them and their capacity to represent more general ecological processes influencing the landscape in southern Ontario. Rather than repeat such details here, we encourage review of the Interim Report (section 3) but again share the table and figures to provide an overview of all details pertinent to understanding the results and conclusions of our study.

Table 1: Niagara Escarpment field locations near Duntroon, Ontario, utilized in the living mulch (LM) and microhabitat translocation experiment

Code	Location name	Location type	Site description	Area (ha)	UTM (Zone 17T)
D+	LM Donor forest	Primary *Acer saccharum* stand	Primary upland (c. 450 m a.s.l.) *Acer saccharum* forest, with sections requiring clearing prior to licensed aggregate extraction; two such patches (N, S) were partially excavated to extract bulk LM (i.e. forest floor litter and topsoil layers) for immediate relocation to recipient seres in Oct. 2017	6.0	559709.00 m E 4915535.00 m N
S1	LM Recipient Sere 1: Primary succession	Disused gravel pit	Site of limestone sand and gravel extraction (c. 1940-1990) located < 7 km NE of D+; undergoing spontaneous succession, having never been rehabilitated	1.5	565109.00 m E 4919943.00 m N
S2	LM Recipient Sere 2: Afforestation at stand-initiation	Old field afforested in 2015	Native deciduous and coniferous trees planted on former farmland (< 0.5 km N of D+) to help offset clearing of D+; field underwent spontaneous succession for 5 years prior to planting with 20 tree species, which was followed by 2 years of irrigation and weed-control	6.0	559640.00 m E 4915723.00 m N
S3	LM Recipient Sere 3: Afforestation at stem-exclusion	Old field afforested c. 1985	*Pinus strobus* + *Picea glauca* plantation, established along edges and patches of the licensed extraction site (< 1 km NE of D+) that will not be extracted, and which required soil stabilization; not managed for wood production	1.5	559965.00 m E 4916232.00 m N
S4	LM Recipient Sere 4: Afforestation at understorey reinitiation	Old field afforested c. 1940	*Pinus resinosa* + *Picea glauca* plantation, established on former farmland < 4 km E of D+, to help stabilize soil; not managed for wood production	1.3	563981.00 m E 4916209.00 m N
S5	LM Recipient Sere 5: Old-growth forest	Primary *Acer saccharum* stand	Mature forest that is contiguous with and identical to D+, but outside the planned extraction zone (<0.5 km W of D+)	4.5	559439.37 m E 4915438.26 m N

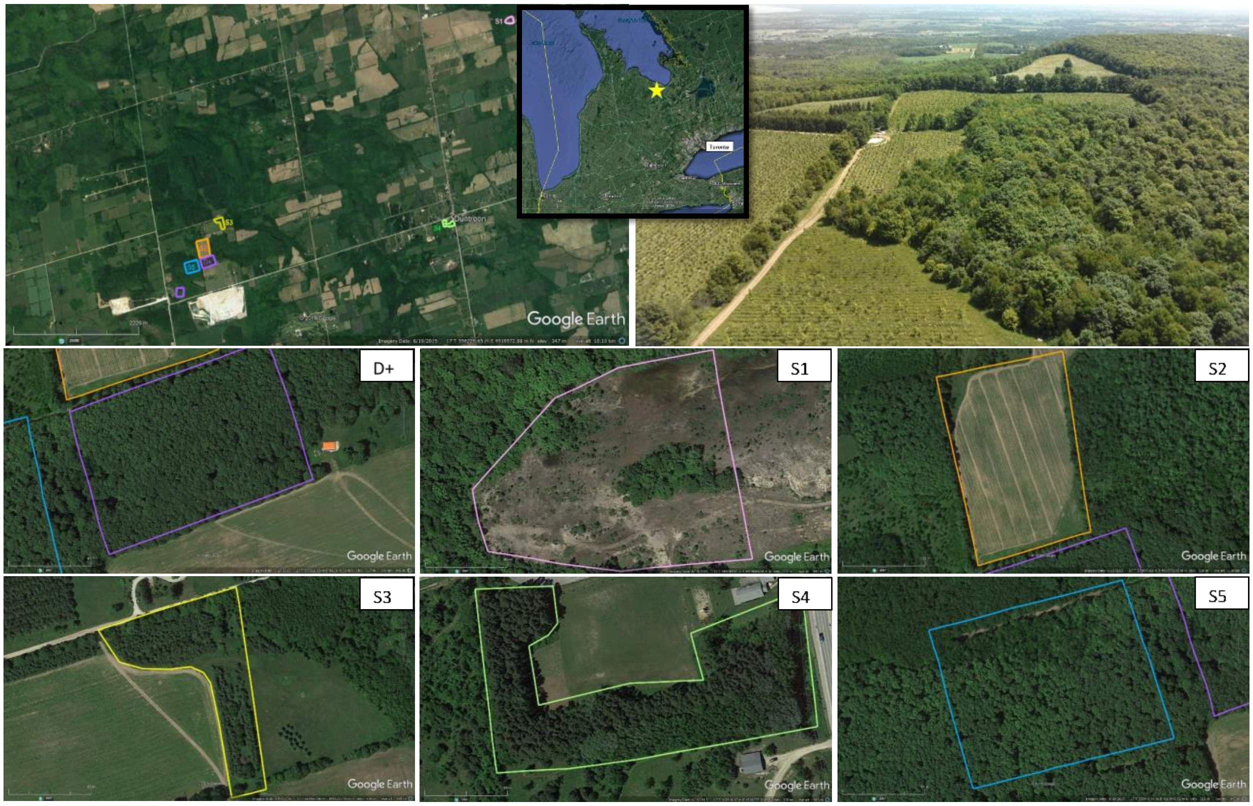

Figure 1. Overhead satellite imagery of the donor forest (D+) and recipient seres (S1-S5) incorporated into the living mulch and microhabitat translocation experiment (Duntroon, ON, Canada). Produced using Google Maps.

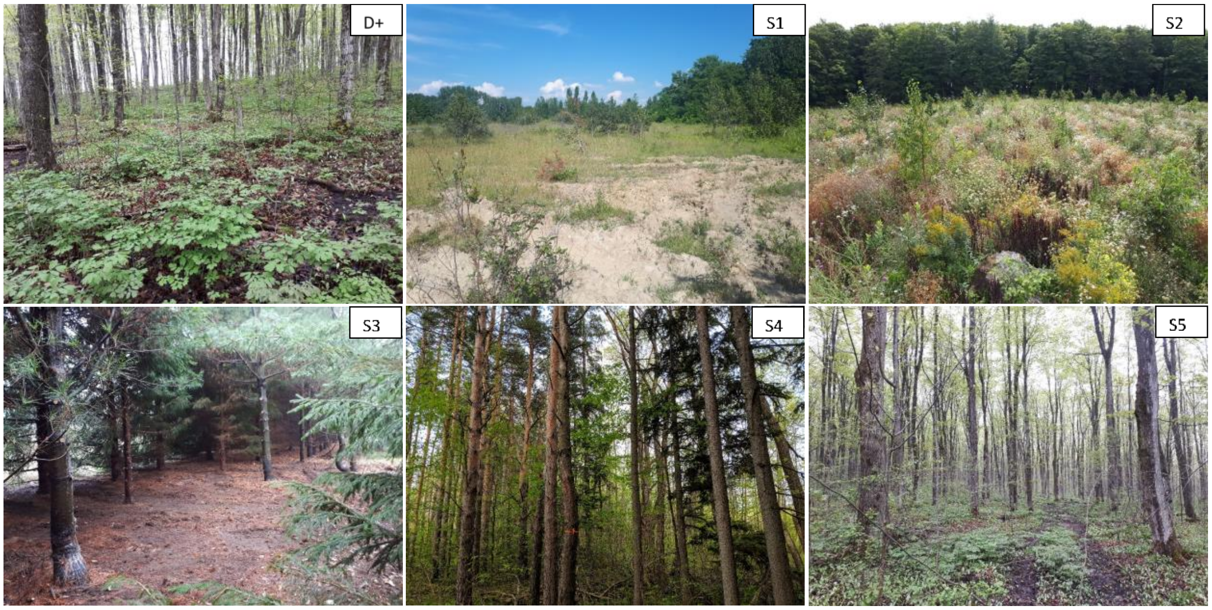

Figure 2. Donor (D+) and recipient (S1-S5) seres incorporated in the living mulch and microhabitat translocation experiment (Duntroon, ON Canada).

3.2. Applying the living mulch (+LM)

We began installation of the experiment at the end of October 2017, after most vegetation had entered states of dormancy for winter but before winter weather could interfere with operations. The work consisted of progressively extracting LM from selected zones within D+ using light excavation equipment and transporting truckloads of the material to recipient blocks at S1-S5 on the same day as extraction. The excavated LM included forest floor organic litter layers (leaf litter, small (fine) woody debris, some larger (coarse woody debris) plus the underlying 30 cm of topsoil. The topsoil component included inherent vegetation, propagules (e.g. seeds, spores, roots), micro-fauna and microbes. We salvaged 1-3 m tall saplings with intact root balls during excavation and hand-planted them in the freshly deposited LM at recipient blocks (ca. 5-7 saplings per block). Each recipient block consisted of a 12.5 m x 10 m areas which was cleared of major obstructions (including mowing and herbicide application for the dense herbaceous cover at S2) and then filled with a 30 cm deep layer of LM (including working around existing trees). To facilitate the logistics of LM application, we established recipient blocks in the wooded sites within areas that included small natural clearings more than dense tree cover. Within S2, we established recipient blocks at five locations within a field planted with trees in 2015 and at five locations within a field planted in 2016. After confirming conditions and early responses in the two fields were essentially the same, we selected five blocks from across the two fields to represent site S2 in the remainder of our sampling surveys.

At each of the other recipient environments (S1, S3-S5), we installed five replicates of the LM block. In total, we installed 30 LM recipient blocks, each corresponding to 125 m^2 of ground area.

3.3. Mimicking target habitats by installing refuge structures

To meet our objective of determining whether replicating ground level habitat conditions likely important to understorey vegetation in mature unplanted forests can improve the effectiveness of LM applications, we created “microhabitat refuge structures”. These correspond to relatively small-scale physical changes that managers can at LM recipient sites that will likely make the environment less stressful for organisms adapted to shady habitats featuring sporadic piles of decaying hardwood trunks, stumps and fallen limbs. We subdivided each of the LM recipient blocks into four equal quadrants (6.25 m x 5 m) and, in spring 2018, we imposed the following four levels of our microhabitat refuge treatment. Table 2 displays a summary of the treatment levels. In one of the quadrant areas in each recipient block, we did not impose any additional changes after depositing the LM; we refer to this level as +LM.

3.3.1. Translocating additional woody debris (+LM+WD)

To the remaining three quadrants in each block, we introduced approximately 10-15 m^3 of additional woody debris (hereafter WD) which we had extracted from D+ in the spring following LM translocation – mainly as fallen trunks, limbs and old stumps spanning a range of sizes and states of decomposition. We distributed the WD sporadically throughout each area to create small piles and other structures resembling natural woody debris formations in D+. In spontaneous old-growth forests, such formations provide valuable physical variability (heterogeneity) with respect to a number of ground-layer environmental conditions crucial to plants and soil organisms. These include light intensity, heat, humidity, and biochemical products of wood decomposition. At each site’s recipient blocks, we made no further alterations within at least one of the three quadrants treated with additional WD. The label for this treatment level is +LM+WD.

3.3.2. Planting dogwood shrub clusters (+LM+WD+SC)

In a second WD-treated quadrant, we planted a shrub cluster (SC) of six alternate-leaved dogwood saplings (*Cornus alternifolia*). Each sapling was approximately 1 m tall and the clusters held a circular formation approximately 1.5 m in diameter. This species of dogwood is a quick-growing native hardy to a range of light conditions and is a common component of local hardwood forests at developmental stages ranging from understorey re-initiation through old growth. The woody growth varies in height from 1-2 m tall shrubs to 4+ m small trees, contributing variably to ground shading and facilitating ground-layer biodiversity. We refer to this treatment level as +LM+WD+SC.

Table 2: Five levels of habitat refuge creation within the Living Mulch relocation treatment

Code	Level	Microhabitat treatment applied	Test of effect
NT	1. No Treatment	None; refers to areas within recipient locations which did not receive relocated materials or other alterations. Sampling of NT was carried out 10-20 m adjacent to the installed Living Mulch Recipient (LMR) plots.	-
+LM	2. Addition of Living Mulch	Living mulch (LM) was excavated in patches from donor forest floor (e.g. upper 30 cm of topsoil, propagule banks, litter layers, etc.) and relocated immediately in bulk to recipient locations (Oct. 2017). Translocated materials were deposited evenly onto 12.5 m x 10.0 m patches of ground, to a depth of 30 cm, working around existing trees but otherwise completely covered resident vegetation and surface features. One quadrant was designated "+LM" and assigned to receive no further alterations.	+LM *vs.* NT
+LM+WD	3. Addition of Living Mulch and Woody Debris	Pieces of dead, fallen trees (e.g. stumps, trunks, limbs) varying in size and decomposition state were collected from the donor forest and relocated to the LMR plots (May 2018). Approximately 15 m^3 of woody debris (WD) was distributed evenly throughout the three remaining quadrants per plot. One quadrant was designated "+LM+WD" and assigned to receive no further alterations.	+LM+WD *vs.* +LM
+LM+WD+SC	4. Addition of Living Mulch, Woody Debris and Shrub Cluster	Six *Swida alternifolia* nursery-stock saplings (1 m height) were planted in a 2 m diameter circular shrub cluster (SC) near the centre of one quadrant which had received WD, in each LMR plot (May 2018).	+LM+WD+SC *vs.* +LM+WD
+LM+WD+SS	5. Addition of Living Mulch, Woody Debris and Shade Shelter	A shade shelter (SS) was constructed near the centre of the remaining quadrant which had received LM and WD, in each LMR plot at locations S1 and S2. Each structure consisted of cedar fence posts installed in the four corners of a 4 m x 4 m area, and cut to a height of 1.8 m. A sheet of black horticulural shade cloth, able to reduce peak incident solar radiation by 70%, was spread across the tops of the posts and used to cover the ground below (May 2018; tarps removed and reinstalled seasonally).	+LM+WD+SS *vs.* +LM+WD

3.3.3. Constructing artificial shade shelters (+LM+WD+SS)

We also aimed the final type of applied environmental modification at increasing ground shading, but in a manner designed to dodge some potential constraints of living shading agents. We had recognized that planted shrub clusters could fail to survive, fail to produce meaningful canopy in a useful amount of time, or possibly even reduce the success of other organisms emerging from LM due to competition for nutrients or water. We therefore erected artificial shade shelters (SS) within the remaining WD-treated quadrant. Due to logistical challenges and likely lack of need for them, we did not attempt to construct shelters within S3-S5 recipient blocks (i.e. they already experienced a mostly-closed canopy). We built each SS using four peeled-cedar posts (12 cm diameter), installed to a height of 1.8 m in the corners of a 4 m x 4 m area located near the centre of each designated quadrant. We then attached across the tops of the posts a removable tarp made of black horticultural shade-cloth which was manufactured to reduce incident solar radiation by 70%. We extended the tarps in early summer and took them down again in late autumn corresponding to canopy leaf-out and shedding in D+, beginning in 2018 and continuing through 2020. The label for this treatment level is +LM+WD+SS.

3.4. Required controls: Not-treated (NT) areas at S1-S5

The most important test of the potential usefulness of the LM application is determining the extent to which depositing living mulch in an environment produces understorey vegetation communities which are more similar to the donor forest than the plant communities that the recipient environment otherwise tends to support. We therefore included “not-treated” (NT) areas in which we evaluated plant communities and other properties, using all of the same measures as in the treated areas. We established one NT area for each recipient block at each site, generally located 5-10 m adjacent to the recipient block and ecologically representative of conditions at the recipient block prior to our experiment. We refer to this treatment level as NT.

3.5. Ecosystem responses: Vegetation composition and environmental covariates

Given the large amounts of biodiversity as well as nutrient resources inherent in living mulch, effects from its deposition have potential for positive impacts with a wide ecological scope. The composition and functioning of biological communities at recipient sites could become more similar to mature unplanted forests (or otherwise altered), with respect to taxa ranging from soil fungi, bacteria and invertebrates through to plants and all of the animals that respond to changes in vegetation (birds, butterflies, small mammals, etc.). Each level of ecosystem responses would have structural and functional aspects that could be valuable to study (e.g. how species diversity and abundances change; how cycling of nutrients through food webs change) but measuring and analyzing all of these would require multiple research projects.

Here, we focused on ground-layer vegetation communities as a sort of “master” ecosystem response variable, important for its own sake (i.e. a chief “function” of forests is the refuge provided to plant biodiversity that mostly inhabits ground-layer microhabitats) and because it likely indicates the direction of response at other levels of the ecosystem. Where depositing living mulch produces understorey communities highly similar to the donor forest, for example, soil biota likely also survived translocation intact as the vegetation depends upon the soil organisms (i.e. the plants would indicate major problems in the soil by failing to flourish). Similarly, where responding plant communities include many species that typically inhabit the donor forest, it would likely only be a matter of time before insects, birds and other animals that normally exploit those plant species begin utilizing the recipient blocks likewise. Information about soil organisms and processes could be useful in helping to explain cases where living mulch fails to produce any of its expected effects so, early in our study, we prepared to gather relevant data is such need arose (collected soil samples, etc.).

As indicated in the Results section below, information from our plant community data had all of the appropriate properties to answer our present research questions without an extensive soil-based study. Some of the baseline physical and chemical soil properties assessed early in the study will be useful supporting aspects of scientific publications going forward (but not this report). Furthermore, we gathered soil samples and have them stored for potential analysis using “eDNA” technologies, or meta-genomic barcoding. We have developed a good relationship with facilities capable of collaborating on such analyses in a future research project but the cost of the approach most likely to be successful requires approximately $40,000 for lab expenses alone, making this incompatible with the current RERAS project.

3.6. Vegetation sampling procedures

The process of sampling vegetation communities required visiting all LM recipient blocks and NT areas multiple times each year that surveys were possible, beginning approximately 7 months after the translocation (i.e. first sampling occurred in May 2018). Initial visits sought to determine the best methods for evaluating plant communities, including identifying and counting individual plants within a fixed 1 m^2 area near the centre of each block-quadrant. This approach turned out less suitable for separating the "signal" of compositional similarity between donor and recipient sites from the "noise" inherent to plant community data (discussed below) than the method that we ultimately adopted and employed most consistently throughout the study. The preferred method was to place, at random locations within each block-quadrant and NT area at each visit, 3-4 smaller temporary "quadrates". Each such quadrate was a simple frame of consistent dimensions – squares with an area of 0.25 m^2 – laid on the ground to demarcate the area requiring vegetation assessment, then removed after. We used the same approach in the donor forest but did not constrain the area sampled to the same small size as the 125 m^2 recipient blocks as the goal of sampling the donor forest was to capture the most complete picture of the vegetation community as possible.

Within each quadrate, we recorded every plant species that we could identify that presented biomass within the frame (i.e. plants were not necessarily rooted within the framed area), from a perspective approximately 2 m above the ground. We photographed most quadrates (including detailed close-ups of many plants within) for later evaluation of species composition, a step required to permit the frequent sampling the study demanded. We recorded dominant "types" of bryophytes including mosses and liverworts that were present in the frames but did not have expertise for full identification to species. We omitted those records from the analysis presented here, in order to focus on the species occurrences in which we have greatest confidence. Similarly, we excluded from this analysis some occurrences of sedges, grasses and varieties of raspberry that we could only identify to "types" but not species. Otherwise, we recorded with high confidence (in-person and from photographs) nearly all vascular vegetation observed within every quadrate, including grasses, sedges, rushes, ferns, horsetails, wildflowers, shrubs, vines and small trees.

3.7. Data collection timeline

Between May 2018 and July 2020, across all sites, we assessed more than 2000 quadrates, encompassing visits representing "early-season" vegetation (e.g. wildflower species active and identifiable in May and June) in 2019 and 2020, and "late-season" communities (e.g. vegetation generally identifiable between August and October) in 2018 and 2019. We visited and extensively photographed all sites during the 2020 and 2021 "late-seasons" but constraints imposed by the Covid-19 pandemic limited our ability to gather suitable data for inclusion in our quantitative analysis. The site visits were nevertheless useful in helping us draw conclusions from the analysis, as they largely confirmed that everything looked the same as it had during the last seasons of intensive sampling. The focused analysis reported here examined data from 228 quadrates located throughout various sections of D+, and 1642 quadrates located throughout treated and not-treated areas of recipient sites S1-S5.

3.8. Measuring environmental covariates

During the early-season 2020 vegetation survey, we collected additional information about the environmental conditions within treated and not-treated areas at each recipient site and the donor forest. The purpose was primarily to quantify the amount and pattern of coarse woody debris throughout the different environments in order to explain vegetation responses. Specifically, it could help test the hypothesis that building woody debris habitats at recipient sites that are more similar to the donor forest causes emergence of plant communities that are more similar to the donor forest. While assessing the degree to which grounds were covered by large woody debris ("coarse", with smallest dimension larger than 10 cm) we took the opportunity to also assess other common types of surface cover ("microhabitats") including "fine" woody debris, broadleaf litter, conifer needles, bare soil and standing tree trunks (living or dead). We likewise assessed the degree to which shorter woody vegetation produced a sub-canopy layer, by quantifying the frequency of presence by such plants approximately 1-3 m directly overhead the ground-layer sampling plots.

We accomplished all of this microhabitat sampling by evaluating one 9 m^2 square quadrate centred on each of the 0.25 m^2 vegetation quadrates. The quadrate was comprised of nine equal-sized cells in which we evaluated ground cover by each type of microhabitat using a 0-4 scale (i.e. visualizing the cell divided into four quadrants, how many quadrants include ground with each cover type?). This enabled our calculation of percent frequency of ground cover by each microhabitat in the area immediately surrounding each sampled vegetation quadrate. We additionally calculated the means from the three replicate quadrates within each quadrant-block in order to estimate average levels of ground cover for that quadrant-block. This allows for analysis of possible relationships between average ground-cover values assessed in 2020 (but presumably unchanged since we implemented all treatments) and the vegetation data gathered in those same quadrant-blocks at other points in the study. Our analysis of vegetation-environment relationships has proven interesting and will be important to forthcoming scientific publications but would unnecessarily complicate the "big picture" results we seek to communicate here.

We only include one microhabitat variable in the below analyses, percent ground cover by coarse woody debris. This is the major environmental feature expected to promote woodland plant communities that we manipulated in a controlled fashion, enabling us to draw inferences about causal relationships. Each recipient block was mostly cleared of woody debris prior to the experiment then treated with woody debris collected from the donor forest such that various patches exhibited abundant piles, small scatterings, or none whatsoever. As such, if many areas sporting abundant woody debris consistently exhibit plant communities that are more similar to the donor forest than at less-woody patches, the differences in debris cover more likely caused the vegetation pattern compared to some unmeasured variable that would need to differ in a similar pattern among samples, by chance.

3.8. Analysing the data

Our study seeks to understand ecosystem responses to treatments through the lens of "community composition" or biodiversity in the understorey, but that can mean many things. Our data tells us how many vascular plant species were present in each quadrate (understorey richness), some of the properties of these species (native or exotic, lifeform) and their taxonomic identities. Our hypothesis is less concerned with the specific workings of each sample community and more concerned with the degree of general similarity between the donor forest community and the communities at recipient sites. We therefore employed a commonly used community similarity metric, the Jaccard index, to help focus analysis on compositional differences among samples without getting lost in the precise details of what those differences are.

3.8.1. Estimating community similarity

The Jaccard coefficient represents a comparison between two samples (e.g. quadrates) that produces a value between zero and one depending on the proportion of all species that overlaps between the two samples (i.e. if the samples have no species in common, the score is 0; if each quadrate corresponds to an identical “species list”, the Jaccard value is 1). We calculated the average Jaccard compositional similarity for each recipient-site quadrate by comparing it to every quadrate sampled at the donor forest within the same season (i.e. early or late, not confined to the same year) (D+) and taking the mean.

To help interpret the meaning of the values we similarly compared each donor-forest quadrate to the set of all donor-forest quadrates sampled within-season and calculated the mean Jaccard score. This value represents the average compositional similarity of donor-forest quadrates to each other and provides a useful “bar” for judging the scores exhibited by recipient sites. If we observed similar scores at recipient sites, it would indicate the communities there were composed of similar sets of species as the donor forest quadrates, with similar levels of spatial variation from quadrate-to-quadrate. Put another way, the score from the donor-forest quadrates puts a realistic ceiling on what “success” should look like; we shouldn’t expect the quadrates at recipient sites to somehow be *more* similar the set of donor-forest quadrates than each donor-forest quadrate is to the same set.

3.8.2. Generalized linear interactive mixed models

We compared the set of all recipient-site quadrates with respect to their compositional similarity to the donor forest using a statistical approach called generalized linear interactive mixed models (performed using the GLIMMIX procedure in the S.A.S. 9.41 statistical software). Most of the finer details are not necessary for this report; they will likely appear in “Supplementary Materials” sections of scientific journal articles. The analytical approach is very similar to traditional “Analysis of Variance” or ANOVA tests but it incorporates specialized terms to account for the many potential sources of “random” variance in our “noisy” dataset (e.g. related to sampling each block-quadrant at multiple points in space and time).

The big picture is that we assessed how variability in Jaccard scores at each recipient site is related to the treatment level (i.e. NT or one of the +LM groups) and season of sampling (E or L) while accounting for random spatial and temporal variation among plots related to the experimental design. All data was processed in the same analytical model but the terms enabled evaluation of each site independently (i.e. the treatment level effect was nested within the “sere” effect), with separate sets of statistical tests for the early and late-season community types. The chief comparisons were pre-planned contrasts between average similarity scores at NT versus +LM quadrates; at +LM+WD versus +LM quadrates; at +LM+WD+SC versus +LM+WD quadrates; and at +LM+WD+SS versus +LM+WD quadrates.

To help understand patterns of community similarity indicated by the analysis of Jaccard values, we carried identical analyses but focussing on responses related to sample richness (i.e. the number of species present per quadrate). We examined patterns in total richness as well as the component attributable to native plant species and that attributable to exotics.

3.8.3. Evaluating community responses to percent ground cover by woody debris

We leveraged the information gathered regarding percent ground cover by coarse woody debris in two different ways, for this report. First, we examined just the set of quadrate data collected in early-season

2020, again assessing the Jaccard similarity to the donor forest as the response variable but now including woody debris cover as an explanatory covariate (still using the GLIMMIX procedure). We considered just two treatment levels for this analysis, NT and “recipient”, the latter considering each LM recipient block without respect to the various quadrant-level treatments (for clarity and because exploratory analysis demonstrated the distinction did not change the result).

For this analysis, the test of our hypothesis that woody debris habitats are important to achieving desirable results from living mulch applications is whether the compositional similarity scores increase significantly with woody debris cover under the “recipient” treatment, at any sere or season. The value of this approach is that beyond possibly demonstrating the hypothesis to be correct, it can inform us as to the form and strength of the relationship and indicate what levels of woody debris cover manager may seek to establish following future living mulch applications at other sites.

3.8.4. A complementary analytical approach: multivariate ordination

The analyses of Jaccard scores makes certain assumptions that were not necessarily always valid in our datasets and comes with other constraints we will not detail here aside from this one. Although we do not wish to get “lost in the details” of all the species differences among quadrates, we do want some idea of which species may be particularly important in causing the observed patterns (e.g. where relevant to testing our specific hypotheses). To help circumvent the constraints of our parametric (“ANOVA-like”) analyses we carried out complementary non-parametric analyses including multivariate ordination approaches that we will not describe in detail here except to aid in interpreting the results. Images we share in the below Results section come from “canonical correspondence analysis” (CCA; carried out using Canoco 5.1 software) of the vegetation quadrate data (“species lists”) at all recipient sites and the donor forest (early and late-seasons, 2018-2020) in a single analysis.

The analysis calculates the degree to which the composition of species in quadrates shifts or “turns over” as surrounding environmental conditions change (e.g. along a gradient of solar intensity from beneath closed forest canopy to locations at more open sites). Community sample data from quadrates organizes in an “ordination space” such that samples with similar species compositions appear clustered together and samples supporting very divergent sets of species are located far apart on the resultant graph. The analysis tests how each species responds to changes in measured environmental covariates (e.g. ground cover by coarse woody debris) as well as classification variables such as season, sere and LM treatment level (all of which are considered “explanatory variables” in the analysis). This approach facilitates testing our hypotheses about the utility of translocating living mulch and mimicking habitat features by allowing for examination of how near or far the “centroids” of different treatment levels at different sites lie relative to the donor forest. A “centroid” is a way of showing the “centre” of multivariate data (e.g. summarizing all of the quadrate samples at a particular treatment level at a particular site), like a mean or average.

Our CCA applies appropriate statistical tests as to the “significance” of the factors considered but ultimately the interpretation of results is visual and highly intuitive. For example, if the centroids for NT and Recipient treatment levels at a given sere lie equally far from the centroid for the donor forest then we would have to reject the hypothesis that our treatment makes understorey communities at recipient sites more similar to the donor forest. Perhaps the greatest advantage of our ordination approach is that it allows simple examination of the roles played by different species in causing the patterns among treatments and seres.

The graphs shared below overlay species name codes on the same ordination space alongside centroids for seres and treatments, showing the upper-third of all species sampled that are statistically best-described by the analysis (showing all of the species makes the graph unreadable). Species codes lie at locations in the ordination space corresponding to their greatest abundances. This means that the sets of species named nearest to any given centroid provides an apt way to characterize the plant community at that centroid (and the important species that nearby centroids therefore share). Finally, the influence of measured environmental covariates (in this case, just coarse woody debris cover) appears on ordination graphs as an arrow ("vector") with length proportional to its importance in correlating with community turn-over and pointed in the direction that its values increase in across the ordination space. Centroids near the head of the vector correspond to groups with greater woody debris cover those near the tail; species reaching maximum abundance in high-debris environments would appear named near the arrowhead.

4.0. RESULTS & DISCUSSION

The results of all of the quantitative analyses of understorey community data from the RERAS project strongly corroborate the conclusions we have been drawing since 2019, based on initial analyses and the many subsequent field visits. Translocating living mulch and replicating woody debris habitat conditions can contribute significantly to helping recipient environments produce ground-layer plant communities that are compositionally similar to the mature, unplanted donor forest. The strength of these effects depended strongly on the nature or the recipient sere, however, and early and late-season components responding somewhat differently to the effects of sere and treatment level.

4.1. Responses estimated using the Jaccard Community Similarity metric

As illustrated in Figure 3 by the solid horizontal bar across the top of the plot (surrounded by parallel dotted lines above and below), the average Jaccard compositional similarity score calculated for the quadrates in the donor forest based on early-season sampling was approximately 0.21 (the surrounding dotted lines indicate variation around this mean value based on its standard error). Compared to this "bar" quantifying how similar individual donor-forest quadrates were to the set, on average, the mean values observed at S5 (upper-rich corner of the plot) are very close. This indicates that the areas of S5 (the mature, unplanted forest connected to the donor forest) treated with living mulch supported communities described by nearly identical lists of species as the donor forest, and with similar levels of quadrate-to-quadrate variability across the physical areas investigated. We expected this outcome under the baseline assumption that the technique for excavating and relocating the donor forest floor (i.e. after frost and without stockpiling) has minimal negative impacts on the viability of plant biodiversity in the living mulch. Not-treated areas at S5 support the same community because it is contiguous forest with D+. The results at S5 set the stage for understanding the outcomes at the earlier seres because it indicates we should interpret similarity scores below this bar as compositional dissimilarity from the target community that is more likely due to inhospitable habitat conditions at the recipient sites rather than failure of the translocation technique itself.

In the sections of the Fig. 3 plot that correspond to recipient sites S1-S4, large gaps exist between the square symbols that indicate not-treated areas and all of the other symbols that indicate the various quadrant-level treatments in the LM-recipient blocks. The square symbols correspond to very low donor-similarity scores for the former gravel pit (S1) and the very recently afforested field (S2), and only slightly higher scores for the middle-aged (S3) and old (S4) conifer plantations. Circle symbols indicate average donor-similarity scores at areas treated with living mulch but not extra woody debris or refuge structures. The relatively huge gaps between the squares and the circles, which occupy positions on the graph much closer to the donor-forest "bar", provides clear evidence from every sere that translocating living mulch produced a substantial increase in ground-layer community resemblance to the donor forest. Each statistical contrast between the NT and +LM treatment levels indicated highly significant differences (e.g. $p < 0.0001$).

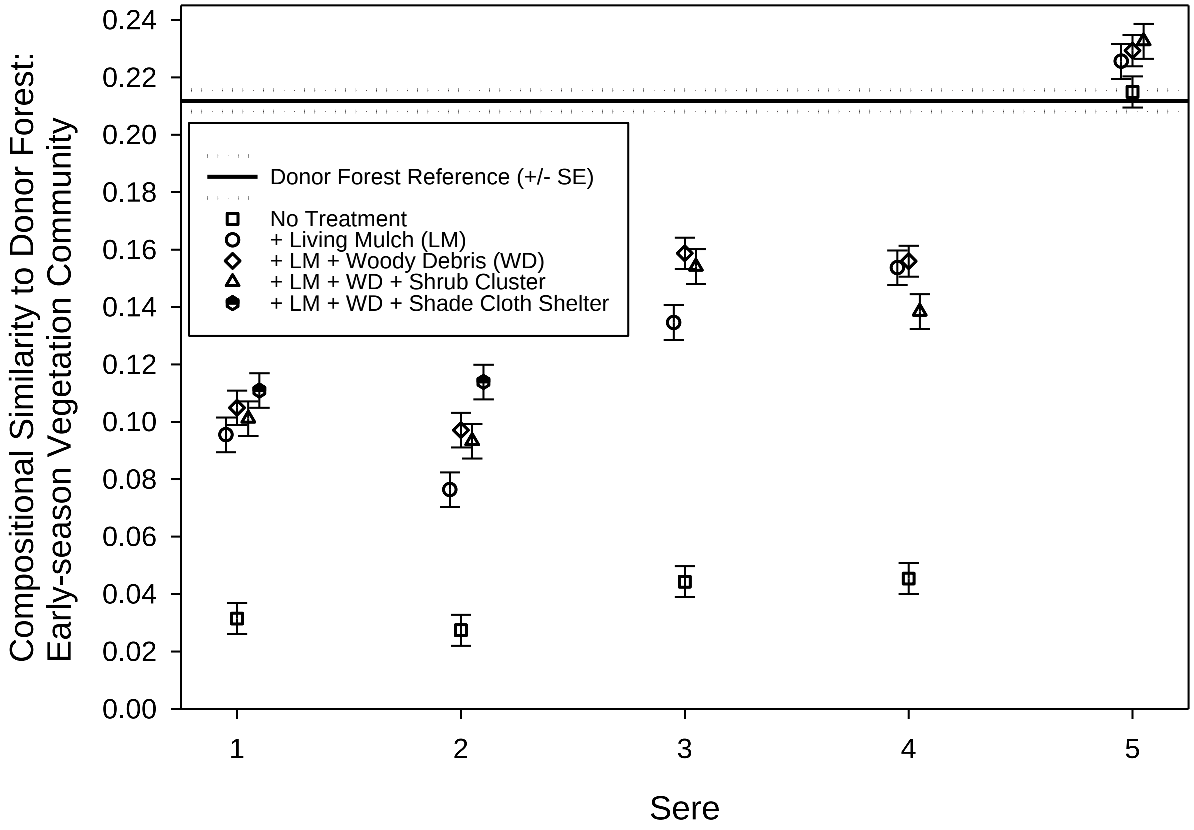

Figure 3. "Similarity-to-donor" observed in early-season vegetation communities, in response to living mulch translocation, habitat treatment and recipient sere. Symbols show least-squared means and standard errors for treatment levels described in the inset legend. See text for explanation.

The scatter among the other symbols at each sere indicates the effects of the different habitat-refuge structures (extra woody debris, alone or in combination with a shrub cluster or shade shelter) on compositional similarity to the donor forest. Some differences are wider than other ones; contrast tests indicated that a few are statistically significant. The clearer picture is that the affect of altering microhabitat conditions on donor-forest similarity scores is somewhat weaker than the influence of selecting recipient sites at different stages of succession. Translocating living mulch to S1, for example, caused the ground-layer community to jump from a similarity score approximately 15% of the "bar" for success (high similarity) set by the donor-forest quadrates, to a value 45% this "target" value. The apparent minor gains from additional habitat refuge structures were not statistically significant. At S2, the similarity-to-donor score increased from a value 13% of the target to one 36% of the target as an outcome of LM alone. Addition of extra woody debris accumulations caused a significant increase to a value 46% the target; under shade shelters, this value significantly increased further to 54% the target score.

At S3 and S4, not-treated areas were slightly more similar to the donor forest than the younger seres (i.e. average donor-similarity scores were both approximately 21% of the target value) but the gains from translocating living mulch were much greater. At S3, adding living mulch alone increased the similarity score to a value 63% the target and adding extra woody debris significantly increased the score to a value 75% the target. At S4, applying living mulch alone achieved a similarly high score (73% the target value) but adding woody debris piles made no further difference. The average similarity-to-donor score for the +LM+WD+SC treatment level was never significantly greater than that for the +LM+WD level, at any sere, indicating negligible impacts of the planted shrub clusters on vegetation composition.

4.2. Community similarity in response to percent ground cover by woody debris

Analysis of the early-season compositional similarity to the donor forest in 2020, in response to the measured cover by coarse woody debris, indicated that the treatment had significant impacts in some cases. Figure 4 shows how the Jaccard similarity scores at each sere and the donor forest respond to the amount of woody debris cover on the ground. Quadrates from not-treated areas of the recipient sites appear as open circles while those from LM-recipient blocks appear as open triangles (we ignored the different habitat treatments within the block, for this analysis). Filled-in shapes show the average similarity scores for each treatment group at levels of woody debris corresponding to the minimum, mean, and maximum values observed in each group. The donor forest and not-treated areas of neighbouring S5 exhibited woody debris cover ranging from nearly zero to more than 60%, averaging around 30%. Not-treated areas of S1-S3 featured woody cover that ranged to less than 30% and averaged less than 10%; the older plantation, S4, bore slightly greater cover without the additions, averaging around 11% and ranging to nearly 40%.

In the areas of recipient sites that we added living mulch to (and applied the other treatments), average woody debris cover ranged from approximately 25% to 30% across the five sites, and the maximum values observed ranged from around 55% to nearly 80%. The regression lines on each plot show the relationships between ground cover by woody debris and the similarity-to-donor scores. Most of the lines are dashed, indicating that no statistically significant ($p<0.05$) correlations between the variables exists within the corresponding treatments and seres. Even without significance, however, the positioning of the lines indicates average similarity scores for the treatments and the gaps between lines for not-treated and recipient groups at each site illustrate how much greater the level of donor-forest similarity in the treated sections is (as also shown in Fig. 3).

The regression lines for recipient blocks at S2 and S3 are solid and show similarity scores increase in value as the amount of ground covered by woody debris increases. The solid lines indicate that these relationships are statistically significant ($p<0.05$), meaning we should have high confidence in concluding that experimentally increasing the levels of woody debris cover caused the applied living mulch to produce ground-level vegetation with increased similarity to the donor forest. At the young afforestation site, S2, the degree of increase across the gradient of debris cover was relatively small but at S3 (the middle-aged conifer plantation), the difference was considerable.

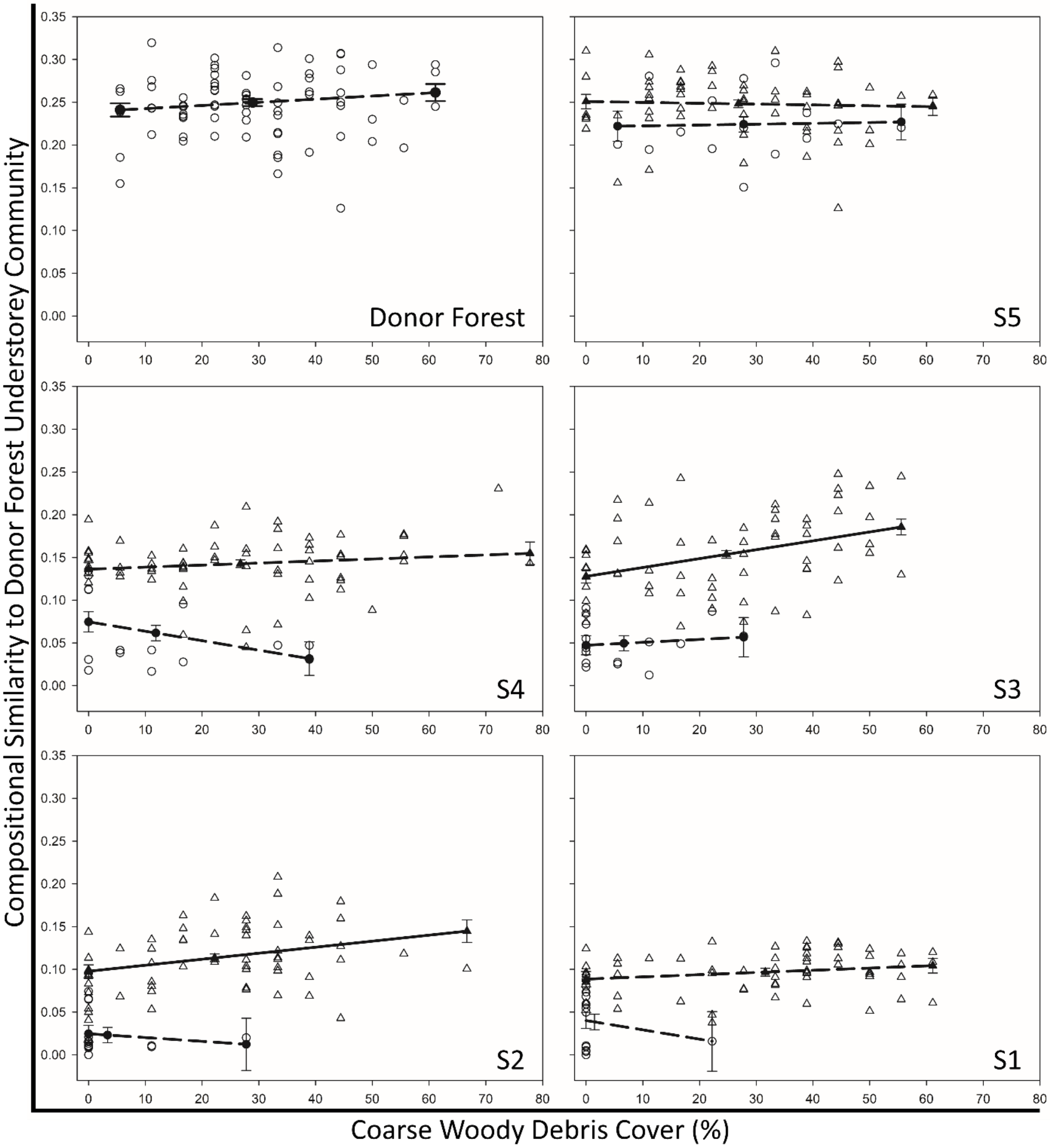

Figure 4. "Similarity-to-donor" observed in early-season vegetation communities at each sere, in response to living mulch translocation and percent ground cover by woody debris. Circle symbols show data from not-treated areas while triangles show results from the living-mulch recipient blocks. Open symbols show individual quadrate samples; closed symbols show least-squared means for each treatment level at the minimum, mean and maximum woody debris cover values observed.

Statistical analysis of the early-season 2020 data estimates that plant communities emerging from living mulch at areas of S3 with minimal woody debris nearby produce communities with donor-similarity scores 51% of the target value but at the maximum observed level of woody debris, this value jumps to 74%. The results suggest that preparing living-mulch recipient sites by ensuring average ground cover by woody debris is in the 45-55% range would help the living mulch produce optimal outcomes. This target must represent only the middle of a much larger range of cover, likely corresponding to different structural arrangements (piles, spread out sporadically, etc.). Area with less and more woody debris than the average is likely important for different species to exploit different opportunities

4.3. Responses by native and exotic species richness helps explain

The analysis of the number of different native and exotic plant species in each community sample provides insight as to why the living mulch applications produced different outcomes at different treatments and seres. The similarity-to-donor scores grow larger where sampled ground contains more species that also occur in the donor forest, and fewer species that do not. The living mulch was extracted from a donor forest where small patches of sampled ground generally supported around 5 native plant species (Fig. 5a, the horizontal “bar”) and 1 exotic species (Fig. 5b), on average. When we relocated the material to nearly identical habitat at S5, sampled areas produced these same richness values. When we did the same thing but at earlier-successional sites S1-S4, resultant levels of species richness were much greater. The small sampled patches of S1 ground tended to support approximately 4 native and 3 exotic species where left untreated, but reached maximum average levels of 9 natives and 7 exotic species, in areas of the LM-recipient blocks that received woody debris and shrub clusters (Fig. 4a, b).

Similar or larger increases in the richness of native species occurred in response to living mulch at S2-S4, especially in the treatments involving extra woody debris alone or alongside a shrub cluster. The pattern of growth by exotic species was not consistent, however, across those seres. S2 recipient areas had among the highest levels, tending to be slightly greater than the number of natives, at 6-7 exotic species per sample. In contrast, S2 and S3 averaged only 2-3 exotic species per sample, where we had applied LM. This suggests that although S2-S3 gained a similar number of new native species following LM application, the final communities at S2 are comprised of many natives and many exotics, those at S3 and S4 feature many natives and few exotics. The high load of exotic species at the younger recipient sites, which are not shared by the donor forest, would drive down similarity scores even if all of the same native species where present across the sites.

The evidence that not-treated areas of S2 supported 7 exotic species per small patch whereas not-treated areas of S3 and S4 supported two or fewer exotic species suggests that relative barrenness of the conifer plantations may provide advantages rather than liabilities, with respect to ecological restoration using living-mulch type applications. The plantation habitats were tolerable enough to species typical of the donor forest for them to establish, following living mulch applications and habitat amendments. The relative absence of other vegetation within the immediate surroundings (“green deserts”) then likely served as a barrier keeping the community compositions from changing via colonization by exotics or other species (producing high similarity scores).

At the younger sites, the abundance of exotic plants dominating the “old field”-like surrounding habitats likely quickly colonized the pulse of resources offered by the deposited rich forest topsoil but many transplanted natives also survived. The outcomes, in some cases, represent relatively “novel” plant communities because the species do not normally intermix. The shade-cloth shelters helped compositions emerge that were slightly more like the donor forest, particularly at S2, and the reason for this likely relates to less establishment by non-forest species under the shelters, including by old-field exotic “weeds”. As illustrated in Fig.5, the shade shelter treatment tended to support fewer native and exotic species than the other treatments.

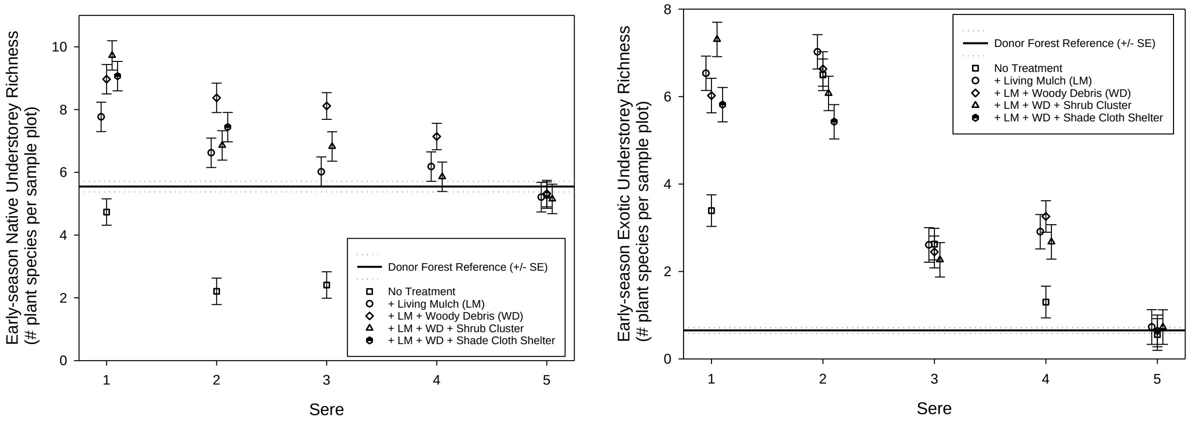

Figure 5. Native and exotic species richness in early-season vegetation communities, responding to living mulch translocation, habitat treatment and recipient sere. Symbols show least-squared means and standard errors for treatment levels described in the inset legend.

4.4. Photographs illustrating results from the early-season vegetation communities

Site visits and photographs from 2021 confirm similar patterns to those sampled quantitatively in 2020, which appear summarized somewhat in the following photos. Many of the typical donor-forest species are still alive and growing alongside the typical field species. When we observed this phenomenon during the 2018 field season, we expected it would be temporary and that the forest native would eventually succumb to competition and less than ideal habitat conditions. That this has not occurred offers hope that appropriate habitat mimicry combined with living mulch at young afforestation sites can produce desirable and lasting changes to the understorey community. However, if the goal is to direct living mulch to a location capable of producing understorey vegetation as similar to the donor forest as possible, targeting middle-aged and older plantations (e.g. 40-80 y) will be most likely to yield high success.

Figure 6. Two ‘young’ living mulch recipient locations shown before (2017) vs. after (spring 2020) the application. The top row shows an area of a former gravel pit undergoing passive rehabilitation (Clearview Nursery). The bottom row shows a field planted with diverse native trees in 2015 to create a biodiversity offset (Walker Aggregates).

Figure 7. Two 'middle aged' living mulch recipient locations shown before (2017) vs. after (2020) the application. Both occupy aggregate production lands planted with conifers in the 1980s to help prevent soil erosion (Walker Aggregates).

Figure 8. Two 'old' living mulch recipient locations shown before (2017) vs. after (2020) the application. Both occupy a 70-80 year-old conifer plantation established on Niagara Escarpment farmland (Clearview Township).

4.5. Responses by late-season vegetation communities to the experiment

The results from the late-season quadrates present overall similar patterns to the early season but with somewhat less spread between some of the treatment and sere average similarity scores. All differences between NT and +LM groups were statistically significant but effects of the habitat refuge structures (extra woody debris, etc.) were less pronounced and tended not to be significant (Fig. 9). The average similarity of donor forest quadrats to each other was also lower than in spring. The weaker distinction among all of the quadrats at the time of late-season sampling, with respect to Jaccard similarity scores, was somewhat due to more "noise" in the dataset. More species overall were identifiable everywhere (including many from midsummer) and the most abundant species tended to be asters and goldenrods that grow equally well in fields and mature forests that feature canopy gaps like the donor forest. One sign of this is that quadrates from the not-treated areas at each recipient site tended to express donor-similarity scores considerably closer to the target "bar" in the late season compared to early.

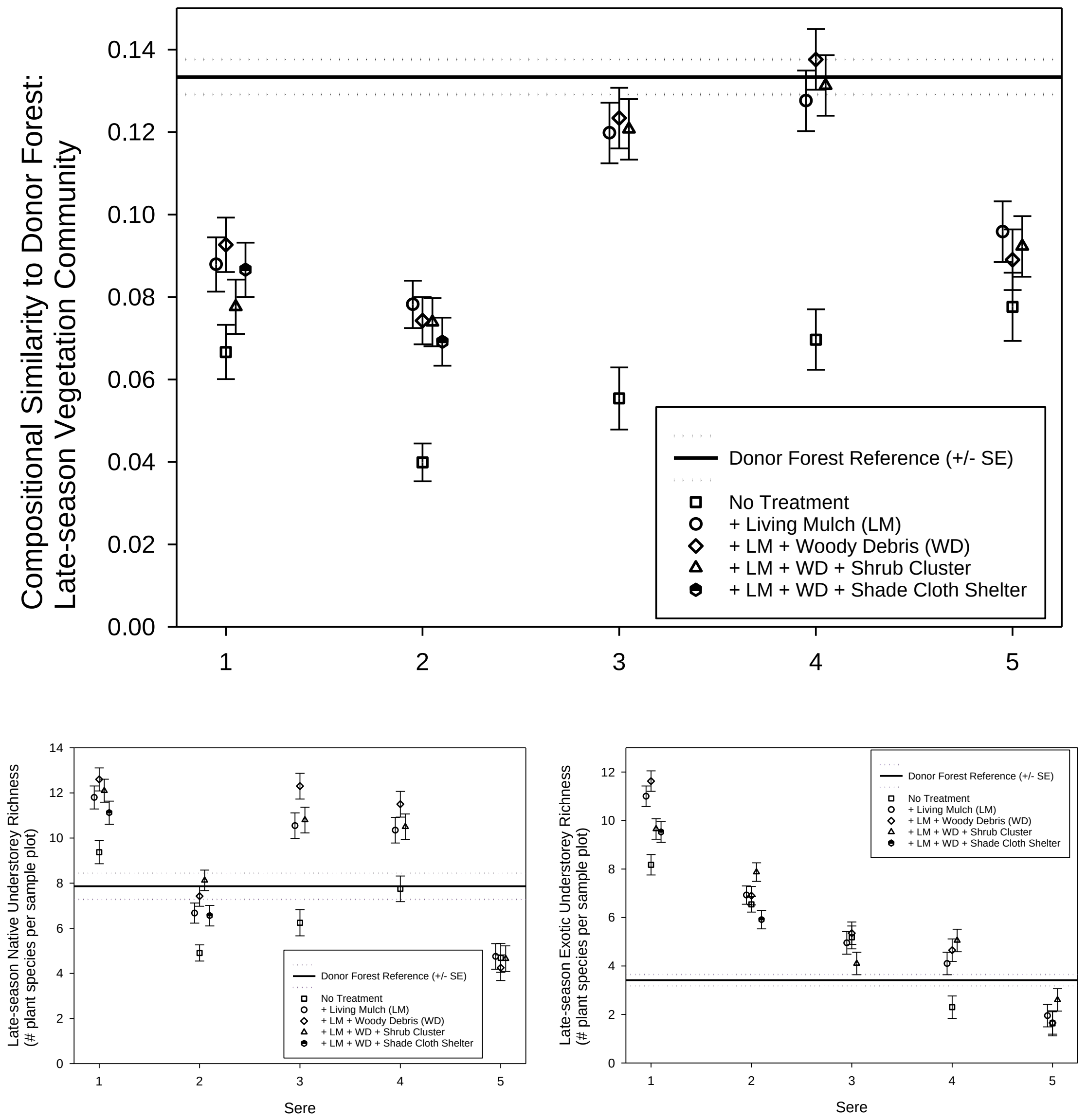

Figure 9. "Similarity-to-donor" observed in early-season vegetation communities, in response to living mulch translocation, habitat treatment and recipient sere. Symbols show least-squared means and standard errors for treatment levels described in the inset legend. See text for explanation.

4.6. Results from multivariate ordination analyses

The Canonical Correspondence Analysis evaluated data from both early and late-season sampling in a manner that tracked each species' particular influence on communities rather than consolidating an index. It revealed a clear and detailed picture of how the treated areas of recipient sites differed from not-treated areas and produced a ground-layer composition more similar to the donor forest (Fig. 10). Open triangles in the drawing show the locations of not-treated areas of S1-S5 in "ordination space" relative to the donor forest, which is shown as an open diamond symbol with the letter "D" in the centre. The amount of graph space between symbols is proportional to how different the plant communities at the different sites are, with species labelled at the locations where they occurred most frequently. The graph shows maximal separation between communities sampled at the donor forest and S5 (at the far right of graph) versus communities sampled at not-treated areas of young recipient sites S1-S2 (far left). This triangulation shows that gravel pit, afforested field typically support communities bearing relatively low resemblance to one another, sharing few species commonly.

The species labels nearest the open S2 triangle, for example, highlight typical agricultural weeds like white goosefoot (*Chenopodium alba*, label truncated to "Chen_alb") and field sowthistle ("Sonc_arv"). Appendix Table A1 provides a full list of the 283 species included in the analysis, including their corresponding label codes and common names. Appendix Table A2 indicates the percent frequency of occurrence by each species within recipient blocks and not-treated areas of each sere. Only the best-fitting top-third of this list appears labelled on the ordination graphs, for clarity. Sedges, least spikerush, panic grass and hawkweeds, in contrast, characterized the former gravel pit, whereas ferns, baneberries, trilliums, leeks, trout lilies and cohosh species best characterized the donor forest and S5.

The shaded-in triangle symbols in Fig. 10 indicate the centers of community composition data corresponding to the areas at recipient sites that received living mulch. We ignored the quadrant-level habitat treatments for this analysis but included ground cover by coarse woody debris as an environmental variable capable of explaining the variation in community composition. The length of the arrow on the graph indicates how well this variable explains the "turn-over" in community structure (i.e. shifting from one set of species to another) while its' heading points in the "direction" of ordination space where the values of woody debris cover reach their maxima.

The results in Fig. 10 therefore show plainly that translocating living mulch to S1 and S2 produced major "jumps" in the compositions of the plant communities to resemble the donor forest more closely. Despite not-treated areas occupying opposite corners of the graph, treated areas appear somewhat closer to each other (along the vertical axis) and to the donor forest (along both vertical and horizontal axes). S2 recipient plots are characterized by weedy herbs including sneezeweed, burdock and catchflies; we certainly also observed some more typically woodland species but as these were relatively infrequent, their labels occur elsewhere. S1 recipient blocks were somewhat characterized by field weeds but also species associated with woodland edges and openings, including strawberry, coltsfoot, asters and goldenrods.

The CCA in Fig. 10 shows the pattern of greatest turnover in species composition along the horizontal axis (CCA1) and it further separates this variation along the vertical axis (CCA2), which reveals an independent pattern of compositional turnover explaining a slightly smaller proportion of the variation within the quadrate data. In our results, the horizontal axis most likely corresponds to the typical shifting in species composition that occurs during ecological succession from an open environment to a woodland, as the positioning of not-treated areas in the middle-aged (S3) and older-aged (S4) plantations along the CCA1 axis (open triangles).

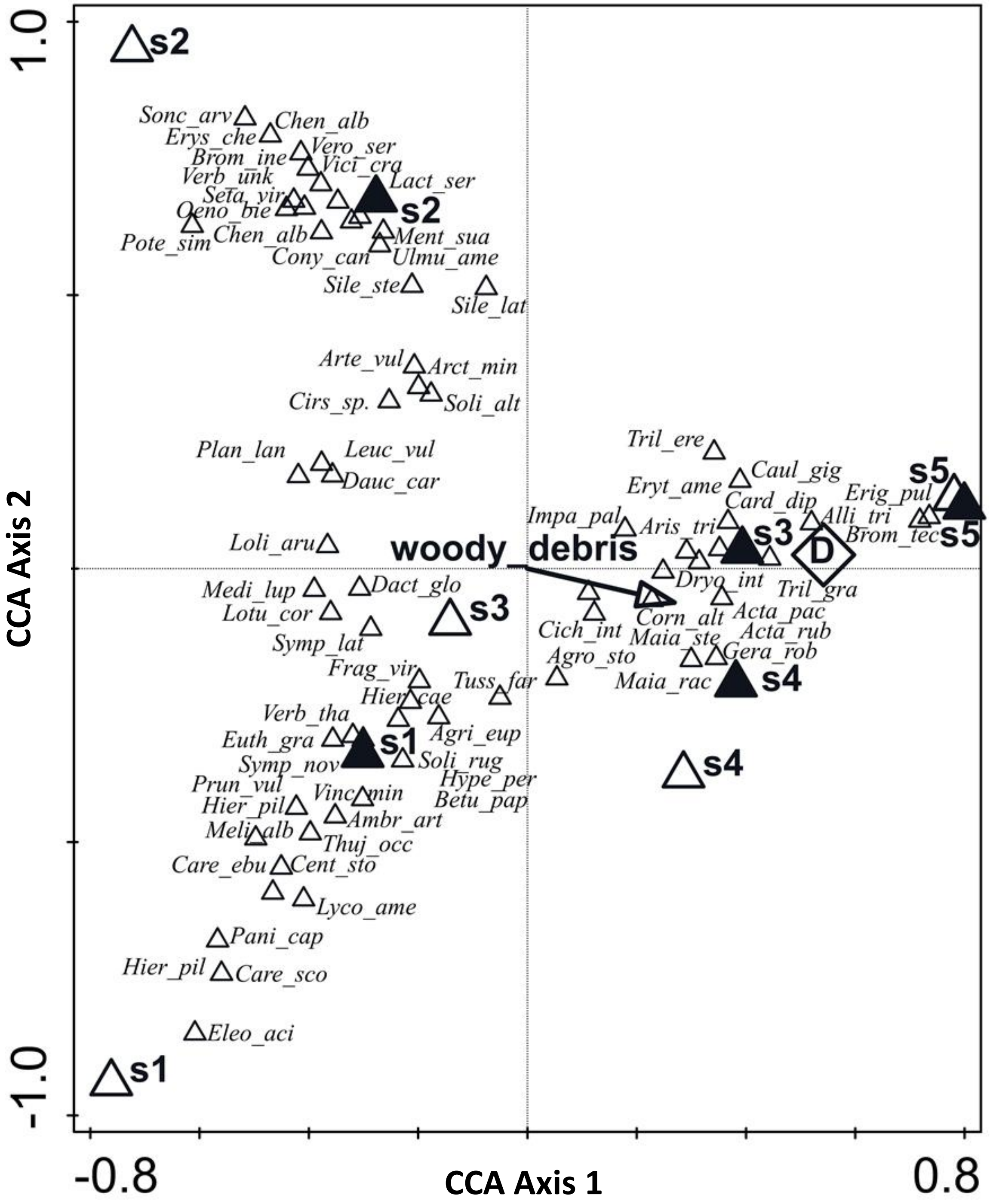

Figure 10. Canonical Correspondence Analysis (CCA) of early- and late-season vegetation communities at the donor forest (D) and in response to living mulch translocation at recipient seres S1-S5. Open triangles show centroids from not-treated areas while closed triangles show living-mulch recipient blocks at seres corresponding to the labels. See text for further explanation. See Table A1 in the Appendix to translate the species codes to their scientific and common names.

The separation between the two plantations along the vertical axis likely corresponds to the younger site presenting deeper shade and a thicker needle layer than the older one, which had more canopy openings and deciduous trees and litter throughout. The conditions at S3 meant that very few species colonized anywhere but those that did tended to be relatively hardy weedy grasses and herbs from the surrounding fields, encroaching on edges and openings in the plantation. At S4, such species were less abundant (possibly excluded as the plantation aged and physical conditions changed) and the understorey supported more woodland generalist species including some that also occurred in the donor forest. Conditions at not-treated areas of S4 were generally challenging for most woodland species, however, meaning those that tolerated S4 almost always reached peak abundances at other sites like the donor forest (leaving the empty space around the S4 symbol on the graph).

Translocating living mulch from the donor forest to the older plantation resulted in ground-layer community "species lists" at S4 positioned slightly closer to the donor forest along the horizontal axis, and a more substantial shift toward the donor forest symbol along the vertical axis. Applying the treatment to the middle-aged plantation resulted in a relatively large shift along the horizontal axis and a minor one along the vertical axis (i.e. the closed triangle representing the not-treated site to the open one showing data from living-mulch recipient blocks at S3). Both axis explained species composition shifts that changed in the direction of increased similarity to the donor forest.

One outcome was that nearly all of the species reaching peak abundances at S3 recipient blocks appeared with similar frequency at the donor forest, including trilliums, baneberries, wood ferns, jack-in-the-pulpit and the two-leaved toothwort (all native species generally considered "iconic" to southern Ontario's heritage deciduous forests). Species of Solomon's seal were notably more abundant at S4 than S3. The arrow indicating the explanatory power of our woody debris ground-cover measurements at each treatment and site shows that increasing woody debris cover correlates significantly with occurrences by typical forest-specialist species characterizing the donor forest. Given that we created most of the observed variation in woody cover experimentally, the positioning of S3 and S4 recipient block symbols relatively near the arrow head as well as the donor forest symbol likely indicates that creating woody debris "refuge structures" following living mulch translocation causes emergence of plant communities with increased community similarity to the donor forest.

4.7. Effects of shade shelters according to multivariate ordination

The "close-up" CCA of just S1, S2 and the donor-forest data indicated that constructing shade-cloth shelters within quadrants of the living-mulch recipient blocks did produce small but statistically significant changes to the compositions of emergent plant communities. Open triangles in Figure 11 show not-treated areas again and closed triangles symbols indicate areas within recipient blocks but outside the shade shelters; the open squares show results from beneath the shade shelters. The position shift corresponding to the difference between the not-treated areas and the areas treated but not sheltered shows the same pattern as Fig. 10 (although the particular orientation of the plot changed – it is the relative spacing of symbols that is important). S2 shows a major jump along the vertical axis and S1 shows a leap of similar proportion but along the horizontal axis, both in the direction of increasing similarity to the donor forest.

The open squares indicating the shade-sheltered portions of the living-mulch recipient blocks do not overlap with the closed triangles, as expected under the null hypothesis that shade shelters have no influence on species composition. Instead, they are another "step" closer to the donor forest symbol:

i.e. change in the same direction as the overall living mulch application, but reaching a point nearer the "goal". Both changes also fall in the general direction of greater donor-similarity observed during early- rather than late-season sampling, as indicated by the centroids for these levels of the "season" explanatory variable included in the analysis (a similar pattern applies to the Fig. 10 CCA but we withheld the symbols there for clarity).

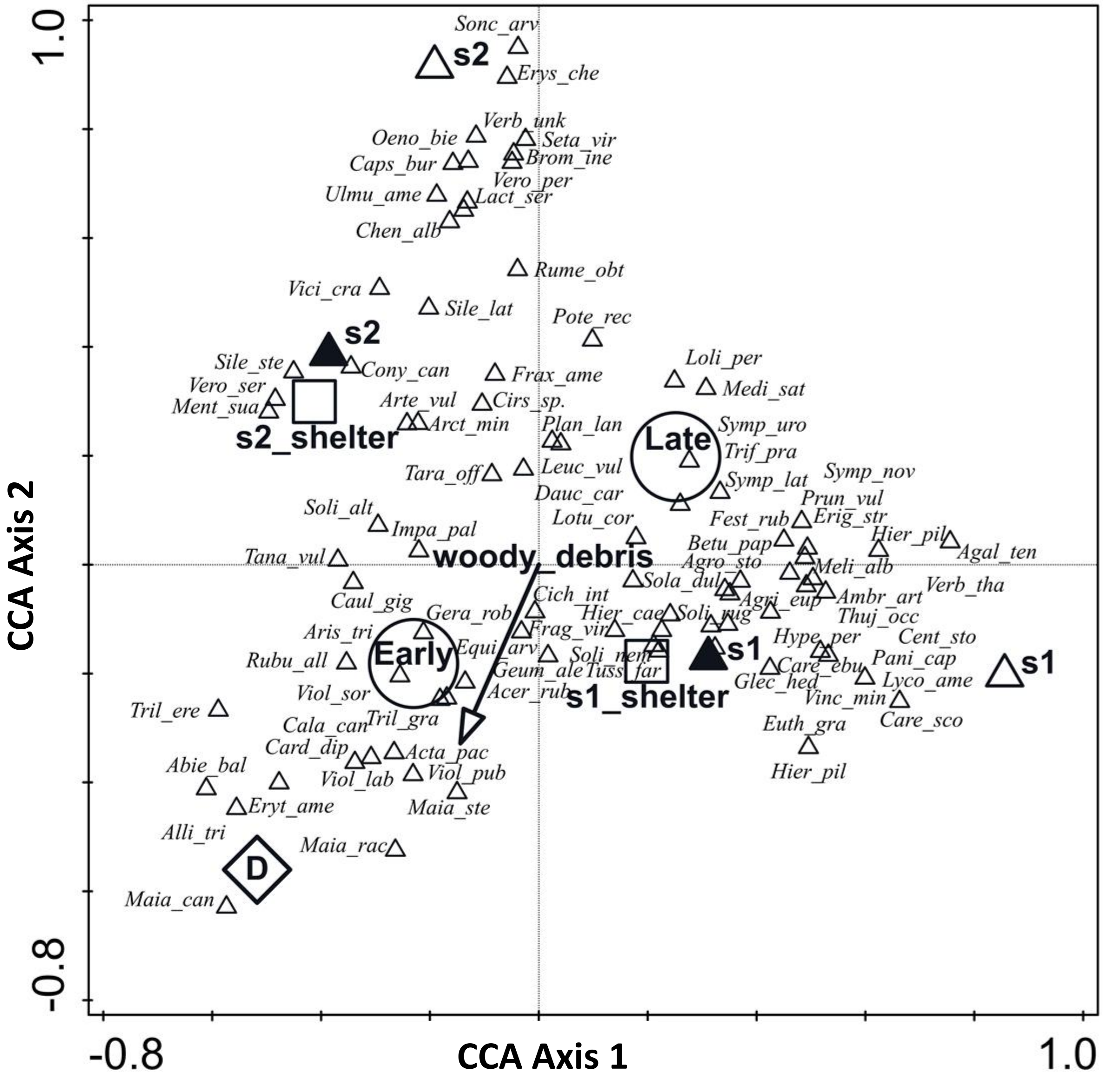

Figure 11. Canonical Correspondence Analysis (CCA) of early- and late-season vegetation communities at the donor forest (D) and in response to living mulch translocation and shade shelters at recipient seres S1-S2. Open triangles show centroids from not-treated areas while filled-in triangles show samples from all sections of the recipient blocks – except the shade shelters, depicted as open squares. See text for further explanation. See Table A1 in the Appendix to translate the species codes to their scientific and common names.

5.0. CONCLUSIONS

Plant communities and the ecosystems they sustain can be complicated entities that require complex methods to understand [20]. Answering even relatively simple questions requires investigators to contend with multiple sources of "noise", for example, when determining whether environmental alterations produce accurate "signals" of compositional change. The RERAS study utilized multiple sites, treatments, treatments-within-treatments and various levels of sampling (multidimensional) plant community responses, across space and over time. Fortunately, the ultimate outcome of this complicated experiment is the ability to make predictions about complex nature and draw some relatively simple conclusions, with high confidence in the reliability of these.

5.1. Did it work?

The main question we sought to answer was: Can re-using topsoil and surface debris that extractive industries must occasionally clear from forested lands – by directing this "living mulch" to lands at earlier stages of a woodland succession, especially following afforestation – change the understorey biodiversity at recipient sites to more closely match the species composition of the "donor" forest? The answer is a clear "Yes". Both the analyses of community similarity index values and the multivariate ordination that tracked species identities shows dramatically different vegetation communities occurred at not-treated areas of recipient sites compared, to the replicate 125 m2 blocks of land where we deposited a 30 cm layer of "living mulch" and woody debris extracted from the mature, unplanted, sugar maple "donor" forest.

The magnitude of the changes to ground-layer plant composition varied across sites and treatments in ways that provide answers to our secondary questions – related to how managers may learn to apply translocation techniques efficiently – but the major "take home" image from all analyses is that the direction of change was always toward greater similarity to the donor forest. This indicates that applying living mulch appropriately can produce changes in the direction of providing increased refuge to biodiversity associated with older forests. Such biodiversity participates in various complex relationships that ultimately provide multiple ecosystem services to the world. We did not seek to detail these here but recommend future studies investigate functions of particular interest (e.g. related to the cycling of water, carbon and other nutrients) likely influenced by living mulch applications in different contexts.

5.2. Improving sites at-hand vs. directing living mulch to the most suitable habitat

Somewhat different conclusions arise with respect to methods for maximizing the efficiency of translocating living mulch, depending on whether the management perspective focuses on "materials at-hand" versus "recipient sites at-hand". An aggregate producer planning to develop a limestone resource underlying forest cover may take the latter perspective, for example, if the only feasible locations to translocate the living mulch are former extraction areas requiring rehabilitation. The producer would obviously want to know whether the considerable labour of relocating a substantive portion of forest floor to the pit or quarry actually result in plant communities that are more forest-like compared to outcomes of traditional rehabilitation or succession. The magnitude of ecosystem changes, the species involved and expected timeframes would all warrant detailed planning.

The "materials-at-hand" perspective seeks these same answers but with a goal to maximally realizing the biodiversity potential of the living mulch by targeting materials to locations likely to yield the greatest “bang-for-buck”. It prefers recipient locations where a larger, rather than a smaller, fraction of the species inherent in the living mulch is likely to flourish. Directing living mulch to locations optimal for its constituent biodiversity would likely require collaborations among managers that collectively steward a variety of land-use types. These should include silvicultural plantations or other afforested land with at least moderate canopy closure and little undergrowth.

Our results demonstrate that translocating living mulch to more open sites, such as aggregate producers may typically manager (e.g. a post-extraction gravel pit requiring rehabilitation), is likely to enrich local biodiversity including by introducing native plant species that also occupy woodlands (particularly edges and openings). Many other species not particularly forest-adapted (including old-field weeds) will also likely colonize, however, producing communities that resemble the donor forest somewhat – but in a limited way. Even areas with high densities of planted trees are likely to respond the same way, so long as the trees remain too small to provide moderately closed (or heavier) canopy conditions. This is partly due to some of the more specialized woodland plants failing to tolerate the bright and occasionally drought-stricken open environments, and partly due to all of the other species also colonizing the resource “pulse” provided by the living mulch. We were surprised to find that several of the “iconic” understorey species of deciduous forests, such as trilliums, have survived patchily under cover of old-field weeds including burdock (mainly at the recently afforested field, S2). The fate of such populations as the planted trees gradually produce a closed forest canopy requires study.

5.3. Enhancing habitat conditions at more open recipient sites

Adding “microhabitat refuge structures” to open recipient sites can modestly increase the similarity of the emergent plant communities to the ground-layer of the donor forest. Piles of woody debris (extracted from deciduous forest: conifer logs etc. have different physical and chemical properties), ranging in size and decay status, can help increase community similarity to the donor forest by supporting some typical woodland herbs better. Increased ground shading provided by installed shade-cloth shelters may improve this effect slightly, when applied at small scales such as we employed, in part by helping exclude the weed species. Stronger improvements from artificial shading are likely, if attempted over a larger spatial scale but overcoming logistical challenges would require creative solutions.

In contrast to the positive yet limited compositional shifts toward donor-forest similarity that are likely following living mulch translocation to open landscapes, applications to forest environments can produce vegetation cover comprised of most species characterizing the donor forest and relatively few others. Signals of this outcome in our experiment include the analysis of similarity index scores, showing vegetation community samples from treated areas of the middle-aged plantation were nearly as similar to sets of community samples from the donor forest as the donor-forest samples were to each other. Data from this site predicts that covering deposited living mulch with woody debris to the point that random samples of ground exhibit 45-55% woody debris cover, on average, is likely to promote emergence of ground-layer plant communities reaching similarity targets with values approximately 75% those expected from comparing different areas within the donor forest.

5.4. Conifer-plantation surprise

The older-aged plantation performed slightly less remarkably but still very well, producing vegetation cover following living mulch application comprised of many species that otherwise characterize the donor forest. Depictions from the multivariate analysis of the older plantation, the middle-aged one and the donor forest all sharing the same small region of ordination space provides perhaps the clearest evidence as to the potential for achieving large and meaningful compositional shifts in the biodiversity of otherwise “green desert” plantations, via strategic application of living mulch. The most surprising aspect is that conifer plantations were capable of performing ecological roles that may perhaps be expected from cover by old deciduous trees (even planted) but seems unlikely given the many habitat differences between deciduous and coniferous forests (needle litter, minimal seasonal shifts in canopy cover, etc.).

The reason for this surprising potential of conifer plantations likely relates to the overall successional trajectory of the landscape toward deciduous forest combined with plantation management tending to produce canopy openings where such succession can proceed. The ecology of truly coniferous forests (e.g. in boreal regions) likely differs from stands of conifers established within deciduous biological regions. In the latter, the coniferous cover is essentially “temporary” and healthy deciduous forest would likely regenerate, given enough time and management conducive to natural processes. Depositing living mulch from deciduous donor forests throughout the understoreys of such plantations effectively accelerates this succession.

Successful outcomes from translocations to conifer plantations in this study are likely due, at least in part, to the logistical necessity of targeting plantation sections that included clearings, either as a result of harvesting or natural tree fall. Distributing living mulch around dense stands of mature trees would be difficult but also perhaps unlikely to produce the same results, as habitat conditions differ between thinned (e.g. by rows) and not-thinned forest areas. Further research aimed at maximizing living mulch efficiency when applied at large industry or forestry-sector scales should begin by improving understanding of how translocations and different thinning regimes should integrate to maximize propagation of donor-forest biodiversity. Further work should determine conditions under which recipient sites could themselves serve as donor sites, such as after a sufficiently long period of understorey development following the initial translocation.

5.5. Synthesis and implications for aggregates producers

Lands left to natural succession for very long durations produce forests recognized as highly valuable refuges for biodiversity and providers of numerous ecological services, including ones with far-reaching impacts beyond the forest boundaries. This is why advocacy for forest protection can be intense, and managers within land-use industries that require forest-clearance can face difficult regulatory hurdles to minimize environmental impacts. All of the reasons for protecting the “natural capital” provided by such forests in the landscape – their particular species compositions and functions – would also be reasons for strategically “re-investing” any such capital that may be salvaged from situations where patches of forest cover require conversion to another land-use. Successful re-investing requires translocating as much forest floor as feasible to other locations lacking in understorey biodiversity and capable of providing suitable habitat to species present in the relocated material and previously important to the ground vegetation layer in the forest undergoing conversion.

We have shown this is largely achievable in clearings of conifer plantations that provide moderate-to-heavy canopy clover, and possible to a limited extent at more open sites, including a former gravel pit and a recently afforested field. We also demonstrated that targeting and preparing microhabitat conditions at recipient sites to resemble the donor forest – e.g. by increasing ground shading and woody debris cover – is likely to improve the ecological "return" on the investment via greater replication of donor-forest vegetation communities. This is not to say that treated lands will necessarily serve as "ecological replacements" for the converted forests; important distinctions would no doubt remain. Rather, converting the forest combined with strategic translocations will benefit regional forest biodiversity and functioning more valuably than the status quo of forest conversion but stockpiling the "overburden" in a manner that prevents most desirable forest biodiversity components from living for long [21]. Although we initially expected the value of applying living mulch may remain unrealizable until relatively far in the future – e.g. once forests currently at the planting stages mature – our results show that excellent opportunities for rapid forest improvements actually exist right now, at middle-aged and older coniferous plantations throughout the landscape.

The RERAS study's results demonstrate in principle that aggregate producers could play a significant positive role in improving the efficacy of afforestation generally, not just in the context of managing extraction sites. The road to realizing this role will undoubtedly require collaboration between the aggregates industry and other sectors, especially government agencies and private companies driving the burgeoning afforestation movement or responsible for traditional silvicultural forestry operations. Credit for the benefits likely achievable from developing the opportunities fully would require appropriate agreements and frameworks for predicting and tracking the outcomes of different large-scale projects. Ultimately, the aggregates industry will more fully achieve its longstanding objective of sustainably providing essential mineral resources to society via maximizing the compatibility between extraction operations and the surrounding environment.

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Table A1: Vascular plant species sampled in the Rapid Ecological Restoration for Aggregate Sites project, 2018-2020 (N=283)

Spec_code	Common Name	Scientific Name[1]	Conservation Status[2]			Origin[3]	Life-form[4]
			Global	*Canada*	*Ont.*		
Abie_bals	Balsam Fir	*Abies balsamea* L. P. Mill.	G5	N5	S5	N	T
Acer_rubr	Red Maple	*Acer rubrum* L.	G5	N5	S5	N	T
Acer_sacc	Sugar Maple	*Acer saccharum* Marsh.	G5	N5	S5	N	T
Acin_arve	Spring Savory	*Acinos arvensis* (Lam.) Dandy	G5	NNA	SNA	E	H
Acta_pach	White Baneberry	*Actaea pachypoda* Ell.	G5	N5	S5	N	H
Acta_rubr	Red Baneberry	*Actaea rubra* (Ait.) Willd.	G5	N5	S5	N	H
Adia_peda	Northern Maidenhair Fern	*Adiantum pedatum* L.	G5	N5	S5	N	FA
Agal_tenu	Slender False Foxglove	*Agalinis tenuifolia* (Vahl) Raf.	G5	N5	S5	N	H
Agri_eupa	European Grovebur	*Agrimonia eupatoria* L.	GNR	NNA	SNA	E	H
Agro_stol	Creeping Bentgrass	*Agrostis stolonifera* L.	G5	N5	SNA	E	G
Alla_peti	Garlic Mustard	*Allaria petiolata* (Bieb.) Cavara & Grande	GNR	NNA	SNA	E	H
Alli_tric	Wild Leek	*Allium tricoccum* Ait. var. *tricoccum* AND var. *burdickii*	G5	N4	S4	N	H
Amar_hybr	Smooth Amaranth	*Amaranthus hybridus* L.	GNR	NNA	SNA	E	H
Amar_powe	Green Amaranth	*Amaranthus powellii S. Wats.*	GNR	NNA	SNA	E	H
Amar_retr	Red-root Amaranth	*Amaranthus retroflexus* L.	GNR	NNA	SNA	E	H
Ambr_arte	Annual Ragweed	*Ambrosia artemisiifolia* L.	G5	N5	S5	N	H
Amor_frut	False Indigobush	*Amorpha fruticosa* L.	G5	N1N2	SNA	E	H
Anem_cyli	Long-fruit Anemone	*Anemone cylindrica* Gray	G5	N5	S4	N	H
Anem_virg	Virginia Anemone	*Anemone virginiana* L.	G5	N5	S5	N	H
Anem_acut	Sharp-lobed Liver-leaf	*Anemone acutiloba* (DC.) G. Lawson	G5	N5	S5	N	H
Apoc_cann	Hemp Dogbane	*Apocynum cannabinum* L.	G5	NA	SNA	E	H
Aqui_cana	Wild Columbine	*Aquilegia canadensis* L.	G5	N5	S5	N	H
Arct_minu	Lesser Burdock	*Arctium minus* Bernh.	GNR	NNA	SNA	E	H
Aren_serp	Thymeleaf Sandwort	*Arenaria serpyllifolia* L.	GNR	NNA	SNA	E	H
Aris_trip	Jack-in-the-Pulpit	*Arisaema triphyllum L. Schott*	G5	N5	S5	N	H
Arte_vulg	Common Wormwood	*Artemisia vulgaris* L.	GNR	NNA	SNA	E	H
Asar_cana	Canada Wild Ginger	*Asarum canadense* L.	G5	N5	S5	N	H
Ascl_inca	Swamp Milkweed	*Asclepias incarnata* L.	G5	N5	S5	N	H

Ascl_syri	Common Milkweed	*Asclepias syriaca* L.	G5	N5	S5	N	H
Athy_fili	Subarctic Ladyfern	*Athyrium filix-femina* L. Roth	G5	N5	S5	N	FA
Atri_patu	Halberd-leaf Orache	*Atriplex patula* L.	GNR	NNA	SNA	E	H
Aven_fatu	Wild Oat	*Avena fatua* L.	GNR	NNA	SNA	E	G
Barb_vulg	Garden Yellow-rocket	*Barbarea vulgaris* Ait. f.	GNR	NNA	SNA	E	H
Betu_papy	Paper Birch	*Betula papyrifera* Marsh.	G5	N5	S5	N	T
Bide_conn	Tickseed Sunflower	*Bidens connata* Muhl. ex Willd.	G5	N4N5	S4	N	H
Bide_fron	Devil's Beggarticks	*Bidens frondosa* L.	G5	N5	S5	N	H
Bras_nigr	Black Mustard	*Brassica nigra L. W.D.J. Koch*	GNR	NNA	SNA	E	H
Bras_rapa	Bird's Rape	*Brassica rapa* L.	GNR	NNA	SNA	E	H
Brom_iner	Awnless Brome	*Bromus inermis* Leyss.	GNR	NNA	SNA	E	G
Brom_tect	Cheatgrass	*Bromus tectorum* L.	GNR	NNA	SNA	E	G
Cala_cana	Blue-joint Reedgrass	*Calamagrostis canadensis* (Michx.) Beauv.	G5	N5	S5	N	G
Caps_burs	Common Shepherd's Purse	*Capsella bursa-pastoris L. Medik.*	GNR	NNA	SNA	E	H
Card_conc	Cutleaf Toothwort	*Cardamine concatenata* (Michx.) Sw.	G5	N5	S5	N	H
Card_diph	Twoleaf Toothwort	*Cardamine diphylla* (Michx.) Wood	G5	N5	S5	N	H
Care_ebur	Bristleleaf Sedge	*Carex eburnea* Boott ex Hook.	G5	N5	S5	N	G
Care_plan	Plantainleaf Sedge	*Carex plantaginea* Lam.	G5	N5	S5	N	G
Care_scop	Broom Sedge	*Carex scoparia* Schkuhr ex Willd.	G5	N5	S5	N	G
Cary_cord	Bitternut Hickory	*Carya cordiformis* (Wangenh.) K. Koch	G5	N5	S5	N	T
Caul_giga	Giant Blue Cohosh	*Caulophyllum giganteum* (Farw.) Loconte & Blackwell	G4G5	N4N5	S5	N	H
Celt_occi	Common Hackberry	*Celtis occidentalis* L	G5	N4	S4	N	T
Cent_stoe	Spotted Knapweed	*Centaurea stoebe* L. ssp. micranthos (Gmelin ex Gugler) Hayek	GNR	NNA	SNA	E	H
Cera_arve	Mouse-ear Chickweed	*Cerastium arvense* L.	G5	N5	SNA	E	H
Cera_font	Common Mouse-ear Chickweed	*Cerastium fontanum* Baumg.	GNR	NNA	SNA	E	H
Chen_albu	White Goosefoot	*Chenopodium album* L.	GNR	NNA	SNA	E	H
Chen_albu	White Goosefoot	*Chenopodium album* L.	G5	NNA	SNA	E	H
Cich_inty	Chicory	*Cichorium intybus* L.	GNR	NNA	SNA	E	H
Cirs_sp.	Thistle Unknown	*Cirsium sp. Unknown*	???	???	???	???	H

Clay_caro	Carolina Springbeauty	*Claytonia caroliniana* Michx.	G5	N5	S5	N	H
Clem_virg	Virginia Virgin's-bower	*Clematis virginiana* L.	G5	N5	S5	N	V
Clin_vulg	Field Basil	*Clinopodium vulgare* L.	G5	N5	S5	N	H
Coma_palu	Marsh Cinquefoil	*Comarum palustre* L.	G5	N5	S5	N	H
Conv_arve	Field Bindweed	*Convolvulus arvensis* L.	GNR	NNA	SNA	E	H
Cony_cana	Canada Horseweed	*Conyza canadensis L. Cronq.*	G5	N5	S5	N	H
Copt_trif	Goldthread	*Coptis trifolia L. Salisb.*	G5	N5	S5	N	H
Corn_alte	Alternate-leaf Dogwood	*Cornus alternifolia* L. f.	G5	N5	S5	N	S
Corn_seri	Red-osier Dogwood	*Cornus sericea* L.	G5	N5	S5	N	S
Dact_glom	Orchard Grass	*Dactylis glomerata* L.	GNR	NNA	SNA	E	G
Dauc_caro	Wild Carrot	*Daucus carota* L.	GNR	NNA	SNA	E	H
Depa_acro	Silver False Spleenwort	*Deparia acrostichoides* (Sw.) M. Kato	G5	N5	S4	N	FA
Digi_sang	Hairy Crabgrass	*Digitaria sanguinalis L. Scop.*	GNR	NNA	SNA	E	G
Dryo_cris	Crested Shieldfern	Dryopteris cristata L. Gray	G5	N5	S5	N	FA
Dryo_inte	Evergreen Woodfern	*Dryopteris intermedia* (Muhl. ex Willd.) Gray	G5	N5	S5	N	FA
Echi_crus	Barnyard Grass	*Echinochloa crus-galli L. Beauv.*	GNR	NNA	SNA	E	G
Echi_loba	Wild Mock Cucumber	*Echinocystis lobata* (Michx.) Torr. & Gray	G5	N5	S5	N	H
Echi_vulg	Common Viper's-bugloss	*Echium vulgare* L.	GNR	NNA	SNA	E	H
Eleo_acic	Least Spikerush	*Eleocharis acicularis L. Roemer & J.A. Schultes*	G5	N5	S5	N	G
Elym_repe	Creeping Wild Rye	*Elymus repens L. Gould*	GNR	NNA	SNA	E	G
Epil_colo	Purpleleaf Willowherb	*Epilobium coloratum* Biehler	G5	N5	S5	N	H
Epil_parv	Small-flower Hairy Willowherb	*Epilobium parviflorum* Schreb.	GNR	NNA	SNA	E	H
Epip_hell	Eastern Helleborine	*Epipactis helleborine L. Crantz*	GNR	NNA	SNA	E	H
Equi_arve	Field Horsetail	*Equisetum arvense* L.	G5	N5	S5	N	FA
Erig_annu	White-top Fleabane	*Erigeron annuus L. Pers.*	G5	N5	S5	N	H
Erig_phil	Philadelphia Fleabane	*Erigeron philadelphicus* L.	G5	N5	S5	N	H
Erig_pulc	Robin's-plantain	*Erigeron pulchellus* Michx.	G5	N5	S5	N	H
Erig_stri	Daisy Fleabane	*Erigeron strigosus* Muhl. ex Willd.	G5	N5	S5	N	H
Erys_chei	Wormseed Wallflower	*Erysimum cheiranthoides* L.	G5	N5	S5	N	H
Eryt_amer	Yellow Trout-lily	*Erythronium americanum* Ker-Gawl.	G5	N5	S5	N	H

Eupa_perf	Common Boneset	*Eupatorium perfoliatum* L.	G5	N5	S5	N	H
Euph_cypa	Cypress Spurge	*Euphorbia cyparissias* L.	G5	NNA	SNA	E	H
Euth_gram	Grass-leaved Goldenrod	*Euthamia graminifolia L. Nutt.*	G5	N5	S5	N	H
Fago_escu	Buckwheat	*Fagopyrum esculentum* Moench	GNR	NNA	SNA	E	H
Fagu_gran	American Beech	*Fagus grandifolia* Ehrh.	G5	N5	S4	N	T
Fall_conv	Black Bindweed	*Fallopia convolvulus L. A. Löve*	GNR	NNA	SNA	E	H
Fest_rubr	Red Fescue	*Festuca rubra* L.	G5	N5	S5	N	G
Frag_virg	Virginia Strawberry	*Fragaria virginiana* Duchesne	G5	N5	S5	N	H
Frax_amer	White Ash	*Fraxinus americana* L.	G5	N5	S4	N	T
Gale_spec	Showy Orchis	*Galearis spectabilis L. Raf.*	G5	N4	S4?	N	H
Gale_tetr	Brittle-stem Hempnettle	*Galeopsis tetrahit* L.	GNR	NNA	SNA	E	H
Gali_quad	Fringed Quickweed	*Galinsoga quadriradiata* Ruiz & Pavon	GNR	NNA	SNA	E	H
Gali_apar	Catchweed Bedstraw	*Galium aparine* L.	G5	N5	S5	N	H
Gali_trif	Sweet-scent Bedstraw	*Galium triflorum* Michx.	G5	N5	S5	N	H
Gall_mull	Great Hedge Bedstraw	*Gallium mullugo* L.	G5	N5	S5	N	H
Gent_crin	Fringed Gentian	*Gentianopsis crinita* (Froel.) Ma	G5	N5	S5	N	H
Gera_macu	Wild Crane's-bill	*Geranium maculatum* L.	G5	N5	S5	N	H
Gera_robe	Herb-Robert	*Geranium robertianum* L.	G5	N5	S5	N	H
Geum_alep	Yellow Avens	*Geum aleppicum* Jacq.	G5	N5	S5	N	H
Geum_cana	White Avens	*Geum canadense* Jacq.	G5	N5	S5	N	H
Glec_hede	Ground-ivy	*Glechoma hederacea* L.	GNR	NNA	SNA	E	H
Glyc_stri	Fowl Mannagrass	*Glyceria striata* (Lam.) A.S. Hitchc.	G5	N5	S5	N	G
Hibi_trio	Flower-of-an-Hour	*Hibiscus trionum* L.	GNR	NNA	SNA	E	H
Hier_caes	Meadow Hawkweed	*Hieracium caespitosum* Dumort.	GNR	NNA	SNA	E	H
Hier_pilo	Mouse-ear Hawkweed	*Hieracium pilosella* L.	GNR	NNA	SNA	E	H
Hier_pilo	Tall Hawkweed	*Hieracium piloselloides* Vill.	GNR	NNA	SNA	E	H
Hydr_cana	Bluntleaf Waterleaf	*Hydrophyllum canadense* L.	G5	N4	S4	N	H
Hydr_virg	Virginia Waterleaf	*Hydrophyllum virginianum* L.	G5	N5	S5	N	H
Hylo_tele	Garden Stonecrop	*Hylotelephium telephium L. H. Ohba.*	GNR	NNA	SNA	E	H
Hype_kalm	Kalm's St. John's-wort	*Hypericum kalmianum* L.	G4	N4	S4	N	H
Hype_perf	Common St. John's-wort	*Hypericum perforatum* L.	GNR	NNA	SNA	E	H
Hype_punc	Spotted St. John's-wort	*Hypericum punctatum* Lam.	G5	N5	S5	N	H

Impa_pall	Pale Jewelweed	*Impatiens pallida* Nutt.	G5	N5	S4	N	H
Jugl_nigr	Black Walnut	*Juglans nigra* L.	G5	N4?	S4?	N	T
Junc_balt	Baltic Rush	*Juncus balticus* Willd.	G5	N5	S5	N	G
Juni_comm	Ground Juniper	*Juniperus communis* L.	G5	N5	S5	N	S
Lact_cana	Canada Lettuce	*Lactuca canadensis* L.	G5	N5	S5	N	H
Lact_serr	Prickly Lettuce	*Lactuca serriola* L.	GNR	NNA	SNA	E	H
Lami_albu	White Deadnettle	*Lamium album* L.	G5	NNA	SNA	E	H
Laps_comm	Common Nipplewort	*Lapsana communis* L.	GNR	NNA	SNA	E	H
Lari_lari	American Larch	*Larix laricina* (Du Roi) K. Koch	G5	N5	S5	N	T
Lech_unko	Pinweed Unknown	*Lechea unkown*	???	???	???	??	H
Leon_card	Common Motherwort	*Leonurus cardiaca* L.	GNR	NNA	SNA	E	H
Lepi_camp	Field Pepper-grass	*Lepidium campestre L. Ait. f.*	GNR	NNA	SNA	E	H
Leuc_vulg	Oxeye Daisy	*Leucanthemum vulgare* Lam.	GNR	NNA	SNA	E	H
Linn_bore	Twinflower	*Linnaea borealis* L.	G5	N5	S5	N	H
Lith_parv	Soft-hairy False Gromwell	*Lithospermum parviflorum* Weakley, Witsell & D. Estes	G4	NNA	S2	N	H
Lobe_infl	Indian-tobacco	*Lobelia inflata* L.	G5	N5	S5	N	H
Lobe_kalm	Kalm's Lobelia	*Lobelia kalmii* L.	G5	N5	S5	N	H
Loli_arun	Tall Rye Fescue	*Lolium arundinaceum* (Schreb.) S.J. Darbyshire	GNR	NNA	SNA	E	G
Loli_pers	Persian Ryegrass	*Lolium persicum* Boiss. & Hohen. ex Boiss.	GNR	NNA	SNA	E	G
Lotu_corn	Bird's-foot-trefoil	*Lotus corniculatus* L.	GNR	NNA	SNA	E	H
Luzu_camp	Common Woodrush	*Luzula campestris L. DC.*	GNR	NNA	SNA	E	G
Lyco_amer	American Bugleweed	*Lycopus americanus* Muhl. ex W. Bart.	G5	N5	S5	N	H
Lyco_unif	Northern Bugleweed	*Lycopus uniflorus* Michx.	G5	N5	S5	N	H
Lyth_sali	Purple Loosestrife	*Lythrum salicaria* L.	GNR	NNA	SNA	E	H
Maia_cana	Canada Mayflower	*Maianthemum canadense* Desf.	G5	N5	S5	N	H
Maia_stel	Star-flowered False Solomon's-seal	*Maianthemum stellatum L. Link*	G5	N5	S5	N	H
Maia_race	False Solomon's-seal	*Maianthemum racemosum L. Link ssp. racemosum*	G5	N5	S5	N	H
Malv_mosc	Musk Mallow	*Malva moschata* L.	GNR	NNA	SNA	E	H
Malv_negl	Common Mallow	*Malva neglecta* Wallr.	GNR	NNA	SNA	E	H
Matt_stru	Ostrich Fern	*Matteuccia struthiopteris* L. Todaro	G5	N5	S5	N	FA
Medi_lupu	Black Medic	*Medicago lupulina* L.	GNR	NNA	SNA	E	H
Medi_sati	Alfalfa	*Medicago sativa* L.	GNR	NNA	SNA	E	H
Medi_unkn	Medic unkown	*Medicago unknown*	GNR	NNA	SNA	E	H

Meli_albu	White Sweet-clover	*Melilotus albus* Medik.	GNR	NNA	SNA	E	H
Ment_suav	Apple Mint	*Mentha suaveolens* Ehrh.	GNR	NNA	SNA	E	H
Myos_laxa	Small Forget-me-not	*Myosotis laxa* Lehm.	G5	N5	S5	N	H
Myos_scor	True Forget-me-not	*Myosotis scorpioides* L.	G5	NNA	SNA	E	H
Nepe_cata	Catnip	*Nepeta cataria* L.	GNR	NNA	SNA	E	H
Nutt_cana	Old-field Toadflax	*Nuttallanthus canadensis L. D.A. Sutton*	G5	N2N3	S1	N	H
Oeno_bien	Common Evening-primrose	*Oenothera biennis* L.	G5	N5	S5	N	H
Onoc_sens	Sensitive Fern	*Onoclea sensibilis* L.	G5	N5	S5	N	FA
Onop_acan	**Scotch Cotton-thistle**	*Onopordum acanthium* L.	GNR	NNA	SNA	E	H
Orig_vulg	Wild Marjoram	*Origanum vulgare* L.	GNR	NNA	SNA	E	H
Ostr_virg	Eastern Hophornbeam	*Ostrya virginiana* (P. Mill.) K. Koch	G5	N5	S5	N	T
Oxal_stri	Common Yellow Woodsorrel	*Oxalis stricta* L.	G5	N5	S5	N	H
Pack_plat	Prairie Ragwort	*Packera plattensis* (Nutt.) W.A. Weber & A. Love	G5	NNA	S2S3	N	H
Pani_capi	Common Panicgrass	*Panicum capillare* L. ssp. capillare	G5	N5	S5	N	G
Pari_pens	Pennsylvania Pellitory	*Parietaria pensylvanica* Muhl. ex Willd.	G5	N5	S4	N	H
Part_quin	Virginia Creeper	*Parthenocissus quinquefolia* L. Planch.	G5	N4?	S4?	N	V
Pers_macu	Spotted Lady's-thumb	*Persicaria maculosa* Gray	G4	NNA	SNA	E	H
Pers_sagi	Arrowleaf Tearthumb	*Persicaria sagittata L. H. Gross*	G5	N5	S4S5	N	H
Phle_prat	Meadow Timothy	*Phleum pratense* L.	GNR	NNA	SNA	E	G
Pice_glau	White Spruce	*Picea glauca* (Moench) Voss	G5	N5	S5	N	T
Pinu_resi	Red Pine	*Pinus resinosa* Soland.	G5	N5	S5	N	T
Pinu_stro	Eastern White Pine	*Pinus strobus* L.	G5	N5	S5	N	T
Pinu_sylv	Scotch Pine	*Pinus sylvestris* L.	GNR	NNA	SNA	E	T
Plan_lanc	Narroleaf Plantain	*Plantago lanceolata* L.	G5	NNA	SNA	E	H
Plan_majo	Common Plantain	*Plantago major* L.	G5	NNA	SNA	E	H
Pluc_odor	Shrubby Camphorweed	*Pluchea odorata L. Cass.*	G5	NNA	SNA	E	H
Poa _comp	Canada Bluegrass	*Poa compressa* L.	GNR	NNA	SNA	E	G
Poly_avic	Prostrate Knotweed	*Polygonum aviculare* L.	G5	NNA	SNA	E	H
Poly_acro	Christmas Fern	*Polystichum acrostichoides* (Michx.) Schott	G5	N5	S5	N	FA
Popu_bals	Balsam Poplar	*Populus balsamifera* L.	G5	NNR	S5	N	T

Popu_delt	Eastern Cottonwood	*Populus deltoides* Bartr. ex Marsh.	G5	N5	S5	N	T
Popu_trem	Trembling Aspen	*Populus tremuloides* Michx.	G5	N5	S5	N	T
Pote_cana	Canada Cinquefoil	*Potentilla canadensis* L.	G5	N2N3	S2	N	H
Pote_norv	Norwegian Cinquefoil	*Potentilla norvegica* L.	G5	N5	S5	N	H
Pote_rect	Rough-fruited Cinquefoil	*Potentilla recta* L.	GNR	NNA	SNA	E	H
Pote_simp	Common Cinquefoil	*Potentilla simplex* Michx.	G5	N5	S5	N	H
Pote_anse	Common Silverweed	*Potentilla anserina* L. *ssp. anserina*	G5	N5	S5	N	H
Prun_vulg	Self-heal	*Prunella vulgaris* L.	G5	N5	S5	N	H
Prun_pens	Fire Cherry	*Prunus pensylvanica* L. f.	G5	N5	S5	N	S
Prun_virg	Choke Cherry	*Prunus virginiana* L.	G5	N5	S5	N	S
Prun_sero	Black Cherry	*Prunus serotina* Ehrh. *var. serotina*	G5	N5	S5	N	T
Pycn_virg	Virginia Mountainmint	*Pycnanthemum virginianum* L. T. Dur. & B.D. Jackson ex B.L. Robins. & Fern.	G5	N4	S4	N	H
Pyro_amer	American Wintergreen	*Pyrola americana* Sweet	G5	N5	S4	N	H
Quer_rubr	Northern Red Oak	*Quercus rubra* L.	G5	N5	S5	N	T
Ranu_abor	Kidneyleaf Buttercup	*Ranunculus abortivus* L.	G5	N5	S5	N	H
Ranu_acri	Tall Buttercup	*Ranunculus acris* L.	G5	NNA	SNA	E	H
Ranu_recu	Hooked Crowfoot	*Ranunculus recurvatus* Poir.	G5	N5	S5	N	H
Ranu_repe	Creeping Buttercup	*Ranunculus repens* L.	GNR	NNA	SNA	E	H
Ranu_unkn	Buttercup unknown	*Ranunculus unknown*	???	???	???	???	H
Rhus_typh	Staghorn Sumac	*Rhus typhina* L.	G5	N5	S5	N	S
Ribe_amer	Wild Black Currant	*Ribes americanum* P. Mill.	G5	N5	S5	N	S
Ribe_cyno	Prickly Gooseberry	*Ribes cynosbati* L.	G5	N5	S5	N	S
Robi_pseu	Black Locust	*Robinia pseudoacacia* L.	G5	NNA	SNA	E	T
Rosa_mult	Multiflora Rose	*Rosa multiflora* Thunb. ex Murr.	GNR	NNA	SNA	E	S
Rubu_alle	Allegheny Blackberry	*Rubus allegheniensis* Porter	G5	N5	S5	N	S
Rubu_idae	Red Raspberry	*Rubus idaeus* L. unknown ssp.	???	???	???	???	S
Rume_cris	Curly Dock	*Rumex crispus* L.	GNR	NNA	SNA	E	H
Rume_obtu	Bitter Dock	*Rumex obtusifolius* L.	GNR	NNA	SNA	E	H
Sali_bebb	Bebb's Willow	*Salix bebbiana* Sarg.	G5	N5	S5	N	S
Samb_race	Red Elderberry	*Sambucus racemosa* L.	G5	N5	S5	N	S
Scut_gale	Hooded Skullcap	*Scutellaria galericulata* L.	G5	N5	S5	N	H
Scut_late	Mad-dog Skullcap	*Scutellaria lateriflora* L.	G5	N5	S5	N	H

Scut_parv	Small Skullcap	*Scutellaria parvula* Michx.	G4	N4	S4	N	H
Seca_cere	Cultivated Rye	*Secale cereale* L.	GNR	NNA	SNA	E	G
Sedu_ukno	Stonecrop unknown	*Sedum uknown*	???	???	???	???	H
Sene_jaco	Tansy Ragwort	*Senecio jacobaea* L.	GNR	NNA	SNA	E	H
Seta_pumi	Yellow Foxtail	*Setaria pumila* (Poir.) Roem. & Schult. ssp. pumila	GNR	NNA	SNA	E	G
Seta_viri	Green Bristle Grass	*Setaria viridis L. Beauv.*	GNR	NNA	SNA	E	G
Shep_cana	Canada Buffaloberry	*Shepherdia canadensis* L. Nutt.	G5	N5	S5	N	H
Sile_lati	Bladder Campion	*Silene latifolia* Poir.	GNR	NNA	SNA	E	H
Sile_noct	Night-flowering Catchfly	*Silene noctiflora L.*	GNR	NNA	SNA	E	H
Sile_stel	Starry Campion	*Silene stellata* L. Aiton f.	GNR	NNA	SNA	E	H
Sile_vulg	Catchfly	*Silene vulgaris* Moenke (Garcke)	GNR	NNA	SNA	E	H
Sina_arve	Corn Mustard	*Sinapis arvensis* L.	GNR	NNA	SNA	E	H
Sisy_mont	Little Blue-eyed-grass	*Sisyrinchium montanum* Greene var. *montanum*	G5	N5	S5	N	H
Sola_dulc	Climbing Nightshade	*Solanum dulcamara* L.	GNR	NNA	SNA	E	V
Soli_alti	Tall Goldenrod	*Solidago altissima* L.	G5	N5	S5	N	H
Soli_junc	Early Goldenrod	*Solidago juncea* Ait.	G5	N5	S5	N	H
Soli_nemo	Field Goldenrod	*Solidago nemoralis* Ait.	G5	N5	S5	N	H
Soli_rugo	Roughleaf Goldenrod	*Solidago rugosa* P. Mill.	G5	N5	S5	N	H
Soli_cana	Canada Goldenrod	*Solidago canadensis* L. *var. canadensis*	G5	N5	S5	N	H
Sonc_arve	Field Sowthistle	*Sonchus arvensis* L.	GNR	NNA	SNA	E	H
Sonc_aspe	Spiny-leaf Sowthistle	*Sonchus asper* L. Hill	GNR	NNA	SNA	E	H
Sonc_oler	Common Sowthistle	*Sonchus oleraceus* L.	GNR	NNA	SNA	E	H
Sorb_aucu	Rowan-tree	*Sorbus aucuparia* L.	G5	N5	S5	N	T
Stac_palu	Marsh Hedge-nettle	*Stachys palustris* L.	G5	N3N4	SNA	E	H
Symp_cord	Heartleaf Aster	*Symphyotrichum cordifolium* L. Nesom	G5	N5	S5	N	H
Symp_lanc	Panicled Aster	*Symphyotrichum lanceolatum* (Willd.) Nesom	G5	N5	S5	N	H
Symp_late	Calico Aster	*Symphyotrichum lateriflorum* L. A.& D. Löve	G5	N5	S5	N	H
Symp_nova	New England Aster	*Symphyotrichum novae-angliae* L. Nesom	G5	N5	S5	N	H
Symp_subu	Annual Saltmarsh Aster	*Symphyotrichum subulatum* (Michx.) Nesom	G5	N2	SNA	E	H
Symp_urop	White-arrow Aster	*Symphyotrichum urophyllum* (Lindl.) Nesom	G5	N4	S4	N	H
Symp_eric	White Heath Aster	*Symphyotrichum ericoides* L. G.L.Nesom var. ericoides	G5	N5	S2	N	H
Syri_vulg	Common Lilac	*Syringa vulgaris* L.	GNR	NNA	SNA	E	T
Tana_vulg	Common Tansy	*Tanacetum vulgare* L.	GNR	NNA	SNA	E	H

Tara_offi	Common Dandelion	*Taraxacum officinale* G.H. Weber ex Wiggers	G5	N5	SNA	E	H
Thla_arve	Field Pennycress	*Thlaspi arvense* L.	GNR	NNA	SNA	E	H
Thuj_occi	Eastern White-cedar	*Thuja occidentalis* L.	G5	N5	S5	N	S
Thym_prae	Mother-of-Thyme	*Thymus praecox* Opiz *ssp. arcticus* (E. Durand) Jalas	GNR	NNA	SNA	E	H
Tili_amer	American Basswood	*Tilia americana* L.	G5	N5	S5	N	T
Tori_japo	Erect Hedge-parsley	*Torilis japonica* (Houtt.) DC.	GNR	NNA	SNA	E	H
Toxi_radi	Eastern Poison-ivy	*Toxicodendron radicans* L. Kuntze	G5	N5	S5	N	V
Trag_prat	Meadow Goat's-beard	*Tragopogon pratensis* L.	GNR	NNA	SNA	E	H
Trif_camp	Low Hop Clover	*Trifolium campestre* Schreb.	GNR	NNA	SNA	E	H
Trif_hybr	Alsike Clover	*Trifolium hybridum* L.	GNR	NNA	SNA	E	H
Trif_prat	Red Clover	*Trifolium pratense* L.	GNR	NNA	SNA	E	H
Trif_repe	White Clover	*Trifolium repens* L.	GNR	NNA	SNA	E	H
Tril_erec	Red Trillium	*Trillium erectum* L.	G5	N5	S5	N	H
Tril_gran	White Trillium	*Trillium grandiflorum* (Michx.) Salisb.	G5	N5	S5	N	H
Tsug_cana	Eastern Hemlock	*Tsuga canadensis* L. Carr.	G5	N5	S5	N	T
Tuss_farf	Colt's-foot	*Tussilago farfara* L.	GNR	NNA	SNA	E	H
Ulmu_amer	American Elm	*Ulmus americana* L.	G4	N5	S5	N	T
Ulmu_rubr	Slippery Elm	*Ulmus rubra* Muhl.	G5	N5	S5	N	T
Urti_dioi	Stinging Nettle	*Urtica dioica* L.	G5	N5	S5	N	H
Verb_phlo	Clasping-leaf Mullein	*Verbascum phlomoides* L.	GNR	NNA	SNA	E	H
Verb_thap	Common Mullein	*Verbascum thapsus* L.	GNR	NNA	SNA	E	H
Verb_unko	Verbena unknown	*Verbena unkown*	???	???	???	?	H
Verb_urti	White Vervain	*Verbena urticifolia* L.	G5	N5	S5	N	H
Vero_arve	Corn Speedwell	*Veronica arvensis* L.	GNR	NNA	SNA	E	H
Vero_offi	Common Speedwell	*Veronica officinalis* L.	G5	NNA	SNA	E	H
Vero_pere	Purslane Speedwell	*Veronica peregrina* L.	G5	N5	S5	N	H
Vero_pers	Bird-eye Speedwell	*Veronica persica* Poir.	GNR	NNA	SNA	E	H
Vero_serp	Thymeleaf Speedwell	*Veronica serpyllifolia* L.	GNR	NNA	SNA	E	H
Vici_crac	Tufted Vetch	*Vicia cracca* L.	GNR	NNA	SNA	E	H
Vinc_mino	Lesser Periwinkle	*Vinca minor* L.	GNR	NNA	SNA	E	H
Viol_arve	Small Wild Pansy	*Viola arvensis* Murr.	GNR	NNA	SNA	E	H
Viol_cana	Canada Violet	*Viola canadensis* L.	G5	N5	S5	N	H
Viol_labr	Labrador Violet	*Viola labradorica* Schrank	G5	N5	S4S5	N	H

Viol_soro	Woolly Blue Violet	*Viola sororia* Willd.	G5	N5	S5	N	H
Viol_pube	Downy Yellow Violet	*Viola pubescens* Aiton *var. pubescens*	G5	N5	S5	N	H
Viti_ripa	Riverbank Grape	*Vitis riparia* Michx.	G5	N5	S5	N	V
Notes:	[1] Sourced fron NatureServe (link: https://explorer.natureserve.org/AboutTheData) and the Flora Ontario Integrated Botanical Information System (FOIBIS) (link: https://www.uoguelph.ca/foibis/).						
	[2] Information reported via NatureServe's Explorer database (link: https://explorer.natureserve.org/); lower numbers indicate greater endangerment						
	[3] Biogeographic origins extracted from NatureServe and FOIBIS; "N" indicated the species is native (inidgenous) to Ontario, "E" indicates it is exotic (non-indigenous)						
	[4] The different possible lifeforms were: fern (F), fern ally (FA), graminoid (G), herb (H), shrub (S), tree (T) and vine (V).						

Table A2: Percent frequency of species incidence[1] at each sere, by recipient treatment level[2]

Spec_code	S1		S2		S3		S4		S5		DON
	NT	REC	NT	REC	NT	REC	NT	REC	NT	REC	
Abie_bals	0.00	0.00	1.39	3.64	0.00	1.11	2.11	1.11	4.35	2.22	8.52
Acer_rubr	1.90	23.08	2.78	11.82	2.11	15.00	1.05	6.11	2.17	6.11	14.80
Acer_sacc	13.33	40.38	16.67	22.73	6.32	36.11	9.47	25.56	2.17	4.44	22.87
Acin_arve	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acta_pach	0.95	1.54	0.00	1.82	0.00	28.89	2.11	6.67	6.52	10.00	9.87
Acta_rubr	0.00	1.15	0.00	2.27	1.05	29.44	14.74	15.56	1.09	2.22	4.04
Adia_peda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.26	4.44	1.35
Agal_tenu	4.76	1.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agri_eupa	8.57	18.46	0.69	0.91	3.16	5.00	0.00	1.11	1.09	0.00	3.59
Agro_stol	32.38	23.46	4.17	3.64	23.16	36.11	7.37	16.11	0.00	0.00	0.90
Alla_peti	7.62	30.00	4.17	35.00	16.84	26.67	12.63	80.00	1.09	0.56	8.97
Alli_tric	0.00	1.15	0.00	8.64	0.00	27.22	0.00	13.89	36.96	33.89	27.80
Amar_hybr	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00	2.78	5.83
Amar_powe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.24
Amar_retr	0.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00	1.09	1.67	0.00
Ambr_arte	7.62	13.46	0.00	0.00	0.00	0.00	0.00	2.22	0.00	0.00	0.45
Amor_frut	1.90	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anem_cyli	0.95	8.08	0.00	2.73	0.00	1.11	0.00	3.89	0.00	0.00	1.35
Anem_virg	0.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anem_acut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09	0.00	0.00
Apoc_cann	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17	2.78	0.00
Aqui_cana	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.35
Arct_minu	4.76	12.31	27.78	48.18	10.53	17.22	2.11	9.44	0.00	0.00	0.45
Aren_serp	0.00	1.15	2.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aris_trip	1.90	21.92	8.33	19.55	0.00	57.22	0.00	50.56	18.48	33.89	20.63
Arte_vulg	0.00	4.62	13.19	10.91	2.11	2.78	0.00	0.56	0.00	1.11	1.79
Asar_cana	0.95	0.00	0.69	3.18	0.00	25.56	0.00	1.67	2.17	0.00	5.38
Ascl_inca	0.95	0.77	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ascl_syri	1.90	0.77	3.47	1.82	0.00	0.56	0.00	0.00	0.00	1.67	0.00
Athy_fili	0.00	6.92	0.69	0.00	0.00	0.56	0.00	0.00	10.87	10.56	8.52
Atri_patu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aven_fatu	0.00	1.54	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.90
Barb_vulg	0.00	0.38	2.08	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.45
Betu_papy	13.33	6.54	2.78	1.36	2.11	0.56	6.32	4.44	0.00	0.00	0.90
Bide_conn	0.00	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bide_fron	0.95	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45
Bras_nigr	0.00	0.00	3.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bras_rapa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.78	0.00
Brom_iner	0.00	0.00	5.56	3.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brom_tect	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.35	14.44	6.28
Cala_cana	0.00	16.15	0.00	10.00	0.00	12.78	0.00	5.00	0.00	0.00	2.69
Caps_burs	0.00	0.00	2.08	2.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Card_conc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	4.48
Card_diph	0.00	9.62	0.00	5.00	0.00	17.22	1.05	0.56	11.96	15.56	10.31

Care_ebur	13.33	8.85	1.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Care_plan	0.00	0.38	0.00	0.45	0.00	0.00	0.00	0.00	1.09	0.00	3.14
Care_scop	47.62	6.54	0.00	0.00	0.00	0.00	0.00	3.33	0.00	0.00	0.00
Cary_cord	0.00	0.38	0.69	0.45	0.00	0.56	0.00	0.56	2.17	6.11	3.14
Caul_giga	0.95	3.85	11.11	30.00	0.00	49.44	0.00	21.11	55.43	53.33	29.60
Celt_occi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cent_stoe	14.29	10.00	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.00	0.00
Cera_arve	0.00	0.00	0.00	0.45	0.00	1.11	0.00	0.00	0.00	0.00	0.00
Cera_font	1.90	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.79
Chen_albu	0.00	0.77	18.75	5.91	0.00	0.00	0.00	0.56	0.00	0.00	0.00
Chen_albu	0.00	0.38	6.25	7.73	0.00	0.00	0.00	0.00	0.00	0.00	0.90
Cich_inty	9.52	81.92	4.17	46.82	7.37	59.44	9.47	80.00	9.78	33.89	21.52
Cirs_sp.	3.81	16.54	36.11	32.73	3.16	7.22	1.05	2.78	0.00	1.67	0.90
Clay_caro	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.35
Clem_virg	0.00	2.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.35
Clin_vulg	0.95	13.46	0.00	13.18	5.26	6.67	0.00	1.11	0.00	1.67	2.69
Coma_palu	0.00	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Conv_arve	0.00	0.77	0.69	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cony_cana	0.00	2.31	6.25	33.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copt_trif	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.00	0.00	0.00	0.00
Corn_alte	1.90	22.31	2.78	8.64	11.58	18.33	17.89	17.22	26.09	13.33	13.90
Corn_seri	14.29	10.38	2.08	7.73	0.00	0.56	2.11	1.11	9.78	2.78	5.83
Dact_glom	35.24	24.23	24.31	16.82	26.32	8.89	4.21	8.33	0.00	0.00	0.00
Dauc_caro	33.33	56.15	77.78	65.00	12.63	6.11	1.05	0.00	0.00	0.00	0.90
Depa_acro	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09	2.22	0.45
Digi_sang	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dryo_cris	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09	1.11	4.93
Dryo_inte	2.86	16.92	0.00	7.73	0.00	16.11	1.05	1.67	28.26	20.00	14.80
Echi_crus	0.00	0.38	0.69	2.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Echi_loba	0.00	0.38	0.00	0.00	0.00	0.00	4.21	1.11	0.00	0.00	0.45
Echi_vulg	2.86	1.54	0.00	0.00	2.11	0.00	0.00	0.00	0.00	0.00	0.00
Eleo_acic	11.43	0.00	0.00	0.00	0.00	0.00	1.05	0.56	0.00	0.00	0.00
Elym_repe	1.90	1.92	1.39	1.36	0.00	0.00	0.00	0.00	0.00	0.56	0.90
Epil_colo	6.67	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Epil_parv	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.78	0.45
Epip_hell	0.00	0.77	0.00	0.91	11.58	0.56	6.32	6.11	0.00	0.00	1.35
Equi_arve	32.38	46.15	4.86	15.00	0.00	16.67	6.32	2.78	28.26	20.00	14.80
Erig_annu	3.81	2.31	3.47	1.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Erig_phil	2.86	4.62	3.47	9.09	1.05	0.00	0.00	0.00	0.00	0.00	0.00
Erig_pulc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.43	13.89	4.48
Erig_stri	1.90	6.54	0.00	0.00	2.11	0.00	1.05	0.00	0.00	0.00	0.45
Erys_chei	0.00	0.00	2.78	4.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eryt_amer	0.00	26.15	0.00	42.27	0.00	53.33	0.00	35.00	72.83	64.44	62.33
Eupa_perf	0.95	2.69	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Euph_cypa	0.00	0.00	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.00	0.00
Euth_gram	32.38	36.92	6.94	5.91	4.21	2.78	0.00	2.78	0.00	0.00	0.90
Fago_escu	1.90	0.00	0.69	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Fagu_gran	0.95	1.54	3.47	9.55	8.42	2.78	4.21	4.44	10.87	8.89	5.38
Fall_conv	0.00	0.77	1.39	0.91	0.00	0.00	0.00	0.00	0.00	1.11	2.69
Fest_rubr	0.95	5.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Frag_virg	42.86	72.31	4.86	11.82	22.11	5.56	4.21	2.78	3.26	7.78	10.31
Frax_amer	3.81	4.23	18.75	9.55	30.53	12.22	29.47	26.11	6.52	11.11	8.07
Gale_spec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90
Gale_tetr	0.95	1.15	0.69	4.09	5.26	6.11	0.00	1.11	0.00	0.00	0.00
Gali_quad	0.00	0.38	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.00	0.00
Gali_apar	0.00	0.00	0.00	0.45	0.00	1.11	1.05	0.00	1.09	0.56	1.35
Gali_trif	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.59
Gall_mull	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09	0.56	0.00
Gent_crin	2.86	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.04
Gera_macu	0.00	2.31	0.00	0.45	0.00	0.56	0.00	0.00	0.00	0.00	1.35
Gera_robe	7.62	63.46	1.39	34.09	35.79	63.33	35.79	90.56	3.26	8.89	26.91
Geum_alep	5.71	52.31	2.08	18.18	8.42	13.89	2.11	20.00	2.17	4.44	9.87
Geum_cana	0.00	1.92	1.39	2.27	0.00	0.56	0.00	0.56	1.09	1.11	2.24
Glec_hede	1.90	11.92	0.00	0.00	9.47	2.22	2.11	5.56	0.00	0.00	0.00
Glyc_stri	2.86	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hibi_trio	0.00	2.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hier_caes	10.48	19.23	1.39	4.09	5.26	6.11	0.00	1.67	0.00	0.56	2.24
Hier_pilo	7.62	6.54	0.00	0.00	2.11	0.00	0.00	0.00	0.00	0.00	0.45
Hier_pilo	26.67	8.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydr_cana	0.00	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydr_virg	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.00	0.00	0.00	0.45
Hylo_tele	0.00	0.38	0.00	0.00	5.26	5.00	0.00	0.00	0.00	0.00	0.00
Hype_kalm	1.90	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.79
Hype_perf	12.38	7.31	2.08	0.45	1.05	1.67	1.05	0.56	0.00	0.00	1.79
Hype_punc	0.95	3.08	0.00	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impa_pall	6.67	27.69	5.56	66.36	2.11	87.22	8.42	85.00	5.43	15.00	31.84
Jugl_nigr	0.00	0.00	0.69	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Junc_balt	0.95	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Juni_comm	2.86	0.38	0.00	0.00	0.00	0.56	0.00	0.56	2.17	1.11	0.90
Lact_cana	0.00	0.00	2.08	4.09	0.00	0.56	0.00	0.00	0.00	0.00	0.00
Lact_serr	0.00	0.38	2.08	10.45	0.00	0.56	0.00	0.00	0.00	0.00	0.00
Lami_albu	0.00	0.00	0.00	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laps_comm	0.00	0.00	3.47	0.00	3.16	1.11	1.05	0.56	0.00	0.00	0.45
Lari_lari	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lech_unko	0.00	0.00	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.00	0.00
Leon_card	0.00	0.00	0.00	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lepi_camp	1.90	0.00	11.11	3.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leuc_vulg	16.19	38.08	58.33	34.55	15.79	6.11	0.00	1.11	0.00	0.00	0.00
Linn_bore	0.00	0.00	0.00	0.00	4.21	11.67	1.05	6.67	0.00	0.00	0.00
Lith_parv	0.95	0.77	0.00	0.00	0.00	1.11	0.00	0.00	0.00	0.00	0.00
Lobe_infl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45
Lobe_kalm	2.86	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45
Loli_arun	9.52	15.38	2.78	15.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Loli_pers	1.90	4.23	2.08	2.73	0.00	0.00	0.00	0.00	0.00	0.00	0.45

Lotu_corn	15.24	30.77	10.42	13.18	0.00	0.00	0.00	0.00	0.00	0.00	2.24
Luzu_camp	0.00	0.00	0.00	0.00	0.00	2.22	0.00	0.00	0.00	0.00	0.00
Lyco_amer	8.57	3.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45
Lyco_unif	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lyth_sali	0.00	0.00	2.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maia_cana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	1.09	0.00	4.48
Maia_stel	2.86	6.54	0.00	0.45	0.00	0.00	0.00	28.33	2.17	3.33	9.87
Maia_race	0.00	4.23	0.00	0.00	1.05	0.00	0.00	29.44	1.09	3.33	5.83
Malv_mosc	0.00	1.54	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Malv_negl	0.00	3.08	2.78	4.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Matt_stru	0.00	8.46	1.39	7.73	0.00	10.00	0.00	1.11	1.09	0.00	2.24
Medi_lupu	10.48	11.15	16.67	5.45	0.00	0.56	0.00	0.00	0.00	0.00	1.35
Medi_sati	5.71	3.08	3.47	3.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Medi_unkn	1.90	5.38	2.08	3.64	1.05	1.11	0.00	0.00	0.00	0.00	0.00
Meli_albu	16.19	16.92	2.08	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.45
Ment_suav	0.00	0.00	4.17	9.55	1.05	1.11	0.00	0.56	0.00	0.00	0.45
Myos_laxa	0.00	1.54	0.69	4.55	1.05	3.89	0.00	3.33	0.00	0.00	0.00
Myos_scor	0.00	1.54	0.00	2.73	0.00	1.67	0.00	0.56	0.00	0.00	0.45
Nepe_cata	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nutt_cana	0.95	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oeno_bien	0.00	0.77	29.86	27.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Onoc_sens	0.00	1.15	0.00	4.09	0.00	0.00	0.00	0.00	0.00	0.00	0.45
Onop_acan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.35
Orig_vulg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ostr_virg	0.00	1.54	0.00	0.00	0.00	8.33	6.32	10.56	0.00	0.00	1.35
Oxal_stri	1.90	21.15	6.25	9.09	7.37	33.89	0.00	4.44	0.00	2.22	0.45
Pack_plat	4.76	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pani_capi	43.81	10.38	0.00	0.00	0.00	0.56	0.00	0.00	3.26	2.78	1.35
Pari_pens	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90
Part_quin	0.95	0.38	0.00	0.00	0.00	0.00	3.16	1.67	0.00	0.00	0.00
Pers_macu	0.00	0.77	0.00	2.27	0.00	0.56	0.00	0.00	1.09	0.00	3.14
Pers_sagi	0.95	1.92	2.08	3.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phle_prat	0.00	1.54	3.47	0.45	0.00	0.56	0.00	0.00	2.17	0.56	0.00
Pice_glau	8.57	3.46	0.00	0.91	4.21	1.67	5.26	2.78	0.00	0.00	0.00
Pinu_resi	0.00	0.77	0.69	0.91	1.05	0.00	0.00	0.00	0.00	0.00	0.45
Pinu_stro	0.95	1.15	2.78	0.00	1.05	0.00	1.05	0.00	0.00	0.00	1.79
Pinu_sylv	5.71	2.31	0.69	0.00	0.00	0.56	0.00	0.00	0.00	0.00	0.00
Plan_lanc	19.05	32.69	60.42	25.45	7.37	0.56	0.00	0.56	0.00	0.00	0.45
Plan_majo	3.81	6.92	2.08	6.82	2.11	6.67	0.00	0.00	0.00	0.56	2.24
Pluc_odor	0.00	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poa _comp	11.43	7.69	1.39	4.55	2.11	0.00	1.05	1.67	1.09	0.56	0.00
Poly_avic	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poly_acro	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.00	0.00	0.45
Popu_bals	3.81	2.31	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Popu_delt	4.76	0.77	0.00	0.00	0.00	0.00	1.05	0.00	0.00	0.00	0.00
Popu_trem	8.57	2.69	0.00	0.00	0.00	2.22	0.00	0.56	0.00	3.33	6.28
Pote_cana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.00	0.00	0.00

Pote_norv	0.00	5.38	3.47	2.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pote_rect	1.90	2.69	5.56	5.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pote_simp	2.86	0.00	11.11	2.27	1.05	0.00	0.00	0.00	0.00	0.00	0.00
Pote_anse	0.95	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prun_vulg	19.05	28.46	6.25	4.55	4.21	2.22	1.05	2.78	0.00	0.00	1.35
Prun_pens	0.95	2.69	0.00	0.45	5.26	1.11	11.58	20.00	0.00	0.56	2.24
Prun_virg	16.19	5.00	3.47	12.27	17.89	1.67	66.32	18.33	2.17	7.22	4.04
Prun_sero	3.81	3.85	3.47	6.36	0.00	10.56	1.05	27.22	1.09	0.00	7.17
Pycn_virg	0.00	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.00
Pyro_amer	0.00	1.54	0.00	0.00	0.00	4.44	0.00	1.67	0.00	0.00	0.00
Quer_rubr	0.00	0.77	0.00	0.91	0.00	0.00	0.00	0.00	1.09	0.00	0.00
Ranu_abor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ranu_acri	4.76	5.00	2.78	0.45	4.21	1.67	2.11	4.44	0.00	0.00	2.24
Ranu_recu	0.95	16.92	4.86	4.09	0.00	12.22	1.05	26.67	0.00	2.22	8.97
Ranu_repe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.78	0.00	0.00	0.45
Ranu_unkn	0.00	1.54	0.69	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhus_typh	0.00	3.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ribe_amer	0.00	0.00	0.00	0.00	0.00	3.33	7.37	2.78	1.09	0.00	2.69
Ribe_cyno	0.00	1.15	0.00	2.73	1.05	3.33	4.21	3.33	0.00	2.22	1.79
Robi_pseu	0.00	0.38	0.00	0.00	0.00	0.00	16.84	1.67	0.00	0.00	0.00
Rosa_mult	0.00	0.00	0.69	1.36	0.00	0.56	0.00	0.00	0.00	0.00	0.00
Rubu_alle	1.90	13.08	0.69	14.09	11.58	8.33	0.00	4.44	3.26	8.89	4.48
Rubu_idae	10.48	48.08	5.56	28.18	16.84	13.33	7.37	13.33	11.96	10.00	11.66
Rume_cris	0.95	4.62	1.39	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.90
Rume_obtu	0.00	1.92	4.86	2.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sali_bebb	0.95	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Samb_race	2.86	8.08	4.86	20.91	0.00	5.00	1.05	1.67	16.30	6.11	9.42
Scut_gale	1.90	0.77	2.78	3.18	0.00	0.56	0.00	0.00	0.00	0.00	0.45
Scut_late	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45
Scut_parv	0.95	0.77	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seca_cere	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sedu_ukno	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sene_jaco	0.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seta_pumi	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seta_viri	0.95	1.54	13.89	14.55	1.05	0.00	0.00	0.00	0.00	0.00	0.00
Shep_cana	0.00	0.38	0.00	0.00	0.00	0.00	1.05	0.00	0.00	0.00	0.00
Sile_lati	0.00	0.77	22.92	14.09	0.00	0.00	0.00	0.00	1.09	5.56	6.28
Sile_noct	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sile_stel	0.00	0.38	6.94	8.18	1.05	5.56	0.00	0.56	0.00	0.00	0.00
Sile_vulg	1.90	8.08	6.94	4.09	3.16	0.00	0.00	0.00	0.00	0.00	0.90
Sina_arve	3.81	0.38	3.47	3.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sisy_mont	12.38	1.15	2.08	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.45
Sola_dulc	5.71	50.00	1.39	15.00	4.21	22.78	5.26	26.11	0.00	7.22	6.73
Soli_alti	0.95	6.92	8.33	15.45	1.05	3.89	0.00	0.00	0.00	0.00	4.48
Soli_junc	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soli_nemo	6.67	15.77	1.39	1.36	0.00	6.11	0.00	8.33	2.17	0.00	5.38
Soli_rugo	17.14	8.46	2.78	2.27	1.05	3.33	1.05	5.00	0.00	0.00	1.79

Soli_cana	20.00	30.77	36.11	10.91	23.16	5.56	9.47	20.00	4.35	0.00	9.87
Sonc_arve	0.00	0.00	9.72	5.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sonc_aspe	2.86	1.15	6.25	0.91	0.00	0.00	0.00	0.00	2.17	1.67	6.73
Sonc_oler	0.00	2.31	2.08	0.45	0.00	0.00	0.00	0.00	0.00	1.11	0.00
Sorb_aucu	0.00	0.00	0.00	0.00	2.11	0.00	15.79	3.33	0.00	0.00	2.69
Stac_palu	1.90	2.31	0.00	7.27	1.05	3.89	0.00	4.44	2.17	0.56	0.90
Symp_cord	2.86	20.00	0.69	4.55	4.21	11.67	3.16	17.22	2.17	0.00	5.83
Symp_lanc	2.86	3.85	0.00	0.00	7.37	0.56	8.42	2.78	0.00	0.56	1.79
Symp_late	15.24	20.38	6.25	9.55	2.11	0.56	1.05	0.00	1.09	0.56	4.04
Symp_nova	7.62	20.38	2.08	0.91	2.11	0.00	0.00	2.22	0.00	0.00	0.90
Symp_subu	3.81	1.54	0.00	0.00	0.00	0.00	0.00	5.56	0.00	3.33	6.73
Symp_urop	4.76	19.62	9.72	5.00	0.00	12.22	1.05	16.11	1.09	0.56	4.48
Symp_eric	0.00	0.77	0.00	0.00	1.05	0.00	2.11	0.56	0.00	0.00	0.00
Syri_vulg	0.00	0.00	0.00	0.00	0.00	0.00	2.11	0.56	0.00	0.00	0.00
Tana_vulg	0.95	12.31	9.72	23.18	12.63	16.67	10.53	8.33	4.35	4.44	5.83
Tara_offi	10.48	34.23	52.78	41.36	55.79	24.44	51.58	22.78	8.70	2.78	17.94
Thla_arve	0.00	0.00	0.69	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thuj_occi	20.00	11.54	1.39	0.00	0.00	0.00	0.00	0.00	1.09	1.67	1.79
Thym_prae	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tili_amer	0.95	0.77	2.78	0.00	9.47	1.11	2.11	1.67	5.43	9.44	5.83
Tori_japo	0.00	1.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Toxi_radi	0.95	3.46	0.00	0.00	7.37	0.00	28.42	14.44	0.00	0.00	0.45
Trag_prat	0.00	5.00	4.17	1.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trif_camp	1.90	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trif_hybr	0.00	4.23	5.56	3.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trif_prat	6.67	16.15	4.86	3.18	1.05	7.22	0.00	0.00	0.00	0.00	0.00
Trif_repe	0.95	27.31	6.25	6.36	0.00	11.67	0.00	0.56	1.09	3.89	2.24
Tril_erec	0.00	0.00	1.39	15.00	0.00	19.44	0.00	1.11	8.70	10.56	17.49
Tril_gran	1.90	23.85	2.08	14.09	0.00	25.00	1.05	24.44	18.48	23.33	12.56
Tsug_cana	0.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90
Tuss_farf	11.43	70.77	2.08	5.91	0.00	13.33	7.37	58.33	11.96	14.44	9.87
Ulmu_amer	0.95	0.38	11.81	18.64	0.00	1.11	2.11	0.56	0.00	1.11	1.79
Ulmu_rubr	0.00	2.31	0.00	0.91	0.00	1.67	1.05	1.11	1.09	0.00	1.79
Urti_dioi	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Verb_phlo	0.95	5.38	0.00	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Verb_thap	8.57	36.92	0.69	3.18	0.00	0.00	0.00	0.00	1.09	0.00	0.90
Verb_unko	0.00	1.15	7.64	9.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Verb_urti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vero_arve	0.00	0.00	0.00	0.91	1.05	0.00	0.00	0.00	0.00	0.00	0.00
Vero_offi	1.90	1.92	0.00	1.82	2.11	1.11	0.00	0.56	0.00	0.00	0.00
Vero_pere	0.00	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vero_pers	0.00	0.00	3.47	3.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vero_serp	0.00	0.38	8.33	17.73	1.05	0.00	0.00	0.00	0.00	0.00	0.00
Vici_crac	0.00	4.23	66.67	43.64	6.32	2.78	0.00	0.00	0.00	0.00	0.00
Vinc_mino	0.95	12.31	0.00	0.00	0.00	0.00	0.00	0.00	1.09	0.00	0.00
Viol_arve	0.00	0.77	6.94	2.27	0.00	0.00	0.00	0.00	0.00	0.56	1.35
Viol_cana	0.95	4.23	0.00	3.64	1.05	0.56	0.00	0.56	2.17	1.67	0.90

Viol_labr	0.95	14.62	0.00	10.91	0.00	3.89	0.00	3.89	1.09	2.22	9.87
Viol_soro	0.00	17.69	0.00	30.00	2.11	6.11	5.26	6.67	3.26	10.00	11.21
Viol_pube	0.00	18.85	0.00	7.27	2.11	6.67	4.21	2.22	3.26	0.56	11.66
Viti_ripa	15.24	10.38	0.00	1.82	7.37	2.78	7.37	3.33	3.26	9.44	8.07
Notes:	[1] Calculated within each treatment (nested within each sere) as: 100% x [# of quadrate samples with species present / total # of quadrate samples]										
	[2] "NT" indicates quadrates sampled at not-treated areas; "REC" indicates quadrates sampled at recipient blocks of living mulch										