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Seed rain and seedling community assembly changes during secondary succession

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ABSTRACT

The long-term changes in plant communities after natural and anthropogenic disturbances remain little understood. This is in part because the effects of seed dispersal processes on community composition are left unaccounted for by most studies. Here, we explore how seed dispersal patterns affect community assembly during forest succession by characterizing the possible changes in the seed rain composition and seedling recruitment dynamics. We collected seed rain and seedling recruitment data in wind-disturbed and salvage logged areas at Powdermill Nature Reserve for two years and compared it to prior data collected six years earlier at the same microsites. We analyzed changes in community assembly that took place at the sites during succession between these two sampling periods. We found that the density, richness, and diversity of plant species in the seed rain increased with successional time, while the same parameters decreased for the seedlings. Our results show that following a disturbance, diversity in the seed rain significantly increases as succession proceeds and the community composition shifts. In contrast with core ecology theories that assume that changes in composition are independent of the dispersal processes, this study supports the notion that community-level seed dispersal changes concomitantly with the dynamic changes in succession, which adds more complexity to the process of community assembly.

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Introduction

Landscapes are constantly changing as natural disturbances, such as fire and tornados, or anthropogenic disturbances such as logging, continually alter environments and open up new ecological spaces for organisms to occupy (Richards, 1952; Webb et al., 1972). Disturbances are a fundamental natural process that can maintain species diversity by preventing competitive exclusion (Connell, 1978). After a disturbance, community assembly processes change concurrently as time advances (Letcher, 2010). Specifically, four processes govern community assembly: selection, drift, speciation, and dispersal (Vellend, 2010). Natural and anthropogenic disturbances affect the relative contribution of these community assembly mechanisms (Chang & Turner, 2019). Thus, the goal of community ecology is to understand the interplay of all of these factors in shaping habitats, and disturbances present remarkable opportunities to study mechanisms of change in detail.

Dispersal is the unidirectional movement of organisms in space that allows for species to colonize disturbed areas (Camargo et al., 2020; Makoto & Wilson, 2016; Rost et al., 2009; Vellend, 2010). Seeds can be dispersed by wind, gravity, bodies of water, ballistically, and by animals. Some plant species' seeds have mechanical adaptations to facilitate wind dispersal, such as wings (e.g., samaras) or hairs (e.g., pappuses) (Seale & Nakayama, 2020). Other seed species are dispersed by hooking onto animals' fur (ectozoochory), or inside animals' guts (endozoochory) (Carlo et al., 2007; Korablev et al., 2020). How and when dispersal events occur is central to understanding the organization and dynamics of communities because what species are present influences the successional trajectories of communities, sometimes even centuries after a disturbance (Makoto & Wilson, 2016; Vellend, 2010).

Although we know that the interactions between seed dispersal and disturbance play a major role in determining community composition (Sousa, 1984), predicting long-term changes in plant communities after disturbances such as wind or logging remain little understood (Farnsworth et al., 2012; Leverkus et al., 2018). This is in part because dispersal processes and their effects on community composition are left unaccounted for in nearly all studies of succession. Most previous studies fail to account for dispersal because they rely on space-by-time substitutions to infer successional pathways instead of tracking changes in situ over time (Pickett, 1989).

Salvage logging (an anthropogenic disturbance) is a common forest management practice performed after natural disturbances to recoup economic losses and meet increasing timber demand (Lindenmayer & Noss, 2006; Nappi et al., 2004). Due to the modification of biological legacies and other organisms that persist through the disturbance, there is concern that salvage logging negatively impacts forest recovery (Franklin et al., 2000; Leverkus et al., 2018; Lindenmayer & Noss, 2006; Saint-Germain & Greene, 2009). However, infrequent salvage logging after windthrow disturbance may have little effect on plant density, richness, or diversity and could aid in balanced forest succession by creating microsites for light-dependent species, as seen in cases of intermediate disturbance (Connell, 1978; Peterson & Leach, 2008; Royo et al., 2016).

In this study, we explore the dynamics of seed dispersal and plant community assembly during forest succession following wind and salvage logging serial disturbances. We characterized the possible changes in the seed rain and seedling recruitment between disturbed and adjacent undisturbed habitats. We collected and compared the seed rain among salvage-logged, unsalvaged (tornado-disturbed), forest (non-disturbed), and clearcut-edge habitats in

Powdermill Nature Reserve. We also collected seedling recruitment data in association with a subset of seed traps in the salvage-logged, unsalvaged, and forest habitats. By collecting data in the same microsites and seed traps that a previous study used in 2014 and 2015, we were able to examine compositional changes as succession progressed without having to substitute time-for-space. Space-for-time substitution designs, or chronosequences, assume that spatial and temporal variation is equivalent, but such an assumption may not be met as local-scale factors differ from site to site (Pickett, 1989). Thus, our design is robust as we do not have to make such time-space equivalence assumptions.

We saw how the density, richness, and composition of the seed rain and seedling communities changed as succession advanced from years 1-2 (the first study period), to years 6-7 (the second study period) after the tornado and logging disturbances. Because in the first study period, the salvaged habitat had the greatest species richness, even with the least amount of seed rain (Curtze et al., 2018), we predicted that the seed rain richness and diversity would increase in the disturbed habitats with time. We also expected the richness and diversity of seeds to be greater in salvaged versus unsalvaged habitats due to higher light exposure and increasing seed rain density from early successional species. Finally, we expected seedling recruitment richness and diversity to have decreased with time because an increased competition for light would make assemblages more even in composition.

Methods

Study Site

We conducted our study at Powdermill Nature Reserve in Rector, Pennsylvania (40°9'36.3" N, 79°16'19" W). The Carnegie Museum of Natural History operates Powdermill Nature Reserve for research and public education. The 812-hectare reserve is a mixed mesophytic forest with a temperate continental climate and 144 cm average yearly precipitation (Utech, 1999). The elevation is approximately 480 m above sea level. The dominant tree species are red maple (*Acer rubrum*), tulip poplar (*Liriodendron tulipifera*), American beech (*Fagus grandifolia*), black cherry (*Prunus serotina*), and sugar maple (*Acer saccharum*) (Murphy, 2018).

On June 1, 2012, an EF0 tornado caused more than 90% canopy loss in two adjacent hardwood stands, totaling over 40 hectares (Curtze et al., 2018). Half of each study site was salvage-logged one growing season later in fall of 2013. Thus, each site is comprised of four distinct habitats: salvaged, unsalvaged, clearcut edge, and undisturbed mature forest (Figure 1).

Seed Rain

To measure the abundance and species composition of plants, we gathered seed rain using the seed rain traps established by Curtze et al. (2018) in 2014 (Figure 2). The traps were circular laundry baskets 44 cm in diameter (0.15 m²) and approximately 45 cm tall with a suspended net made from screen cloth and 1 cm x 1 cm chicken-wire mesh to protect the captured seeds from seed predation (Carlo & Tewksbury, 2014). The traps are effective at

collecting wind-dispersed, bird-dispersed, and small mammal-dispersed seeds, but typically do not capture seeds hoarded and scattered by rodents.

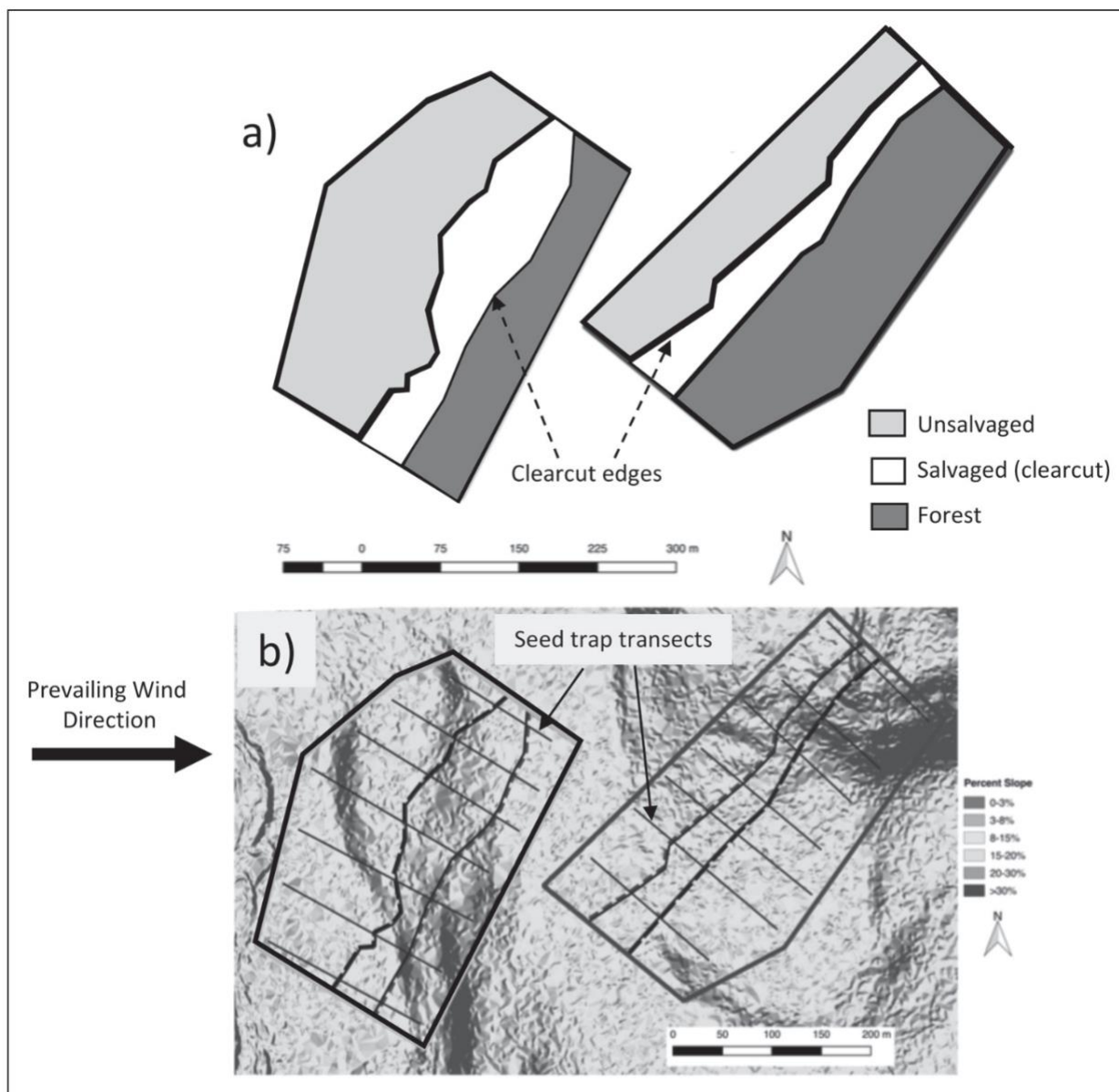


Figure 1. Study site map

(a) Map of the two study sites and habitats (b) Slope-surface map of two study sites with seed trap transects and prevailing wind direction. From “The Effects of a Tornado Disturbance and a Salvaged Timber Extraction on the Seed-Rain and Recruitment Community of an Eastern Temperate Deciduous Forest,” by Curtze et al., 2018.



Figure 2. Seed trap

At both sites, the seed traps were arranged in seven transects, each containing eight seed traps, for a total of 56 seed traps per site and 112 traps in total. The seed-trap transects were approximately 30 m from each other and traversed the four habitats (Figure 1). To capture the presence of all plant species, we collected the seed rain from each trap at the end of spring, summer, and fall, for two years. The collections occurred in May and September of 2019, and January, May, August, and December of 2020. Upon returning from the field, seeds were manually counted and identified.

Woody Plant Recruitment

To measure the abundance and species composition of seedlings in the study sites, we surveyed seedling recruitment in August of 2020. At the 56 seed traps in the east site (Figure 1)

we placed 0.25 m² plots 1 m away from the seed trap in each cardinal direction. Within each plot, we recorded the abundance and species of seedlings. Seedlings were categorized as trees less than 1.4 m high.

Data Analyses

For our statistical analysis, we calculated seed density, richness, and Shannon diversity index as response variables. Shannon diversity is a diversity index that accounts for the abundance and evenness of species in a community. It is the summation of the proportions of each species multiplied by the natural log of the proportions. We looked at the effects of habitat and study period (fixed effects) on the response variables with Generalized Linear Models (GLM) with Poisson error distributions for count data (seed density and richness) and Gaussian errors for Shannon's diversity index (R version 1.2.1335). The resulting coefficients are the changes in the response variable given a one-unit change in the predictor. We used non-metric multidimensional scaling (NMDS) using Bray-Curtis dissimilarity to explore the structure of communities of seed rain and seedlings across habitats and study periods. It is important to note that NMDS ordinations display the data to best represent their dissimilarity and the axes are arbitrary.

Results

Seed rain density, richness, and diversity increased in all habitats in the second study period relative to the first study period (Figure 3). The composition of the seed rain community also changed between the two sampling periods, with most of the differences occurring in the salvaged habitat (Figure 5). As expected, seedling recruitment density, richness, and diversity decreased with succession and the community species composition shifted dramatically toward later-succession shade-tolerant species (Figures 4 & 6).

Seed Rain

Across the four habitats, elapsed time had a significant positive effect on seed rain richness and diversity (Tables 2 & 3). Seed rain density differed between the forest and unsalvaged habitats (Table 1) and significantly increased between study periods in the salvaged habitat (Figure 3a). When comparing between study periods, species richness, and to a lesser degree, diversity, increased in all four habitats with succession age (Figure 3b-c). Interestingly, seed rain richness was not significantly different between the salvaged and unsalvaged habitats in study years 6-7, but seed rain richness in the salvaged habitat experienced the greatest increase between studies (Table 2). The increase in all three parameters between study periods was significant only in the salvaged habitat (Tables 1, 2, & 3).

NMDS axis 1 of the seed rain ordination is positively correlated with succession age: Plots from years 6-7 had higher scores along axis one, while plots from years 1-2 had the lowest scores (Figure 5). The same trend is found along NMDS ordination axis 2 as well. There were compositional shifts in the species of seed rain, however less differentiated than with seedling

recruitment. In years 1-2, there are more early successional species such as red maple (*A. rubrum*) and black birch (*B. lenta*). In years 6-7, later successional species like black cherry (*P. serotina*) gained dominance. The stress value was greater than 0.2 and given that the higher the stress value the less reliable the representation of distances in the original matrix is, the trends shown in this ordination should be interpreted with caution (Figure 5).

Seedling Recruitment

In addition to seed rain, we looked at the changes in seedling recruitment in all habitats. We found reduced seedling density, richness, and diversity in all three habitats in years 6-7 compared to years 1-2, the greatest difference being in the salvaged habitat (Figure 4). In the salvaged habitat, there is a significant positive relationship between study period and diversity, richness, and density. Interestingly, none of the other habitats had any significant effect on seedling recruitment (Tables 4, 5, & 6). Study period was found to have a marginally significant effect on species diversity (Table 4).

The NMDS ordination shows seedling plots along axis 1 positively correlated with succession age: Plots from years 6-7 had higher scores in axis 1 than plots from years 1-2 (Figure 6). The greatest change in seedling communities occurred in the salvaged habitat because these ellipses do not overlap (Figure 6). In years 1-2, the seedling community was dominated by early successional species, notably red maple (*A. rubrum*) and black birch (*B. lenta*). In years 6-7, the seedling community has increasing representation of species typical of mature successional

stages such as American beech (*F. grandifolia*) and sassafras (*S. albidum*). This ordination can be interpreted with confidence because the stress value is less than 0.2 (Figure 6).

Discussion

We found that as succession progressed, seed rain density, richness, and diversity increased, and the plant community composition shifted toward different species. These results show that community-level seed dispersal changes dynamically as succession proceeds and is not operating constantly or randomly as assumed by several important ecological models (Hubbell, 2001; Vellend, 2010). Our data also shows that following a disturbance, diversity in the seed rain significantly increases as succession proceeds. Unlike the seed rain, seedling density, richness, and diversity decreased with succession—most significantly in the salvaged habitat.

As predicted, the seed rain richness and diversity increased across all habitats as succession progressed, with the richness tripling and the diversity almost doubling in the salvaged habitat. Although the unsalvaged and forest habitats had more seed rain density overall, the salvaged habitat seed density was the only one to increase over time and approximately doubled, recovering to the density of the other habitats. As expected, the seedling composition in all disturbed habitats started shifting toward shade-tolerant species, but once again, changes were greatest in the salvaged habitat compared to the other habitats. A shift toward shade-tolerant species is consistent with existing literature because light availability is a major restraint on species composition (Caspersen & Sapruff, 2005; Kurulok & Macdonald, 2007). It is curious that the seed rain richness also markedly increased in the adjacent undisturbed forest. This is

likely a “spillover” effect from the changes taking place in the nearby disturbed habitats, as seeds produced in the disturbed areas can also disperse into the forest (Blitzer et al., 2012).

Salvage-logging following a tornado disturbance has also been observed to increase seed rain richness and diversity in studies in Eastern Europe and the Southern United States (Elliott et al., 2002; Fidej et al., 2016). Other studies have also reported that salvage logging has little to no effect on community composition (Peterson & Leach, 2008; Rost et al., 2009). However, most studies only observe a habitat several years after the disturbance and are chronosequences, unlike our 7-year period where all habitats were present in the same forest plots. It is possible that abiotic and biotic features between sites account for this difference, or that shorter studies miss the long-term effects of disturbances.

The peak in the richness and diversity of seedlings during the first two years post-disturbance declined by about 50% by years 6-7, which was not surprising given the high mortality rate of early life stages of plants (Swaine & Hall, 1983). Similar to the temporal patterns in the seed rain, changes in the seedling community were primarily observed in the salvaged habitat (Tables 4, 5, & 6). These findings are consistent with Greene et al. (2006), which was conducted in a boreal forest post-fire and salvage logging. However, this differs from the results of a study conducted in a mixed mesophytic *Quercus-Pinus* forest, similar to Powdermill, in which researchers determined that species richness, diversity, and density did not differ between salvaged and unsalvaged stands (White et al., 2014). Once again, this study was conducted only two years after the disturbance, and the patterns that we observed might have emerged given sufficient time. For example, there may have been relatively low light competition only two years after salvage logging. By years 6-7, little sunlight was reaching the ground in the salvaged habitat because of extremely dense overstory successional species, mostly

L. tulipifera (also see Keever, 1973). Despite the significant decrease in the sunlight in years 6-7, we found consistently greater richness and diversity of seedlings in years 6-7 in both disturbed habitats than in the undisturbed forest. Our results are in line with prior studies showing that intermittent, moderate disturbance promotes increased biodiversity (Connell, 1978; Sousa, 1979, 1984), especially because wind and logging disturbances increases sunlight which in turn, increases primary productivity and seed production (Leuchner et al., 2011). Furthermore, in the case of forest regeneration, our study shows how seed dispersal patterns are also non-randomly affected by disturbance type and time.

In light of the concerns surrounding the possible negative effects of salvage logging (Franklin et al., 2000; Leverkus et al., 2016; Lindenmayer & Noss, 2006; Saint-Germain & Greene, 2009), we propose that salvage logging can be an effective way to recoup economic losses without damaging the ecosystem, even promoting coexistence of early and late-successional species. However, factors such as how often and severe disturbances are and the time between disturbance and salvage logging could affect the outcome (Leverkus et al., 2018; Royo et al., 2016; White et al., 2014). We also conclude that seed dispersal is a structured process that changes throughout succession. We propose two possible explanations for this: Local community changes are affecting seed dispersal patterns and/or animals that disperse seeds are interacting with the successional habitats in new ways. It is well-established that animals play a crucial role in the dispersal of seeds (Blitzer et al., 2012; González-Castro et al., 2019; Ingle, 2003), and the interactions between habitats and animals change throughout succession (Pearce & Venier, 2005; Urban & Swihart, 2011). Thus, it should also be expected that the proportion of seed dispersal controlled by animals changes accordingly with successional time.

There exists the possibility of slight biotic and abiotic differences between the two study sites that were assumed to be neutral. Additionally, seeds were counted and identified by hand in Curtze et al. (2018) and in our study. Thus, individual observer biases in seed identification accuracy could have affected observed differences between sampling periods.

In summary, disturbance increased the richness and diversity of seed rain and altered community composition, showing that dispersal is a time-structured process since the richness and composition of seeds changed throughout succession. As ecosystems experience more frequent natural disturbances as a result of anthropogenic climate change and increasing anthropogenic disturbances, it is crucial to understand how dispersal processes alter community assembly throughout time.

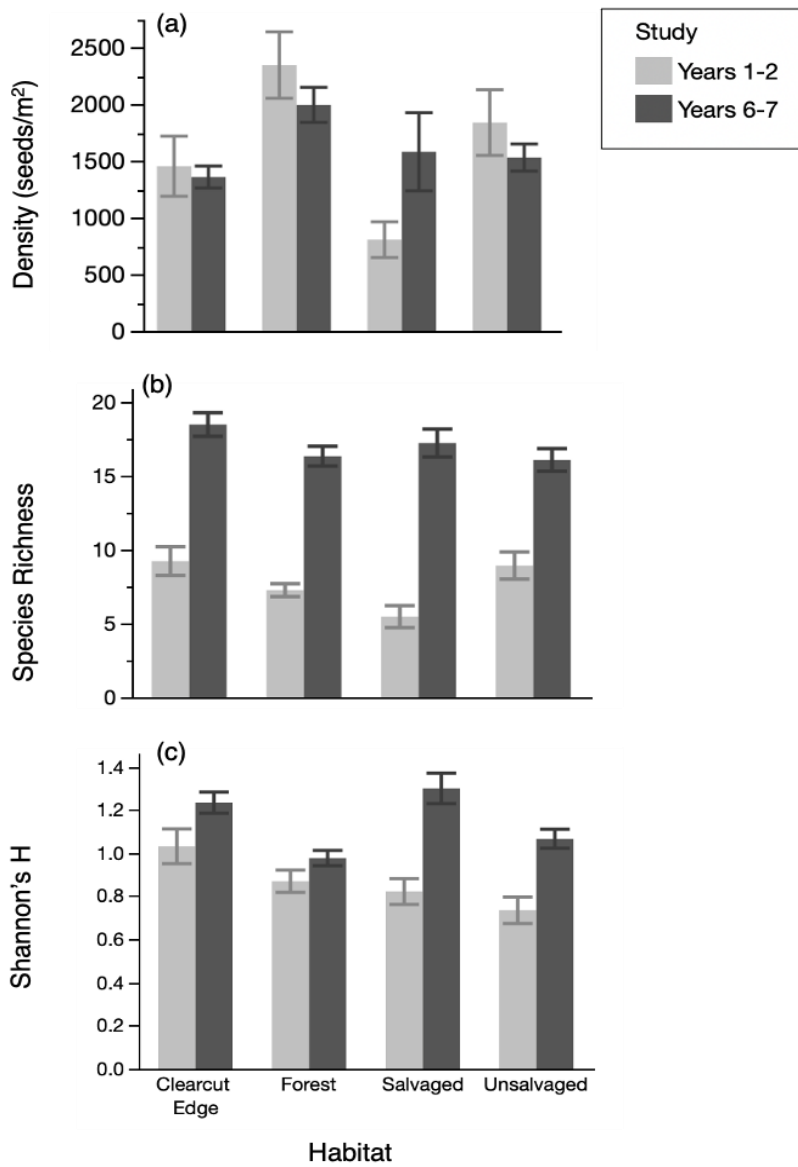


Figure 3. Differences in seed rain across habitats and study years (a) seed density (b) species richness (c) Shannon's diversity index. Vertical bars represent \pm standard error of the mean.

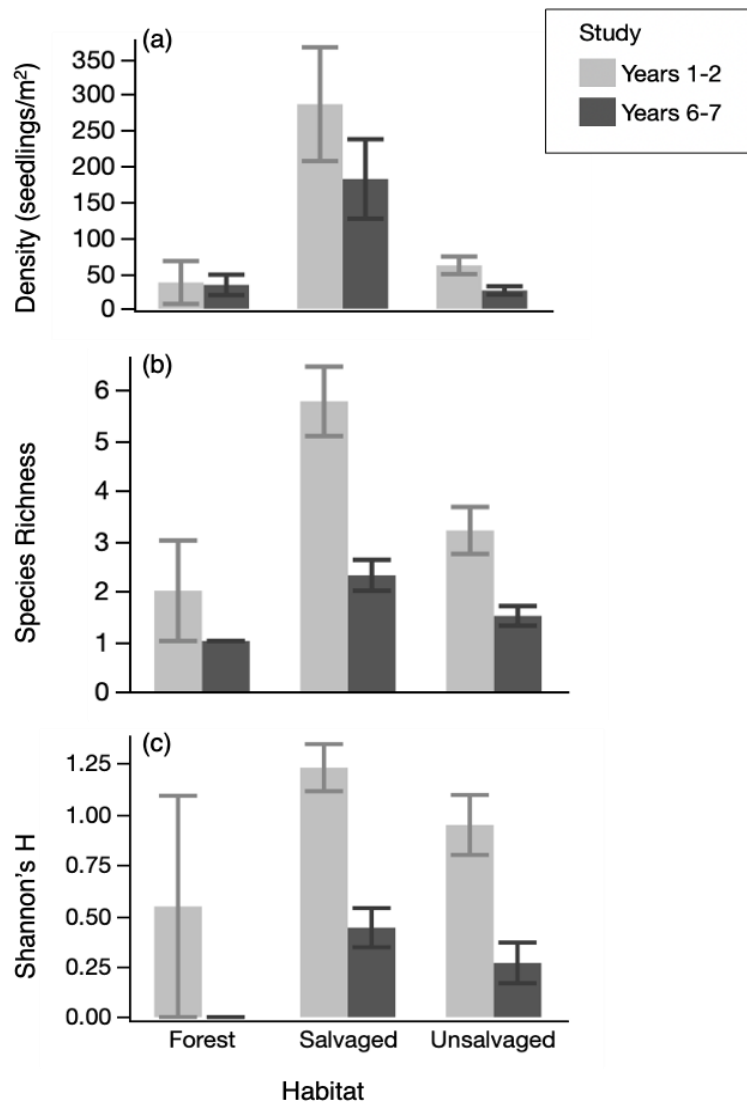


Figure 4. Differences in seedling recruitment across habitats and study years
 (a) seed density (b) species richness (c) Shannon's diversity index.
 Vertical bars represent \pm standard error of the mean.

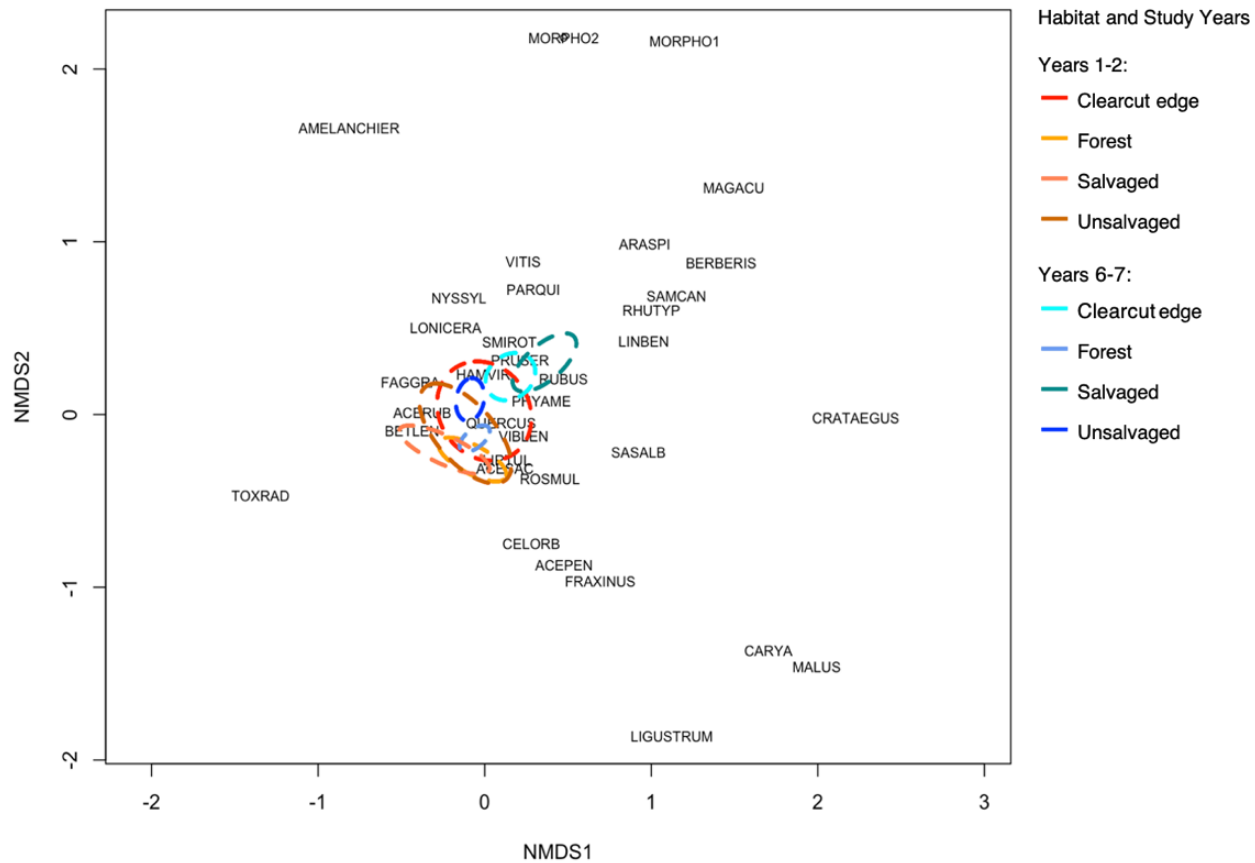


Figure 5. Non-metric multidimensional scaling (NMDS) ordination of seeds (stress=0.24)

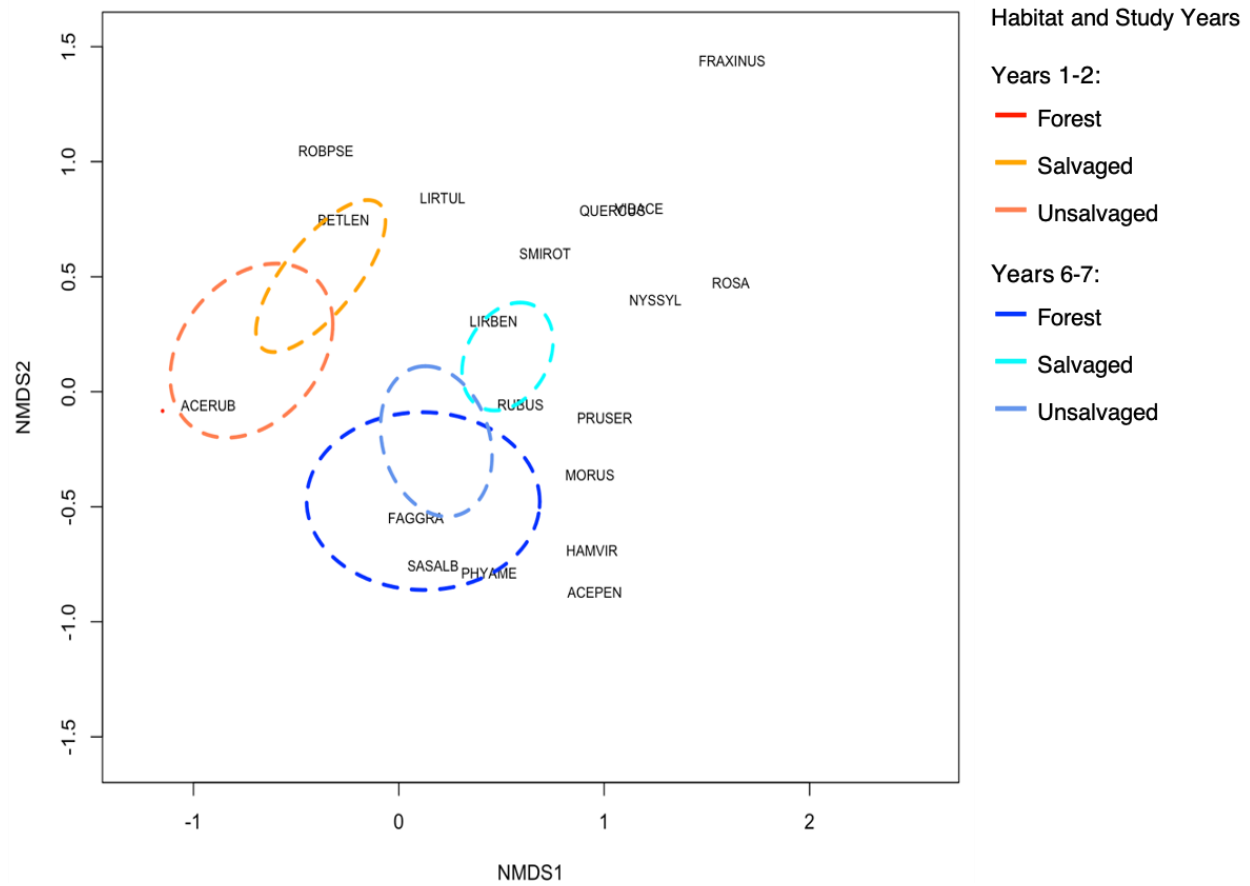


Figure 6. Non-metric multidimensional scaling (NMDS) ordination of seedlings (stress=0.17)

Table 1. Effects of habitat and study on seed rain density

Coefficients	Estimate	Std. Error	t Value	Pr (> t)
(Intercept)	4.060	0.560	7.246	9.22e-12 ***
Clearcut Edge	0.906	0.584	1.552	0.122
Forest	1.579	0.583	2.708	0.007 **
Salvaged	0.222	0.584	0.379	0.705
Unsalvaged	1.224	0.583	2.099	0.037 *
Study Years 6-7	0.084	0.220	.380	0.704
Clearcut:Study Years 6-7	0.168	0.314	0.535	0.593
Forest:Study Years 6-7	-0.103	0.312	-0.331	0.741
Salvaged:Study Years 6-7	0.761	0.314	2.427	0.016 *

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

Table 2. Effects of habitat and study on seed rain species richness

Coefficients	Estimate	Std. Error	t Value	Pr (> t)
(Intercept)	0.896	0.285	3.142	1.936e-03**
Clearcut Edge	1.196	0.297	4.022	8.18e-05 ***
Forest	1.044	0.297	3.517	5.30e-04 ***
Salvaged	0.634	0.297	2.132	0.034 *
Unsalvaged	1.161	0.297	3.912	1.26e-04 ***
Study Years 6-7	0.686	0.112	6.118	4.95e-09 ***
Clearcut Edge:Study Years 6-7	0.111	0.160	0.692	0.490
Forest:Study Years 6-7	0.144	0.159	0.907	0.365
Salvaged:Study Years 6-7	0.590	0.160	3.695	2.84e-04 ***

*** p < 0.001; * p < 0.05

Table 3. Effects of habitat and study on seed rain species diversity

Coefficients	Estimate	Std. Error	t Value	Pr (> t)
(Intercept)	1.030	0.062	16.745	< 2e-16 ***
Forest	-0.162	0.086	-1.880	0.062 .
Salvaged	-0.231	0.087	-2.653	0.009 **
Unsalvaged	-0.296	0.086	-3.436	0.001 ***
Study Years 6-7	0.202	0.083	2.436	0.016 *
Forest:Study Years 6-7	-0.095	0.117	-0.810	0.419
Salvaged:Study Years 6-7	0.297	0.117	2.529	0.012 *
Unsalvaged:Study Years 6-7	0.128	0.117	1.100	0.273

*** p < 0.001; ** p < 0.01; * p < 0.05; . p < 0.1

Table 4. Effects of habitat and study on seedling density

Coefficients	Estimate	Std. Error	t Value	Pr (> t)
(Intercept)	36.667	122.308	0.300	0.766
Salvaged	249.487	131.380	1.899	0.063 .
Unsalvaged	24.000	133.982	0.179	0.859
Study Years 6-7	-3.333	141.229	-0.024	0.981
Salvaged:Study Years 6-7	-101.282	156.680	-0.646	0.521
Unsalvaged:Study Years 6-7	-31.778	159.470	-0.199	0.843

. p < 0.1

Table 5. Effects of habitat and study on seedling species richness

Coefficients	Estimate	Std. Error	t Value	Pr (> t)
(Intercept)	0.549	0.345	1.590	0.118
Salvaged	1.091	0.371	2.941	0.005 **
Unsalvaged	0.500	0.378	1.321	0.193
Study Years 6-7	-0.549	0.399	-1.377	0.175
Salvaged:Study Years 6-7	-0.380	0.443	-0.859	0.395
Unsalvaged:Study Years 6-7	-0.177	0.450	-0.394	0.696

** p < 0.01

Table 6. Effects of habitat and study on seedling species diversity

Coefficients	Estimate	Std. Error	t Value	Pr (> t)
(Intercept)	0.545	0.272	2.000	0.052 .
Salvaged	0.683	0.292	2.335	0.024 *
Unsalvaged	0.402	0.298	1.345	0.185
Study Years 6-7	-0.544	0.314	-1.732	0.089 .
Salvaged:Study Years 6-7	-0.243	0.349	-0.696	0.490
Unsalvaged:Study Years 6-7	-0.134	0.355	-0.379	0.707

* $p < 0.05$; . $p < 0.1$

Supplemental Information

Table S1. Raw Seed Count Data

Study Year	Habitat	<i>Amelanchier</i>	<i>A. pensylvanicum</i>	<i>A. rubrum</i>	<i>A. saccharum</i>	<i>A. spinosa</i>	<i>Berberis</i>	<i>B. lenta</i>	<i>Carya</i>
1-2	Clearcut Edge	3	23	824	40	0	0	907	0
	Forest	0	81	1402	58	0	0	1474	1
	Salvaged	0	18	648	9	0	0	452	0
	Unsalvaged	0	47	1116	17	0	0	1243	1
6-7	Clearcut Edge	0	0	2119	21	5	1	384	0
	Forest	0	0	3385	182	0	0	343	0
	Salvaged	0	0	1239	8	16	0	324	0
	Unsalvaged	0	0	3118	41	0	0	834	0

Table S1 (continued)

Study Year	Habitat	<i>C. orbiculata</i>	<i>Crataegous</i>	<i>F. grandifolia</i>	<i>Fraxinus</i>	<i>H. virginiana</i>	<i>L. benzoin</i>	<i>Ligustrum</i>	<i>Lonicera</i>
1-2	Clearcut Edge	11	1	11	3	1	1	0	0
	Forest	0	0	30	5	5	0	0	5
	Salvaged	30	0	0	1	2	0	0	3
	Unsalvaged	4	0	29	2	21	5	2	4
6-7	Clearcut Edge	0	0	99	0	56	96	0	1
	Forest	0	0	47	0	0	5	0	0
	Salvaged	0	0	2	0	25	86	0	1
	Unsalvaged	0	0	40	0	3	44	0	0

Table S1 (continued)

Study Year	Habitat	<i>L. tulipifera</i>	<i>M. acuminata</i>	<i>Malus</i>	<i>Morphospecies 1</i>	<i>Morphospecies 2</i>	<i>N. sylvatica</i>	<i>P. americana</i>
1-2	Clearcut Edge	2406	0	0	0	0	34	458
	Forest	5466	0	0	0	0	3	13
	Salvaged	1216	0	0	0	0	0	513
	Unsalvaged	3951	0	1	0	0	25	75
6-7	Clearcut Edge	2221	2	0	0	1	98	26
	Forest	3898	0	0	0	0	0	7
	Salvaged	1620	9	0	1	0	19	144
	Unsalvaged	2083	0	0	0	0	30	9

Table S1 (continued)

Study Year	Habitat	<i>P. quinquefolia</i>	<i>P. serotina</i>	<i>Quercus</i>	<i>R. multiflora</i>	<i>R. typhina</i>	<i>Rubus</i>	<i>S. albidum</i>
1-2	Clearcut Edge	3	65	2	2	0	180	23
	Forest	0	23	2	1	0	2	9
	Salvaged	0	4	1	0	0	3	2
	Unsalvaged	0	27	4	2	0	58	5
6-7	Clearcut Edge	2	312	1	0	1	185	4
	Forest	0	508	8	0	0	0	0
	Salvaged	11	230	10	0	1298	1491	15
	Unsalvaged	10	88	4	0	0	12	0

Table S1 (continued)

Study Year	Habitat	<i>S. canadensis</i>	<i>S. rotundifolia</i>	<i>T. radicans</i>	<i>Vitis</i>	<i>V. lentago</i>	<i>V. rafinesquianum</i>
1-2	Clearcut Edge	0	6	1	14	1	0
	Forest	0	6	4	0	0	0
	Salvaged	0	0	0	1	0	0
	Unsalvaged	0	7	0	5	5	0
6-7	Clearcut Edge	10	55	0	10	0	2
	Forest	0	7	0	1	0	0
	Salvaged	49	30	0	21	0	0
	Unsalvaged	19	99	0	2	0	0

Table S2: Raw Seedling Count Data

Study Year	Habitat	<i>A. pensylvanicum</i>	<i>A. rubrum</i>	<i>B. lenta</i>	<i>F. grandifolia</i>	<i>Fraxinus</i>	<i>H. virginiana</i>	<i>L. benzoin</i>
1-2	forest	0	52	6	9	0	3	1
	salvaged	13	190	48	4	4	14	36
	unsalvaged	2	187	20	3	0	28	7
6-7	forest	0	30	0	0	0	0	0
	salvaged	0	74	25	0	0	0	0
	unsalvaged	0	22	7	0	0	0	0

Table S2 (continued)

Study Year	Habitat	<i>L. tulipifera</i>	<i>Morus</i>	<i>N. sylvatica</i>	<i>P. americana</i>	<i>P. serotina</i>	<i>Quercus</i>	<i>R. pseudoacacia</i>
1-2	forest	5	0	0	9	0	0	0
	salvaged	490	11	15	35	1	3	4
	unsalvaged	80	2	4	16	0	0	0
6-7	forest	0	0	0	0	0	0	0
	salvaged	250	0	0	0	0	0	0
	unsalvaged	15	0	0	0	0	0	0

Table S2 (continued)

Study Year	Habitat	<i>Rosa</i>	<i>Rubus</i>	<i>S. albidum</i>	<i>S. rotundifolia</i>	<i>V. acerifolium</i>
1-2	forest	1	0	28	0	0
	salvaged	110	30	103	1	62
	unsalvaged	17	15	95	0	1
6-7	forest	0	0	0	0	0
	salvaged	0	0	5	0	0
	unsalvaged	0	0	2	0	0

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ACADEMIC VITA

Education

The Pennsylvania State University | Schreyer Honors College **University Park, PA**
Eberly College of Science | B.S. Biology, Ecology and Evolution concentration *May of 2021*

Eberly College of Science | Tropical Field Ecology **Osa Peninsula, Costa Rica**
• Collaborated with student teams on three field experiments *Dec 2019-Jan 2020*
• First authored communication manuscript on chemical defense of native tree species

The School for Field Studies | Center for Water and Wildlife Studies **Kimana, Kenya**
• Studied primate behavioral ecology and conservation through fieldwork *June-July 2019*
• Designed and conducted qualitative community survey to explore human-primate conflict

Work Experience

Breathe Project **Pittsburgh, PA**
Data and Communications Support Fellow *August 2020-Present*

- Expand resource database with daily air quality indexes, pollution event footage
- Publish 20 news articles and studies a week to Breathe Project website using WordPress
- Coordinate guest speakers for Beaver County community event series

Eberly College of Science | The Carlo Lab **University Park, PA**
Undergraduate Research Assistant *Sept 2018-Present*

- Lead team of 2-5 volunteers to collect data at 112 field sites three times a year
- Analyze large data sets with Microsoft Excel, JMP, and R
- Compose honors research thesis and prepare manuscript for review

Penn State Learning | Mathematics **University Park, PA**
Peer Tutor *August 2019-Present*

- Teach groups of 1-3 undergraduate students algebra through calculus concepts

Beaver Area School District | Middle School **Beaver, PA**
Special Education Teaching Assistant *May 2019*

- Assisted students in-class with coursework and developing appropriate behavior

Carnegie Science Center | Science Theaters Department **Pittsburgh, PA**
Education Intern *May -August 2018*

- Performed “Brain Power” interactive show to teach brain biology to public audiences
- Engaged the public in educational and interactive science demonstrations
- Redesigned floor demonstration teaching genetic inheritance based on state pedagogical standards

Leadership

Schreyer for Women **University Park, PA**
• Empower female and non-binary students in the Schreyer Honors College *Aug 2017-Present*
• Implement service, community, and career support for a 40-student membership base

Director of Career Development *March 2020-2021*

- Spearhead four career development workshops and five alumni networking events

Director of Community Engagement *March 2019-2020*

- Organized two community-building events per month

Penn State School of Music | Oriana Singers **University Park, PA**
Soprano II Section Leader *Aug 2018-Present*

- Present choral music to audiences of 50-500 people

Eberly College of Science | Calculus I **University Park, PA**
Learning Assistant *Aug 2018-May 2019*

- Conduct 10-student evening sessions twice a week to reinforce course material
- Facilitated in-class group work by assisting students with problems