Topographic Alterations, Forest Structure, and Invasion by English Ivy (*Hedera helix* L.) in the Rock Creek Floodplain, Washington, D.C.

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ABSTRACT: Topographic alteration may encourage invasion of the exotic species English ivy (*Hedera helix* L.) in floodplain forest. To test that hypothesis, I designated 16 sampling stations on the floodplain of Rock Creek Park in Washington, D.C. Eight of the stations were on the spoil ridge that resulted from construction of a sewer line in 1927 (median height = 22 cm). In 1983 the ground layer of half of each station on the spoil ridge and on the "flat" near the ridge were dominated by English ivy; other stations were ivy-free. By 1989 English ivy had invaded four of the ivy-free stations. This increase in ivy abundance was not statistically significant on the "flat" but was significant ($\chi^2_{Y,\ 1df,}$ $p<0.1$) on the ridge. There was no significant difference ($\chi^2_{Y,\ 1df,}$ $p>0.1$) between ivy rooting depth on the sewer ridge and on the flat, indicating that good soil conditions were present in both places. Basal area of the trees dominating the sites differed: the "flat" had 69 $m^2\ ha^{-1}$ while the spoil ridge had 59 $m^2\ ha^{-1}$. The results support the hypothesis that a slight alteration of topography influences patterns of invasion by English ivy.

Index terms: English ivy, exotic species, floodplain, forest structure, human disturbance

INTRODUCTION

The potential for nonindigenous species to affect natural communities is increasingly recognized (U.S. Office of Technology Assessment 1993). The U.S. National Park Service considers invasion by nonindigenous plants to be the most common threat facing its parks (Hester 1991), and the National Audubon Society's wildlife sanctuaries are also experiencing nonindigenous pest problems (National Audubon Society 1994). Although there have been numerous prescriptions for control of nonindigenous species, there are relatively few studies of the factors that facilitate community invasion by these species (White et al. 1993).

English ivy (*Hedera helix* L.), a native of Europe, has a history of escape from cultivation into forests of the eastern United States (Hitchcock and Standley 1919), but only recently has it been recognized as a management problem in parks and natural areas of the region. In the early 1970s, I conducted an ecological study on a National Park Service island in the Potomac River at Washington, D.C., where English ivy had become a problem in both upland and floodplain forests (Thomas 1980). The current study concerns the ecology of English ivy invasion on a floodplain in Rock Creek Park (U.S. National Park System), located in the District of Columbia, USA.

The goals of this study were to determine the extent of topographic alteration imposed by a 1927 sewer line and the relationship of the altered topography to patterns of invasion by English ivy, and to examine factors that might influence ivy growth. The study examined new invasions occurring between 1983 and 1989, ivy rooting depths, and basal area dominance of trees as three factors that might differ in response to topographic alteration.

STUDY AREA

About 10% of the area of the District of Columbia is wild land administered by the National Park Service, of which the largest park is Rock Creek Park (area 762 ha). (Rock Creek Park adjoins a nonfederal park in Maryland by the same name.) The study was conducted in the large floodplain in the northern section of the federally managed park. Osterkamp and Hupp (1984) gave a detailed description of its geomorphic features from stream channel bed up to and including the bank below the floodplain, but not for the floodplain itself. The floodplain slopes at about a 0.6% grade from a high area next to the stream (natural levee) down to a low point at the base of the upland slope. The natural levee is the longest ridge on the floodplain. Tributary streams and uprooted trees dissect the floodplain to form other ridges/hummocks and depressions. The largest depression parallels the toe of the upland slope. Seasonal ponding of water in the depressions results in swampy areas. The study did not include the depressions; the area between ridges or hummocks and depressions is referred to as the "flat."

The density of trees (10 cm dbh minimum) on this floodplain is 368 trees ha^{-1}. The canopy stratum varies from 27 m to about 50 m in height and is dominated by *Liriodendron tulipifera* L. (Table 1). Under the subcanopy is a stratum of smaller trees defined by the height of *Carpinus caroliniana* Walt. However, the dominant in this layer is *Acer negundo* L. *Lindera benzoin* (L.) Blume is a characteristic shrub outside the ponded-water area, but shrubs are not characteristic of the ponded areas. On the higher parts of the floodplain *Arisaema triphyllum* (L.) Schott is found in the ground layer, while the ponded area is mostly bare. When ground-layer vegetation occurs in the ponded area, it is mostly *Symplocarpus foetidus* (L.) Nutt.

METHODS

All English ivy colonies in the northern floodplain were located in November 1983 for another study. At the center of each colony a point was established for tallying trees (10 cm dbh minimum) by the point-centered quarter method. Each of the eight colonies had 100% ground cover of English ivy. Another eight points located at random where English ivy was absent and other nonindigenous species were inconspicuous served as controls. Since the objective was to set up paired observations, no points were designated in depressions (English ivy does not occur in such habitats). The point-to-tree distance allowed calculation of absolute density of trees per hectare. To increase the number of trees for further calculations, the second closest tree in each quarter was also tallied. As a result of this modified point-centered quarter method, the English ivy colonies were now enclosed by the tallied trees. From the standpoint of the English ivy, this was a census of all the large trees that could closely influence the ivy. From the standpoint of the floodplain, this was a sample of the trees. (Species and dominance of trees in and out of the depressions are the same, only the lowest strata differ [Anderson et al. 1977]). Each point with its surrounding tallied trees constituted a sampling station. In the ivy areas a number of 1-m x1-m plots were placed around each point.

Later I learned that a sewer line more or less parallel to the creek had been placed in the large floodplain at the north end of the park in 1927 (Figure 1). Traversing the line in winter, when the topography was obvious, I found that the sewer line passed through eight of the stations on this floodplain. Four of the eight sampling stations on the sewer line were ivy-free when they were established in 1983; by 1989 three of these four stations had been invaded by English ivy. Thus seven of the eight original stations were invaded by ivy (Table 2). I wondered whether this was significant and whether the nonivy stations adjacent to the sewer line ("flat") had also been invaded by ivy. The unplanned overlap of sewer line and sampling stations allowed me to test whether topographic alteration promoted ivy invasion, and if so, to examine what factors favored ivy invasion.

The height of the sewer spoil ridge was determined to 0.0003 m by survey methods using a rod and level. Random points

Table 1. Importance values of trees on the northern Rock Creek Park floodplain based on relative density, relative frequency, and relative basal area (as defined in Phillips 1959).

	Importance Value	Number
Canopy (≥27 m high)		
Liriodendron tulipifera	53[a]	32
Fraxinus pennsylvanica	16	7
Platanus occidentalis	14	7
Carya cordiformis	7	2
Quercus palustris	5	2
Acer rubrum	3	1
Ulmus americana	2	1
Total	100	52
Subcanopy (>11– <27m)		
Acer negundo	42[a]	31
Liriodendron tulipifera	24[a]	14
Fraxinus pennsylvanica	20	8
Fraxinus americana	7	2
Carya cordiformis	4	2
Platanus occidentalis	4	1
Total	101	58
Understory (≤ 11 m high)		
Acer negundo	60[a]	10
Carpinus caroliniana	18	4
Liriodendron tulipifera	10	2
Ulmus americana	6	1
Acer rubrum	5	1
Total	99	18

[a] Dominant species in each layer.

(from a random digits table) were selected within the stations on the ridge. Opposite each point, two elevation measurements were taken perpendicular to the ridge: one on the side toward the creek and one on the side toward the upland. Because of the floodplain slope, these two measurements were averaged to obtain ridge height.

Invasion of English ivy into established stations was evaluated using discrete counts of areas invaded. A chi-square test in a 1 x 2 table was appropriate, with Yates's correction for continuity (Croxton 1953, Freese 1967). Rooting depths of the ivy were sampled both on the ridge (sewer spoil) as well as on the "flat." Tests for normality by histogram, cumulative distributions (ogives) plotted on semi-log paper, and goodness-of-fit for normality (both Kolmogorov-Smirnov and chi-square) showed nonnormal samples (Croxton 1953, Siegel 1956, Day and Quinn 1989, Zar 1996). Because the samples were extremely nonnormal, I used the nonparametric Kruskal-Wallis test. Because of the uncontrolled variation that exists in field surveys, I set significance at the $p = 0.1$ level for all statistical tests, as in past studies (Thomas 1980). Basal area of the trees at the sampling stations on the sewer ridge was compared to that of the trees at the stations on the "flat." Since these were all the trees directly influencing these stations by light or root competition, only descriptive statistics were needed.

Table 2. Number of stations on the northern Rock Creek Park floodplain on sewer spoil ridge and flat with and without English ivy (n=16).

	Sewer Ridge		Flat	
Year	Ivy	No Ivy	Ivy	No Ivy
1983	4	4	4	4
1989	7	1	5	3

"Invasion" was defined as ivy occurring inside the perimeter of the stations or on the trees that defined them. One chi-square test with Yates's correction for continuity was performed for the sewer line ridge invasion and one for the "flat" invasion, with the expected number in each test being the original number of stations with ivy (Croxton 1953).

Rooting depth of ivy was measured at the four ivy stations on the sewer line ridge and at the four ivy stations on the "flat," with the purpose of detecting differences in growing conditions between the two areas. Rooting depths were measured in conjunction with another study, not reported here, in 1-m x 1-m plots laid out in the ivy stations. Two of these plots were randomly selected at each station. Rooting depth was measured to the nearest 0.5 cm at the midpoint of one randomly determined side of each quadrat. Thus the eight root-depth measurements on the ridge were compared with the eight measurements on the "flat" by Kruskal-Wallis test (Siegel 1956).

I also investigated the arboreal environment above the ground-layer vegetation at both

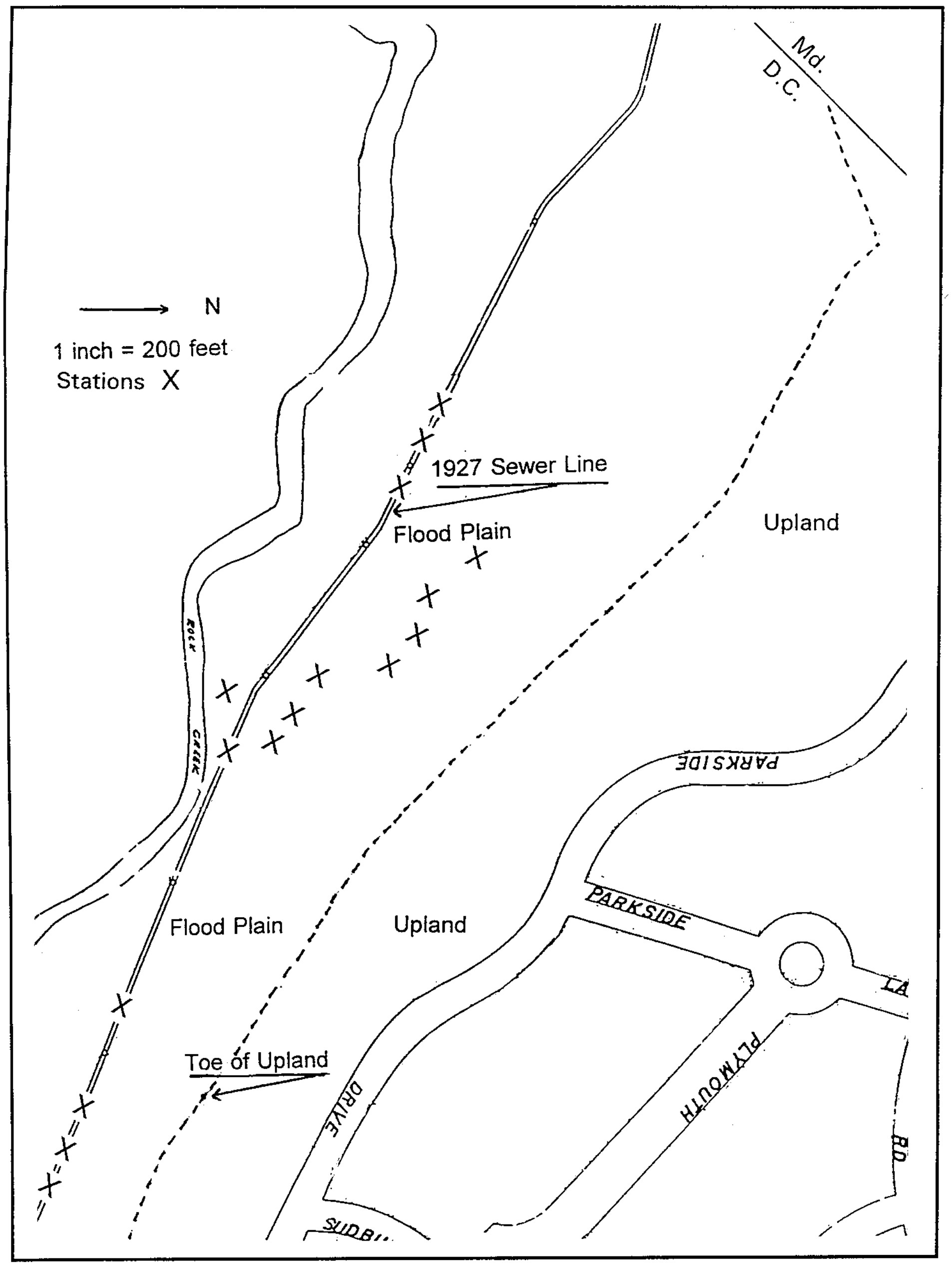

Figure 1. Map of a portion of Rock Creek Park, showing 1927 sewer line, which runs generally parallel to Rock Creek, and sampling stations.

the ridge and "flat" sampling stations and in and out of ivy-dominated ground layers. For basal area, dbh (diameter at breast height) was measured with calipers (long and short diameter) to the nearest 0.5 cm for each of the eight trees at each station. Total basal area in m^2 ha^{-1} for the ridge and for the "flat" were determined from the population of trees at each station (Phillips 1959).

RESULTS

Ridge elevation, from 21 random paired measurements, above the general level of the floodplain varied from 0.0847 m upstream to 0.5953 m downstream or about 8 to 60 cm (median = 0.2234 m).

In 1989 only one station on the "flat" (off the sewer line) had been invaded by English ivy, while three on the sewer line had been invaded (Table 2). Invasion on the "flat" was not significant ($\chi^2_{Y, 1df}$, $p>0.1$), but invasion on the sewer line was significant ($\chi^2_{Y, 1df} = 3.125$, $p<0.1$).

Rooting depths of ivy did not differ statistically ($H_{c, 1df} = 1.359$, $p > 0.1$) between the sewer ridge and the flat. The data were combined to give a range of rooting depths from 3.0 to 10.5 cm (mode = 4.0 cm, median = 5.0 cm).

In 1983 total tree basal area for the ridge stations was 59 m^2 ha^{-1}, whereas for the "flat" stations it was 69 m^2 ha^{-1}.

DISCUSSION

The low ridge from the sewer construction spoil is no higher than the natural levee, so it has been periodically inundated by floods for 62 years. In the larger floods the sewer ridge has been scoured, but it still persists. Decades after construction of the sewer line, English ivy began growing on this floodplain. Ivy growth on the sewer line ridge cannot be explained on the basis of original construction disturbance, because there were an equal number of stations with ivy ground cover off the sewer line, and all possible ivy colonies on this floodplain were included in the study. Disturbance of the soil during sewer construction activities usually affects not only the spoil ridge but the adjacent flat. Ivy was not the dominant in the ground layer at these recently invaded sampling stations. Since all the native ground cover stations were in proximity to English ivy colonies and the "flat" stations were not as rapidly invaded as the sewer ridge stations, this observation suggests that there is resistance to invasion on the "flat." The disturbance due to construction took place in 1927, but ivy did not show up on the floodplain for many years. Park managers were trying to control it in the 1970s and estimated that it had begun growing there in the 1960s.

In an invasion mode English ivy produces more than twice as much biomass in a year on the upland as on the floodplain (in experimentally denuded plots: 36.0 g m^{-2} floodplain, 87.1 g m^{-2} upland [Thomas 1980]). Because the sewer line spoil ridge is more similar to an upland environment than the rest of the floodplain is, invasion on the ridge might be expected to occur faster than on the flat; this scenario would account for the statistical significance of ridge invasion and nonsignificance of "flat" invasion in this study. The levee, being the highest natural elevation in the floodplain, would also resemble an upland habitat. One would not expect a rapid invasion on the natural levee, because ivy does not fare as well as the native plant species during periodic scourings of major floods (Thomas 1980). The natural levee would get the brunt of such scourings, and in fact ivy was not found on the natural levee of this floodplain in 1983. The scouring action of floods removes and breaks the vegetation and also removes soil or sediment. As flood waters abate, however, new sediment is deposited.

Rooting depths of ivy were not significantly different between the ridge ivy and ivy growing on the lower elevation "flat." Although a high water table is known to be a limiting factor for English ivy (Kassas 1952, Thomas 1980), I found no evidence suggesting that excessive moisture in the root zone is a factor limiting the invasion of ivy on the "flat."

Similarity of the sewer line spoil ridge to an upland environment does not completely explain the retarded growth of ivy on the "flat." For plants the main arenas of competition are competition for light by the shoot system and competition for water and other nutrients by the root system. Under the more ideal conditions of an upland environment, the percentage of open sunlight only accounts for 41% of the English ivy biomass produced, suggesting that the species competes well in the shade in an invasion mode (Thomas 1980). The majority of the biomass production (59%), then, is due to other factors. Competition for water and nutrients in the root zone may be one of these other factors.

Trenched plot experiments have shown that severe root competition occurs in forested ecosystems (Toumey 1929, Toumey and Kienholz 1931). Whigham (1984) demonstrated that root competition from vines significantly suppresses growth in diameter of isolated trees of sweetgum (*Liquidambar styraciflua* L.) in an old field. If root competition can be adverse to isolated trees where the tree roots are in the minority, similar competition certainly might suppress or retard vine growth in a forested situation where tree roots are in the majority. Basal area is one phytosociological measure commonly used to assess ecological dominance. One would generally expect that trees with larger basal areas also have larger root systems as well as shoot systems. In this study, although there were the same number of trees on both ridge and "flat," the "flat" had the greater basal area. Higher basal area was associated with lower susceptibility of the site to invasion. In manipulated field experiments on grassland, Robinson et al. (1995) found that plots with weaker dominance were more easily invaded. Their study and the one reported here are consistent with the suggestion that a natural community with an ecologically dominant life form tends to resist biological invasion by other species (Thomas 1988).

The presence of sewer construction spoil increased the total amount of ridge area for the floodplain in this study and simultaneously reduced the area of both "flat" and depressions, thus increasing the habitat for English ivy growth. Trees now growing on this spoil would be younger than those growing on the "flat" and, with the same species mix on and off the sewer ridge, would have smaller trunk diameters. Early secondary succession also facilitates nonindigenous species invasion (Thomas 1988); this effect is still apparent in this study area three decades after the disturbance. There is no evidence that natural regeneration facilitated by silvicultural techniques or horticultural plantings were used to revegetate the spoil (in 1927 little thought was given to restoration).

This study has implications for habitat restoration on forested floodplains. Topography basically integrates all aspects of the physical environment; when it is changed it changes the environment. An earlier study (Thomas 1980) involving a marsh showed that a topographic alteration as little as 1 dm promoted the colonization of the exotic species European yellow iris (*Iris pseudacorus* L.). In the situation reported here, the topography was raised an average of about 2 dm, and this has tended to promote invasion of nonindigenous English ivy. In restoration projects, it is important to restore the topography of the land to the degree required to accommodate the desired habitat. In wetlands, small differences in topographic relief lead to colonization by different species, some of which may be nonindigenous to the site. Upland areas might tolerate greater topographic change without adverse effects.

SUMMARY AND MANAGEMENT IMPLICATIONS

When topographic relief is altered, one can expect such a disturbance to promote invasion by nonindigenous species. To preclude or retard such invasion during restoration projects, the original topography should be restored. In wetlands very small levels of topographic variation are critical, whereas upland sites might tolerate larger variations. Some measure of ecological dominance, such as basal area, should be examined before restoration programs are instituted. One way to promote increased basal area without introducing species and ecotypes that are not already on the site is to dress the site with the surface litter and soil originally on the site. The contained seed bank would likely put a high density of seeds in place for early growth.

L.K. Thomas Jr. recently became Resource Management Specialist for the U.S. National Park Service. Before that he was Research Biologist with both the National Biological Service and the National Park Service. His professional interests are the ecology and management of exotic species and of small protected natural areas.

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