Forest Restoration on a Closed Landfill: Rapid Addition of New Species by Bird Dispersal

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Abstract: *Urban areas often contain sizeable pockets of degraded land, such as inactive landfills, that could be reclaimed as wildlife habitat and as connecting links to enhance remnant natural areas. In the northeastern U.S., many such lands fail to undergo natural succession to woodland, instead retaining a weedy, herbaceous cover for many years. We hypothesize that seed dispersal is a limiting factor, and that a form of secondary succession could be stimulated by introducing clusters of trees and shrubs to attract avian seed dispersers. As a direct test, we censused a 1.5-ha experimental plantation on the Fresh Kills Landfill (Staten Island, New York) one year after installation, in search of evidence that the plantation was spreading or increasing in diversity. The 17 planted species, many from coastal scrub forests native to this region, were surviving well but contributed almost no seedlings to the area, in part because only 20% of the installed trees or shrubs were reproductive. Of the 1079 woody seedlings found, 95% came from sources outside the plantation; most (71%) were from fleshy-fruited, bird-dispersed plants from nearby woodland fringes. Although the restoration planting itself had not begun to produce seedlings, it did function as a site for attracting dispersers, who enriched the young community with 20 new species. One-fourth of all new recruits were from nine additional wind-dispersed species. Locations with a high ratio of trees to shrubs had proportionately more recruits, indicating that plant size contributed to disperser attraction. The density of new recruits of each species was dependent on distance from the nearest potential seed source. Introducing native species with the capacity to attract avian dispersers may be the key to success of many restoration programs.*

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Restablecimiento del bosque en una clausura: Rápida adición de especies por aves dispersoras

Resumen: *Areas urbanas usualmente contienen nucleos aislados de tamaño considerable, de tierras degradadas, como vertederos públicos inactivos que pueden ser reclamados como hábitat para vida silvestre, y como vínculos de conección para ampliar áreas naturales remanentes. En el Noreste de Estados Unidos muchas de estas tierras fracasan en el proceso natural de sucesión hacia bosques, en vez retienen por muchos años una cubierta herbácea de malezas. Nuestra hipótesis es que la dispersión de las semillas es un factor limitante. Una forma de sucesión secundaria puede ser simulada introduciendo conglomerados de árboles y arbustos, para atrear aves dispersoras de semillas. Como test directo nosotros sensamos 1.5-ha de una plantación experimental en el vertedero público de 'Fresh Kills' (Staten Island, New York) un año después de la instalación, en la búsqueda de evidencia que demuestre que la plantación fue dispersada o incrementó en diversidad. Las 17 especies plantadas, muchas de arbustos costeros nativos de la región, sobrevivieron bien, pero, prácticamente, no contribuyeron en semillas en el área, en parte porque sólamente el 20% de los árboles o arbustos instalados fueron reproductivos. EL 95% de las 1079 plántulas leñosas encontrados provienen de fuentes fuera de la plantación; la mayoría (71%) provinieron de frutos de plantas dispersadas por pájaros de tierras de bosques aledáneas. Si bien la restauración de la plantación en sí misma no ha comenzado a producir plántulas, ha funcionado como sitio para atraer dispersores, que han enriquecido las comunidades jóvenes con 20 nuevas especies. Un cuarto de todos los nuevos reclutas provinieron de nueve species dispersadas por el viento. Lugares con altas relaciones de árboles con respecto a arbustos tuvieron proporcionalmente más reclutas, indicando que el tamaño de la planta contribuyó a la atracción del dispersor. La densidad de los nuevos reclutas de cada especie fue dependiente de la distancia desde la fuente potencial de semillas más cercana. La introducción de especies nativas con la capacidad de atraer aves dispersoras puede ser la clave del suceso de muchos programas de restauración.*

Introduction

Restoration ecologists face many challenges as they attempt to coax or retain processes that regulate natural communities. Even when habitats are well prepared and species choices carefully made, successful restoration can be delayed or prevented by local environmental change, such as altered hydrologic patterns (Zedler 1988), competition from invading weeds (Bradshaw 1983), or herbivore damage (Archibold 1979; Anderson 1989). When change is anticipated as part of restoration planning, however, the outcome can be directed in favorable ways. For example, natural succession can be initiated and promoted during land reclamation and habitat restoration (Uhl 1988; Bradshaw 1989; Majer 1989; Luken 1990). Restoration planners can draw from a wealth of knowledge on the ecological processes that accompany successional change, in particular the role of plant reproduction and dispersal during secondary succession (Archibold 1979; Uhl et al. 1982; McClanahan 1986; Aber 1987; Janzen 1988*a*, 1988*b*; Nepstad et al. 1991.)

When degraded lands are abandoned, they rarely change but instead persist as scars on urban and rural landscapes. We have examined a number of abandoned landfills in the New York metropolitan area and have been impressed by the failure of vegetation to develop either diversity or complexity on these sites. What ecologists in the northeastern United States have come to regard as normal succession from open field to woodland (see Pickett 1982) does not occur, or else occurs at a snail's pace. One can find occasional large trees growing on even the poorest, most exposed sites, but these are largely the products of a few wind-dispersed species (Stalter 1984). A likely explanation for the absence of natural succession is that appropriate seeds never arrive. Microsite limitations impose many "filters" on a developing forest community, such as interspecific competition, seed predation, and seedling herbivory (Werner & Harbeck 1982; Myster & McCarthy 1989; De Steven 1991*a*, Gill & Marks 1991), but initial differences in seed dispersal may be overwhelming (De Steven 1991*b*). We focus on this earliest part of secondary succession, the dispersal stage, and its significance in the restoration process.

During secondary succession, animals continuously transport seeds of woody species into open areas (Johnston & Odum 1956; Smith 1975; Guevara et al. 1986; Hoppe 1988; Saulei & Swaine 1988). This is particularly true in the formation of temperate deciduous forests in North America, where most mid-successional species are bird-dispersed (Howe & Smallwood 1982; Stapanian 1986; Willson 1986; Stiles 1989). In open fields, bird dispersers are attracted to trees and shrubs, which at a minimum provide perching sites (Debussche et al. 1982; Uhl et al. 1982; McDonnell & Stiles 1983; McDonnell 1986; McClanahan & Wolfe 1987; Campbell et al. 1990). The process is exponential, with positive feedback between increasing woody plant densities and increasing disperser visits. The fact that highly disturbed lands fail to undergo natural succession may be tied to the lack of a first pulse of woody recruitment—an exponential invasion curve can't get started.

In an effort to rehabilitate portions of the Fresh Kills Landfill (an 800-ha complex), the City of New York Department of Sanitation has begun a series of experimental plantings, including attempts to regenerate native forest communities. We examined one of these reforestation experiments to determine whether it was functioning as a seed source and as an attractant for dispersers. Our hypotheses for this study were:

(1) Native woody species can survive and grow on restored landfills and similar recovering sites, and their absence reflects a lack of natural dispersal. Alternatively, the site is unfavorable for these plants, regardless of dispersal patterns.

(2) The introduction of woody species can stimulate natural succession to a diverse woodland, provided native seed sources are nearby. Alternatively, seed is introduced into the landscape, regardless of the background vegetation.

(3) This attractive function is proportional to average plant size. Alternative hypotheses are that recruitment is instead proportional to planting density, or that dispersal is diffuse and not correlated with plant size or planting density.

Methods

In Fall 1989 and Spring 1990, 1.5 ha of an approximately 4-ha site on the Fresh Kills Landfill (Staten Island, New York; Fig. 1) was designated for restoration and planted with 18 species of trees and shrubs. The species, all of which are native to northeastern North America, were chosen as representative of a coastal scrub forest once found on Staten Island and still occurring on Long Island, New York (Olsvig et al. 1979), and coastal New Jersey (Robichaud & Buell 1973). Prior to planting, the site was covered with a 40-cm cap of highly compacted clay-shale subsoil (to prevent gas and water exchange between the landfill contents and the atmosphere, in accordance with local regulations), and then covered with a planting substrate of 60 cm of sandy mineral soil, into which approximately 15 cm of composted leaf mulch (a commercial nursery product) was incorporated. All soils and amendments were transported to the site from stocks stored at other locations. The planting substrate was graded from 30 to 90 cm deep on the site to create an undulating topography, characteristic of natural coastal sites. Elevation of the site ranged from sea level to 17 m.

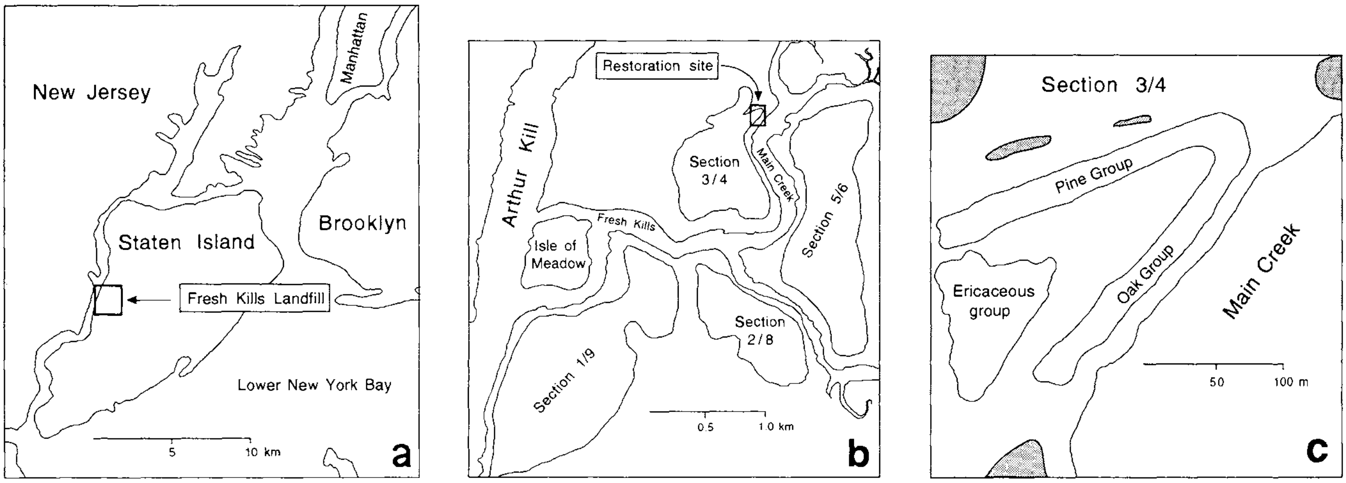

Figure 1. Maps of (a) Staten Island, New York, (b) the Fresh Kills Landfill complex, and (c) the coastal woodland restoration area examined in this study. The four numbered sections in (b) are the landfill mounds, parts of which have been capped with impermeable liners and revegetated. Shaded areas in (c) represent the approximate positions of nearby woodland remnants.

Three separate vegetation mixes were installed in three different portions of the site: (1) a predominantly oak-shrub mix of 14 species, planted on a south-facing slope approximately 25 m inland from Main Creek; (2) a predominantly pine-shrub mix of 14 species, planted on a shallow, north-facing upland swale 30 to 90 m inland from the oak-shrub group; (3) an ericaceous shrub mix of six species, planted upslope from the two other areas on a predominantly east-facing slope (Fig. 1). In the analyses that follow, these are referred to as the oak, pine, and ericaceous sites. Approximately 3000 shrubs were planted in small clusters (6–12 plants of one species per cluster) among the three sites, and 500 trees were distributed over the oak and pine sites. In addition to woody species, each site was planted with native perennial grasses and seeded with a native wildflower mixture.

We censused the plantation in June 1991, during the second growing season after installation. We divided the three sites into 50 contiguous plots, each approximately 10 × 30 m. To study survival and reproductive status of the planted stock, we censused all trees, shrubs, and woody vines within the three sites. To estimate recruitment, we censused all seedlings of woody plants, identified by species. Living individuals were counted, measured, and categorized according to one of four sources: (1) deliberately planted as part of the restoration; (2) a seedling derived from one of the restoration plants (as a conservative estimate, this category included any seedling that matched a planted species that had reproduced in a site); (3) a seedling derived from a nearby source outside the restoration site; (4) a seedling or sprout that arrived in a root ball of a planted individual (presumably from a population at the source nursery).

Following the census, we surveyed the surrounding area to identify potential natural seed sources. Distances from nearby woodland remnants were estimated for all 50 plots to determine approximate minimum travel distances for each new species in every plot. Formal control plots (devoid of trees and shrubs) could not be established because the area surrounding the restoration site was mowed. As a substitute, we compared results informally with censuses taken on another nearby landfill to infer differences between background levels of woody plant recruitment and the putative effect of adding trees and shrubs. The Brookfield Landfill, also located on Staten Island—within 4 km of the Fresh Kills Landfill, was closed in 1985. The 20-ha site, which borders a 105-ha forested reserve, was seeded with commercial grasses upon closure and has since received no maintenance. It is similar to the Fresh Kills Landfill in soil types and surrounding vegetation. We censused all woody plants in three 0.5-ha plots, corresponding to the total area of the Fresh Kills Landfill restoration.

Results

Summary of Natural Recruitment

The majority of individuals and 17 of the 18 species planted were surviving (Table 1). Growth estimates indicate that most trees had moderate increases in girth (0 to 50%) over the first season, whereas most shrubs grew substantially in height, about 60% on average. A low proportion (19%) of plants were reproductive; most were either too young or perhaps suffered transplant shock. This is reflected in the very slight recruitment directly attributable to the plantation (0.4%; Table 2).

After one year, natural recruitment had boosted the

Table 1. Census data for trees and shrubs planted on the Fresh Kills Landfill dune restoration sites.

Species	Total count	Mean height (m)	Number reproductive	New seedlings
Amelanchier stolonifera	178	1.33	145	1
Arctostaphylos uva-ursi	21	0.22	0	0
Leiophyllum buxifolium	4	1.12	0	0
Lyonia mariana	12	0.32	6	0
Myrica pensylvanica	781	0.74	86	0
Pinus rigida	87	1.48	0	0
Pinus virginiana	78	1.67	1	0
Prunus maritima	523	0.66	43	1
Aronia arbutifolia	219	1.20	160	0
Quercus ilicifolia	65	1.13	33	2
Quercus marilandica	47	1.52	9	0
Quercus palustris	4	2.75	0	0
Quercus phellos	59	4.16	0	0
Quercus stellata	28	2.20	8	1
Rhus glabra	14	1.05	13	0
Vaccinium angustifolium	564	0.12	12	0
Vaccinium corymbosum	240	0.42	43	0
Totals	2924	0.80	559	5

All species are native to the region and dispersed by animals. Total count is the number of planted individuals censused throughout the three planted sites. New seedlings were recruits generated by the planted stock.

woody species count from 18 to 50, with the addition of 14 tree, 10 shrub, and 8 vine species (Table 2). Nine of the 32 recruiting species were probably carried in by wind, 20 by birds or mammals. Three additional species and a total of 46 recruits probably arrived via soils in the nursery root balls. In general, for every three installed plants, natural dispersal added a new individual to the community during the first year, for a total of over 1000 woody volunteers.

Recruitment, Plant Density, and Plant Size

Naturally recruiting species totalled 24 in the oak mix, 22 in the pine mix, and 17 in the ericaceous mix. Planting densities varied among the three groups, but recruitment rates (ratios of recruits to installed plants) when adjusted for these differences were similar (oak mix, 0.34; pine mix, 0.34; ericaceous mix, 0.32). The number of new recruits per plot was positively correlated with the number of transplants per plot ($R^2 = 0.11$, $p = 0.02$). The spread of seedlings was diffuse, however, and we could detect no clear correspondence between the number of recruiting seedlings and distance to a planted tree or shrub. An exception was black cherry (*Prunus serotina*), which tended to occur in small clusters in the vicinity of trees.

Results of other research (McDonnell 1986) indicate that most local fruit-eating birds will not perch on plants below a minimum height (1.5 to 2 m). All the planted trees we examined were taller than 1.5 m, and most shrubs were shorter. Since numbers of trees and shrubs varied independently among plots, we compared the ratio of planted trees to shrubs with the number of new recruits in each plot (for those plots with trees). Rank correlations indicate higher recruitment in plots with proportionately more tall plants (Kendall Tau $= 0.24$, $z = 2.10$, one-tailed $p = 0.01$).

Recruitment and Distance from Seed Source

We located potential nearby natural sources, in the form of fruiting adults in fringing woodlands, for most of the newly recruiting species (Table 2). The principal exceptions were those that recruited from root ball soils, and a commonly-planted shade tree, *Albizia julibrissin.* This species, which was found in several plots, may have been transported as a contaminant in soils or mulch. Three-fourths of naturally recruiting plants (745 of 1028) were bird-dispersed species. Mean minimum distances traveled (to a plot from the nearest potential natural seed source) were nearly twice as long for wind-dispersed species (210 ± 92 m) as for those dispersed by animals (129 ± 55 m). For bird-dispersed plants, seedling densities per plot were significantly dependent on distance from the nearest putative seed source for each species, although with considerable variation (regression statistics with 95% c.i.: seedling number $= 12.98 - 1.94 \pm 1.13$ (log distance); $R^2 = 0.05$). No significant relationship was evident for wind-dispersed plants (seedling number $= -0.44 + 0.53 \pm 0.81$ (log distance); $R^2 = 0.01$).

Comparisons with Other Landfill Sites

Without knowledge of a background invasion rate, it is problematic to attribute recruitment of bird-dispersed

Table 2. Census data for woody species naturally recruiting during the first season following installation of the Fresh Kills restoration.

Species	*Origin*	*Total count*	*Distance (m)*	*Principal vector*
Acer rubrum	native	14	228 (50)	wind
Ailanthus altissima	alien	65	299 (70)	wind
Albizia julibrissin	alien	47		wind
Baccharis halimifolia	native	64	162 (21)	wind
Campsis radicans	native*	19	124 (51)	animal
Celastrus orbiculatus	alien	77	131 (50)	animal
Comptonia peregrina	native	22	142 (21)	animal
Cornus stolonifera	native	2	215	animal
Crataegus sp.	native	1		nursery soil
Eleagnus commutata	native*	6		nursery soil
Juglans nigra	native	1		animal
Juniperus virginiana	native	1	397	animal
Liquidambar styraciflua	native	37	299 (55)	wind
Lonicera japonica	alien	2	124 (103)	animal
Parthenocissus quinquefolia	native	40	139 (51)	animal
Paulownia tomentosa	alien	1	179	wind
Populus tremuloides	native	29	143 (60)	wind
Prunus serotina	native	108	120 (47)	animal
Quercus prinus	native	1		animal
Quercus velutina	native	1		nursery soil
Rhus aromatica	native	1		animal
Rhus copallina	native	276	125 (52)	animal
Rhus glabra	native	86	133 (26)	animal
Robinia pseudoacacia	native*	34	121 (46)	wind
Rosa multiflora	alien	5	81 (45)	animal
Rosa sp.	native	2	115 (91)	animal
Rubus sp.	native	87	128 (53)	animal
Salix discolor	native	1	287	wind
Sassafras albidum	native	8		animal
Smilax sp.	native	6	141 (61)	animal
Toxicodendron radicans	native	26	121 (55)	animal
Vitis sp.	native	4	106 (41)	animal
	Total count	1074		

**Native to the U.S. but not to Staten Island (Buegler & Parisio 1982).*
Total count is the number of individuals censused throughout the plantation. Distance is the minimum mean travel distance (±1 SD) from the nearest identified seed source to each plot where a recruit was found. Species without a distance value arrived in nursery soils or from unknown sources.

plants to some attractive feature of the plantation. Censuses of the Brookfield Landfill, where trees and shrubs were never planted, indicate that some woody plants were recruiting. Nineteen species were found, only six of which were wind-dispersed (therefore, animal dispersal was occurring). Stem densities were relatively low however, 145/ha, compared with 640/ha at the Fresh Kills site. Judging by their sizes, approximately half of the recruiting plants were recent seedlings, and this roughly translates to an eight-fold lower rate of annual recruitment on the unplanted site.

Another comparison was afforded by an experimental woodland planted in 1976 on part of the Edgeboro Landfill, East Brunswick, New Jersey (Gilman et al. 1985). By 1990, this plantation had been invaded by a great many new trees, shrubs, and vines—mostly native, berry-bearing species, from nearby riparian forest remnants (Robinson et al. 1992). Stem density of recruits was about 3100/ha, or nearly three times that of the original planted trees and shrubs.

Discussion

Restoration programs are often trial-and-error endeavors, but firmer ecological bases are being developed. For example, recent studies indicate that the pace of restoration and the development of wildlife habitat increase with greater vegetation complexity (Gibson et al. 1985; Parmenter et al. 1985; Schuster & Hutnick 1987; McKell 1989). The natural value of revegetated landfills and similar highly disturbed sites could be greatly improved by landscaping with attention to this need for vegetative complexity. The prospects for using restored lands to enhance biodiversity are sufficiently strong to deserve attention (Bradshaw & Chadwick 1980; Cairns 1988;

Office of Technology Assessment Task Force 1988). If the vegetation were improved, these areas (which represent thousands of hectares of unused land) could contribute significantly to local biodiversity by adding wildlife habitat that would help link remnants of natural forests and wetlands. Urban greenbelts could be enhanced or buffered, and habitat of at least marginal quality could be added to important bird migration corridors (Kane 1991). On the other hand, full-scale landscaping to restore such large areas can be prohibitively expensive. A hopeful alternative is that a modest planting of an appropriate mix of native species can promote the development of diverse natural communities in places that would otherwise remain wastelands.

We are particularly interested in the role of nearby remnant vegetation in promoting the rehabilitation of disturbed sites via secondary succession. By providing inocula of appropriate plants and by paying attention to reproductive ecology, many new individuals and species might be added to degraded lands without increasing the planting effort. In this light, static landscape designs should be replaced with dynamic successional processes that introduce a continuous stream of new elements. This approach has origins in theories of "nucleation" (Yarranton & Morrison 1974; Austin & Belbin 1981), in which patches of vegetation are seen as foci for the rapid spread of invading species (see McClanahan 1986; Moody & Mack 1988). The potential of nucleation is being explored in restoration studies throughout the world. Our results indicate that (1) a variety of woody species can grow in the highly modified soils and open slopes of old landfills, (2) the recruitment phases of succession can be stimulated by planting woody species to promote the invasion of others, and (3) plant size may play a role in determining the strength of that stimulation.

Although survival was high, the restoration plants in this study (chosen on the basis of availability, aesthetic appeal, and site compatibility) contributed very few seedlings. Soils in the immediate vicinity of planted trees and shrubs were covered with a mulching layer of bark chips (from shredded conifers), and this may have been a poor medium for germination. Alternatively, recruits under fruiting plants may have been preferentially removed by herbivores, which could have been attracted to clumped seedlings. In any case, this general result points out the need to monitor restoration sites in order to determine the amount of internal recruitment taking place. It also highlights the importance of reproductive ecology in restoration planning (Bradshaw 1983; Aber 1987; Ashby 1987). A different choice of species might have yielded more seed production and spread, and attention to early reproductive capacity ought to be included in restoration planning (Robinson et al. 1992).

Without true controls, we can only infer that planting trees and shrubs made a substantial difference in recruitment rates. The positive relationship between planting densities and numbers of recruits lends strength to this interpretation, particularly in light of our census results from the two other landfill sites. Compared to commonly reported seed shadow distances for bird-dispersed species (see Howe & Smallwood 1982; Hoppe 1988; Stiles 1989; Izhaki et al. 1991), our estimates of recruitment distances are quite high, and it is likely that many recruits we observed were outliers along distribution paths. Failure to pick up such outliers may be a major limitation to succession on open, highly-disturbed areas. Wind-dispersed recruits apparently travelled further, and their densities were independent of distance from nearest parent plants. Such differences in recruitment rates and distance effects underscore the need to consider the role of dispersal vectors in succession-based restoration programs (Janzen 1988*a*).

Since plots with proportionately more trees had higher recruitment, the simple conclusion is that some tall species ought to be included in restoration plantings of this type (although "tall" in this case might mean a height of 2 m). This issue is an important one in forest restoration programs, since larger trees and shrubs are less likely to survive transplanting, are more susceptible to the stressful environment of open, exposed sites, and carry much higher purchase and installation costs.

Several of the newly arrived species (*Ailanthus altissima, Celastrus orbiculata, Rosa multiflora,* and *Lonicera japonica*) are highly invasive weeds, with the capacity to dominate a site and exclude native species (Hu 1979; Decker & Enck 1987; Harrington & Howell 1990). A management scheme for their control should be part of any restoration protocol, and, since they appeared within the first year, control measures should be swift. Stimulating natural succession by attracting dispersers might be a poor technique when it leads to the unmanaged spread of weedy aliens.

More-detailed, experimental study will be required if specific restoration protocols are to be derived. For example, what kinds of species can be counted on for natural recruitment, and which species will need to be artificially introduced? Are larger plants, beyond some threshold size, more effective than smaller ones? How close should natural seed sources be to ensure optimal dispersal? How should plants be distributed to maximize pollination, disperser attraction, seedling recruitment, and subsequent woodland succession? Together, these issues represent the need to include plant reproductive ecology in the conceptual background of restoration planning. Answers to these and similar questions will provide firmer ecological bases on which to build sound ecological restoration programs.

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