

# Species richness of urban forest patches and implications for urban landscape diversity

Elizabeth R. Hobbs

*Macalester College, St. Paul, Minnesota 55105*

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## Abstract

The vascular plant species richness of upland urban forest patches in St. Paul and Minneapolis, Minnesota, was found to be positively related to their size. There was no significant relationship between species richness and the distance of these patches to other patches. Mowing and trampling reduced species richness of patches, whereas planting increased richness. Landscape richness can be maintained at a relatively high level by leaving even small unmown forested patches within a more disturbed matrix. However, maximizing landscape diversity would require leaving large forest stands unmown. It is suggested that cultivation be deliberately used as a mechanism for increasing native species richness in urban forests.

## Introduction

Species richness has been linked repeatedly with the spatial characteristics of ecosystems. Among the geographic variables used by ecologists to predict species richness are area, isolation, and environmental heterogeneity (Tramer and Suhrweir 1975; Helliwell 1976; Crowe 1979; Scanlon 1981; Riebesell 1982; Middleton and Merriam 1983). Relationships between species richness and area and isolation have been interpreted as supporting the theory of island biogeography (McArthur and Wilson 1967). In this paper, I will examine factors influencing plant species richness of small upland urban forest patches in the Twin Cities of St. Paul and Minneapolis, Minnesota. I will show that the theory of island biogeography has limited applicability to such habitat islands within a matrix of urban land use. I will further consider the implication of the richness of these patches to the species richness of the landscape as a whole.

## *Climate and vegetation of the Twin Cities*

The Twin Cities are located in east-central Minnesota, in the prairie-forest transition zone. They experience cold winters and warm summers, with an average annual precipitation of approximately 30 inches. The presettlement upland vegetation of the Twin Cities consisted primarily of oak openings (*Quercus macrocarpa*, *Q. alba*, *Q. borealis*), with some mesic hardwood forest (*Acer saccharum*, *Tilia americana*, *Ulmus americana*, *Ostrya virginiana*) and prairie (Marschner 1974). River bottom forest (*Acer saccharinum*, *A. negundo*, *Fraxinus pennsylvanica*, *Ulmus americana*, *Populus deltoides*) and wet prairie occupied the floodplains. Species from all of these ecosystems are represented in the present day upland urban forest, along with alien weeds and cultivars. *Fraxinus pennsylvanica* and *Quercus macrocarpa* are the most common and abundant upland trees. Mesic forest tree species are relatively rare except where planted (Hobbs, in press).

Table 1. Structural and disturbance differences between mown and unmown stands

	Mown (LS mean) (n = 19)	Unmown (LS mean) (n = 15)	Prob mown = unmown
Disturbance index	2.8	1.8	0.0001
% Cultivars	19.0	10.2	0.0015
% Tree cover	63.2	86.3	0.0001
% Shrub cover	2.6	57.1	0.0001
% Herb cover	88.2	58.8	0.0001
% Litter cover	3.1	61.7	0.0001
% Bare ground	3.8	25.0	0.0001
% Paved	7.0	2.4	0.0321

Some urban forest patches are relatively undisturbed at present, others are criss-crossed with trails, and others have mown understories. These mown stands include parks, cemeteries, and the grounds of institutions. All types of disturbance are significantly greater on mown stands than on unmown stands (Table 1). Mown stands have more pavement, a larger percentage of the species present are cultivars, and they are more heavily trampled, as humans have easy access away from trails. This has resulted in significant differences in the structure of the vegetation (Table 1). Tree cover and shrub cover have been reduced, probably both by the initial clearing of the understory and by the repeated mowing of seedlings. Herb cover has consequently increased. Mown stands have less litter on the ground and less bare ground, both possibly a function of reduced tree cover. All of these forest patches are surrounded by a matrix of street and yard vegetation referred to as the interstitial forest.

#### *Factors thought to contribute to species richness*

The theory of island biogeography states that, for islands, species richness can be predicted by the island's area and its isolation from the mainland or from other similar islands which function as sources of species (McArthur and Wilson 1967). It has been suggested that this theory should be relevant to the study of urban habitat islands (Davis

and Glick 1978). However, the theory and studies supporting it have been criticized, primarily for two reasons (Sauer 1969; Gilbert 1980; Boecklen and Gotelli 1984). First, a species/area relationship has been well-documented in noninsular communities (Connor and McCoy 1979). Second, area may be acting as a surrogate for environmental heterogeneity (large islands having more habitats) (Johnson *et al.* 1968; Buckley 1982).

Island biogeography theory also fails to consider that shape may be relevant to species richness. Both small and large islands are expected to have sun loving, or xeric, species, at least in edge habitats. However, a large patch or island could still be so narrow that it would not support shade tolerant, or mesic, species because of light penetration (Carlton and Taylor 1983).

Moreover, studies of forest patches in urban settings have demonstrated the importance of disturbance in promoting diversity (Hoehne 1981), as well as in reducing richness (Airola and Buchholz 1984). And Whittaker (1977) suggests that diversity begets diversity, *i.e.*, that the addition of species to a community increases the resources of that community, thus making possible the addition of more species.

The richness of the individual portions of the landscape and the variety of patch types within the landscape are relevant to the species richness of the landscape as a whole. Landscape (gamma) diversity can be increased both by increasing within habitat (alpha) diversity and by increasing between habitat (beta) diversity (Whittaker 1977).

Several hypotheses will be considered here. First, although patch size may be an important determinant of species richness, isolation should be much less important, since the urban matrix includes other vegetated areas which may act as species sources. Second, although some forms of disturbance may enhance species richness, the destruction of the urban forest understory by mowing is expected to have the opposite effect. Third, heterogeneous patches (those mown only in part) should be the most diverse patches within their size classes because they should contain species typical of both mown and unmown stands. Finally, by increasing the species richness of forest patches within the urban area and by increasing the complexity

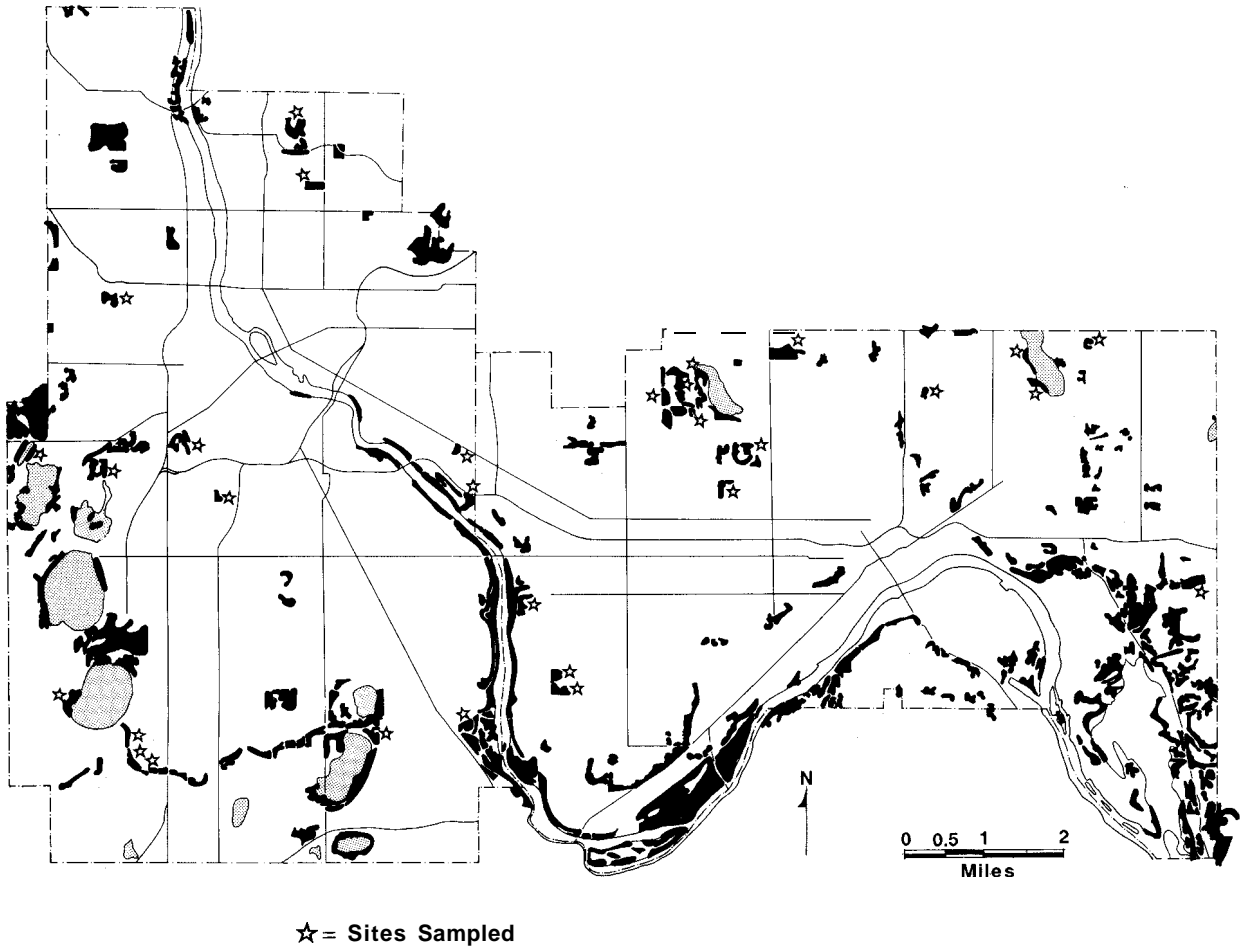


Fig. 1. Map of upland and floodplain urban forest patches in Minneapolis-St. Paul, Minnesota. Upland stands sampled are indicated by stars.

of the landscape pattern, urban species richness should increase.

## Methods

To examine the factors related to species richness in these forest patches, 30 upland stands were sampled in St. Paul and Minneapolis, Minnesota. These upland stands were chosen from 293 forested sites identified and measured on 1980 aerial photographs (Fig. 1). All of the stands sampled were in residential areas. A stratified random sampling design was used in site selection to insure that a wide range of sizes and isolation values was represented.

Stands sampled ranged in size from 1 ha to 8.6 ha, measured from the aerial photographs. Unmown segments of heterogeneous stands were as small as 0.1 ha. Isolation was measured from the aerial photographs as the distance between each patch and the next nearest forest patch and the distance to the nearest patch large enough to contain a 2.3 ha circle, which is the minimum size for a forest to contain mesic species (Levenson 1981). Slope was measured from topographic maps.

In the field, each site was searched thoroughly by two field workers, and all vascular plant species were listed. Percent cover of trees, shrubs, herbs, bare soil, and pavement were estimated visually. A disturbance index, ranging from 1.0 (unmown,

Table 2. Growthform and geographic origin of species

	All stands		Unmown stands		Mown stands		Heterogeneous patches	
	Native	Alien	Native	Alien	Native	Alien	Native	Alien
Trees	43	31	33	18	38	27	32	22
Shrubs	44	22	39	14	21	18	30	15
Herbs	221	128	184	83	104	108	134	77
Vines	10	0	10	0	10	0	9	0
Succulents	3	0	0	0	3	0	0	0
Total	327	181	266	115	176	153	205	114
Total area sampled (ha)	128.4		29.5		66.1		32.8	
Total number of species	508		381		329		319	

trampling only on trails which are weakly developed) to 3.0 (mown and heavily trampled throughout), was assigned. An estimate was made of the number of species in each stand that may have been deliberately planted, based on the known status of species as cultivars. This number was probably an overestimate for unmown stands, since cultivars like *Rhamnus catharticus* and *Lonicera tatarica* are widely established as volunteers (Hobbs, in press). It may have been an underestimate for mown stands if native species were planted.

The 20 patches which were completely mown or completely unmown were classified as homogeneous patches. Ten of the sampled stands had heterogeneous disturbance patterns, with both mown and unmown portions, and were referred to as heterogeneous patches. When comparisons of mown and unmown stands were made, the mown and unmown portions of seven heterogeneous stands which were sampled separately were included in the analysis along with the homogeneous patches. Differences in means of structural and richness measures between different groups of stands was tested using least squares means.

Three groups of independent variables were considered to be potentially important determinants of species richness. First, area and slope were used as indicators of the environmental heterogeneity of the forest patch. Second, the two measures of isolation were considered. Third, human intervention was indicated by the number of cultivars found

growing in the stand, the disturbance index, and the amount of pavement. These factors were entered into stepwise multiple regressions to determine their ability to predict species richness. Correlations between species richness and the independent variables were calculated using Pearson correlation coefficients. Data were analyzed using SAS (Ray 1982). Results are reported at the 0.05 level of significance.

## Results

### *Species richness of all patches*

In total 508 species were found on these sites; 181 (36%) of these were aliens (Table 2). The number of species in the stands sampled ranged from a minimum of 22 to a maximum of 213 (Fig. 2). Mean stand richness was 91 species. Both the correlations (Table 3) and the regression models (Table 4) indicate that increasing area had a significant positive effect on total species richness (Fig. 2), whereas disturbance reduced richness. Richness was apparently not influenced by isolation.

On the whole, native species were more abundant than aliens in these urban forests (Table 2). The mean number of native species per site was 54; the maximum was 159. Native species richness also increased with area (Fig. 2) and decreased with disturbance (Tables 3 and 4). In contrast, aliens aver-

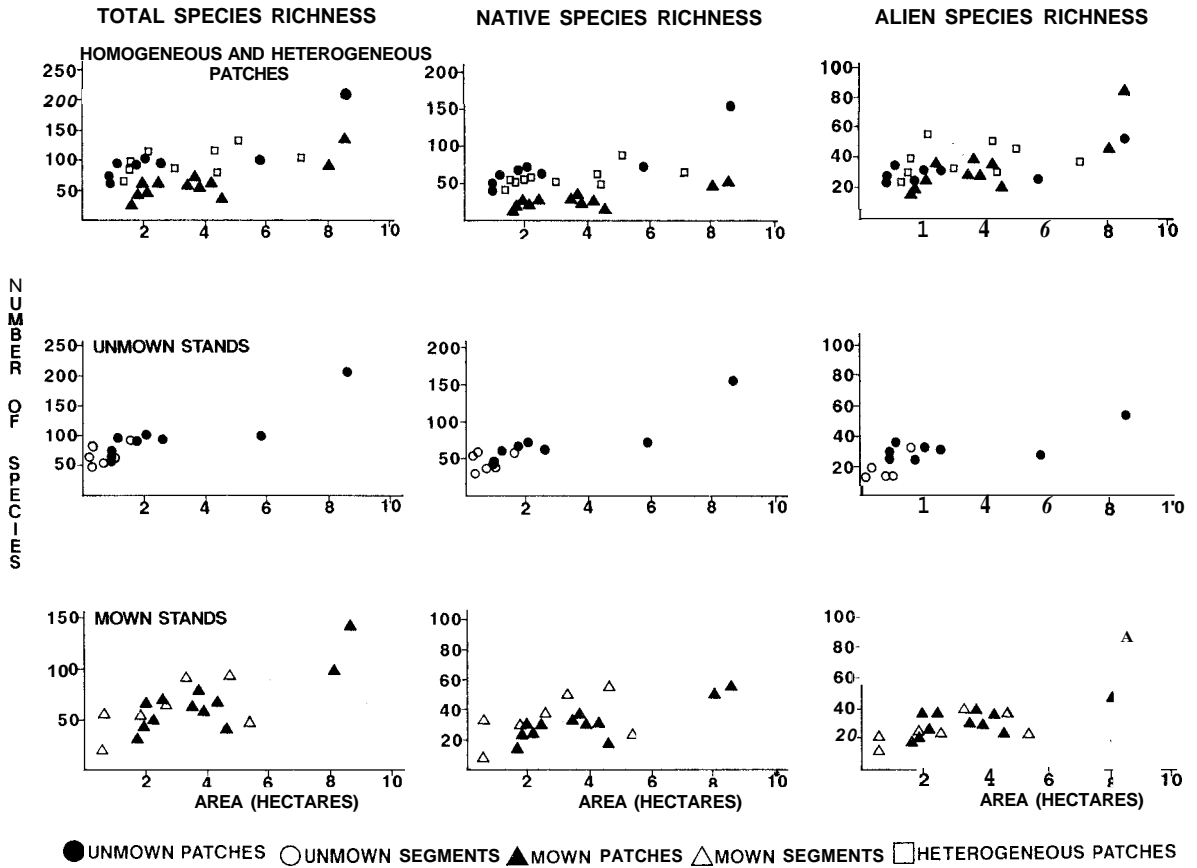


Fig. 2. Plots of species richness by individual stand area for all species, all natives, and all aliens.

aged only 37 species per stand; their maximum richness was 87 species. Although disturbance apparently reduced native species richness, it had no effect on richness of aliens. Alien richness was positively related to area (Fig. 2) and to the number of cultivars (Tables 3 and 4).

Trees, shrubs, and herbs differ in both longevity and resistance to disturbance; consequently differences in richness and the relation of richness to environmental factors should be expected. Trees averaged 20 species per stand, with a maximum stand richness of 31 species. Richness of trees was correlated only with the number of cultivars (Table 3) and was not well-predicted by any regression model including the seven independent variables considered (Table 4). Shrubs had the lowest stand richness, averaging nine species per stand. The maximum number of shrubs on a stand was 29. Herbs had the greatest stand richness, with a maximum of

160 species on one stand and an average richness of 62 species. More than half of the species on most stands were herbs. Both shrub and herb richnesses increased with increasing area and decreased with disturbance (Tables 3 and 4).

#### *Homogeneous and heterogeneous patches*

Twenty of the patches sampled were either entirely mown or not mown at all, giving them a homogeneous structure. Data from these patches were similar to the aggregate data. Total species richness and numbers of native species, shrubs, and herbs all increased with patch size and decreased with disturbance (Tables 3 and 4). Alien species richness increased with patch size and with the number of cultivars. Again, tree richness was not as well predicted by these variables as were the other life-forms.

Table 3. Factors correlating with species richness

	All species	Native species	Alien species	Tree species	Shrub species	Herb species
All patches ( $n = 30$ )						
Area	0.57239 0.0010	0.44456 0.0138	0.61485 0.0003	0.22699 0.2277	0.41638 0.0221	0.58782 0.0006
Disturbance index	-0.52451 0.0029	-0.64946 0.0001	-0.05852 0.7587	-0.22279 0.2367	-0.58695 0.0007	-0.49303 0.0056
Number of cultivars	0.34672 0.0605	0.07430 0.6964	0.76814 0.0001	0.41953 0.0210	0.27158 0.1466	0.30709 0.0988
Homogeneous patches ( $n = 20$ )						
Area	0.63939 0.0024	0.46141 0.0406	0.72857 0.0003	0.31413 0.1774	0.46692 0.0379	0.64494 0.0021
Disturbance index	-0.63497 0.0026	-0.74896 0.0001	-0.10563 0.6576	-0.29795 0.2020	-0.71574 0.0004	-0.59230 0.0059
Number of cultivars	0.27038 0.2489	-0.01518 0.9494	0.75506 0.0001	0.26828 0.2528	0.22111 0.3488	0.25842 0.2713
Heterogeneous stands ( $n = 10$ )						
Number of cultivars	0.74901 0.0127	0.61011 0.06011	0.81341 0.0042	0.83660 0.0025	0.59465 0.0698	0.57655 0.0810
Unmown stands ( $n = 15$ )						
Area	0.88612 0.0001	0.88902 0.0001	0.76002 0.0010	0.58933 0.0208	0.91067 0.0001	0.84122 0.0001
Disturbance index	-0.58173 0.0229	-0.56490 0.0282	-0.55370 0.0322	-0.40169 0.1378	-0.44764 0.0943	-0.57184 0.0259
Mown stands ( $n = 19$ )						
Area	0.74339 0.0003	0.61777 0.0048	0.76620 0.0001	0.33967 0.1548	0.60081 0.0065	0.74146 0.0003
Slope	0.19641 0.4203	0.34941 0.1426	0.05080 0.8364	0.54728 0.0153	0.13695 0.5761	0.08336 0.7344
Number of cultivars	0.86916 0.0001	0.74779 0.0002	0.87723 0.0001	0.56725 0.0113	0.88249 0.0001	0.80436 0.0001
Disturbance index	-0.43330 0.0638	-0.36102 0.1289	-0.44335 0.0573	-0.08685 0.7237	-0.47492 0.0399	-0.46202 0.0464

Mowing of only a portion of a patch creates internal structural heterogeneity. The 10 heterogeneous patches were not significantly richer in species than were homogeneous patches (Table 5). Richness of heterogeneous patches was attributable primarily to the number of cultivars, which correlated positively with total species richness, richness of aliens, and richness of trees (Table 3). The number of cultivars also entered into every regression model predicting richness on heterogeneous stands (Table 4) and was the only variable in the models predicting the numbers of natives and

aliens. Area appeared only in models predicting total species richness, shrubs, and herbs. Disturbance reduced total richness (Table 4), and cultivation and disturbance together best predicted tree richness (Table 4).

#### *Unmown and mown stands*

The unmown portions of the landscape contained significantly more species than did the mown stands (Tables 2 and 6). Because many species were shared

**Table 4.** Multiple regressions of environmental factors on species richness

	All species	Natives	Aliens	Trees	Shrubs	Herbs
<b>All patches (<math>n = 30</math>)</b>						
Area	8.17	5.22	2.29	0.11	1.16	6.99
Disturbance index	-29.28	-28.37		-2.82	-6.07	-21.26
Number of cultivars			0.87	0.29		
Distance to nearest forest patch				-1.38		
Distance to nearest large forest patch				0.001		
Slope				-0.09		
Pavement				-44.71		
Intercept	131.48	104.19	16.90	25.23	19.76	-89.05
F statistic	19.45	20.90	34.14	2.33	13.93	18.39
Probability > F	0.0001	0.0001	0.0001	0.0615	0.0001	0.0001
R <sup>2</sup>	0.5903	0.6075	0.7166	0.4254	0.5078	0.5766
<b>Homogeneous patches (<math>n = 20</math>)</b>						
Area	10.23	5.79	3.06	0.74	1.39	8.15
Disturbance index	-35.03	-33.11		-5.43	-7.50	-25.73
Number of cultivars			0.75			
Slope				-0.36		
Pavement				-51.85		
Distance to nearest forest patch				8.67		
Intercept	130.27	106.12	14.59	32.76	20.58	88.60
F statistic	33.22	26.99	29.68	3.99	21.57	25.77
Probability > F	0.0001	0.0001	0.0001	0.0184	0.0001	0.0001
R <sup>2</sup>	0.7963	0.7605	0.7774	0.5878	0.7174	0.7520
<b>Heterogeneous patches (<math>n = 10</math>)</b>						
Area	4.23				0.46	3.58
Number of cultivars	2.14	1.54	0.28	0.73	0.21	1.18
Disturbance index	-20.29			-7.57		
Pavement	207.55					174.41
Slope		-1.30				
Distance to nearest large forest patch					0.71	
Intercept	99.44	51.48	23.03	30.45	5.06	32.18
F statistic	13.28	8.70	15.64	16.79	2.60	5.23
Probability > F	0.0071	0.0126	0.0042	0.0021	0.1473	0.0412
R <sup>2</sup>	0.9140	0.7131	0.6616	0.8275	0.5652	0.7234

Table 4. Cont

	All species	Natives	Aliens	Trees	Shrubs	Herbs
Unmown stands ( $n = 15$ )						
Area	14.65	11.33	3.31	1.42	2.37	10.98
Number of cultivars				0.71		
Intercept	62.46	41.38	21.08	8.88	6.67	40.48
F statistic	47.53	49.01	17.78	9.87	63.16	31.47
Probability > F	0.0001	0.0001	0.0010	0.0029	0.0001	0.0001
R <sup>2</sup>	0.7852	0.7904	0.5776	0.6219	0.8293	0.7076
Mown stands ( $n = 19$ )						
Number of cultivars	2.06	0.88	1.19	0.2847	0.35	1.01
Slope				0.6494		
Area						3.92
Intercept	37.53	21.02	16.50	9.44	-0.40	16.38
F statistic	52.51	21.56	56.76	9.33	59.85	24.50
Probability > F	0.0001	0.0002	0.0001	0.0021	0.0001	0.0001
R <sup>2</sup>	0.7554	0.5592	0.7695	0.5384	0.7788	0.7539

Stepwise multiple regression with maximum  $r^2$  improvement; above  $r^2 = .50$ , would not accept variable that did not improve  $r^2$  by .10 or more. Numbers are slope (b) values for the best variables.

Table 5. Differences in richness between homogeneous and heterogeneous patches

	Homogeneous (LS mean) ( $n=20$ )	Heterogeneous (LS mean) ( $n=10$ )	Probability homo = hetero
Total species	85.2	102.6	0.2072
Natives	49.8	61.4	0.2779
Aliens	35.5	40.0	0.3924
Trees	19.0	22.0	0.1923
Shrubs	8.1	11.1	0.2370
Herbs	57.8	69.9	0.2565

between mown and unmown stands, heterogeneous patches were intermediate in richness. In fact, though the average number of species in heterogeneous patches was not significantly different than in unmown patches, heterogeneous patches did have significantly more species than mown patches ( $p = 0.01$ , Fig. 2).

Unmown stands were particularly rich in native species, shrubs and herbs (Tables 2 and 6, Figs 2 and 3). Area was the best predictor of richness of

all species groups on unmown stands (Tables 3 and 4). The richness of trees was enhanced by the number of cultivars. Disturbance was negatively correlated with richness of all groups except trees and shrubs (Table 3).

In contrast, the number of cultivars was the best predictor of species richness of all groups on mown stands (Tables 3 and 4). Cultivars represented an average of 19% (and up to 40%) of the species on mown stands. Alien herb richness was greatest on mown stands, where alien herbs were as abundant as natives (Table 2). Area correlated with richness of all groups except trees (Table 3), but only appeared in the regression model predicting herb richness (Table 4). The only species groups negatively correlated with disturbance were shrubs and herbs.

## Discussion

### *Effects of area and isolation*

Large patches, either by virtue of size or environ-

Table 6. Differences in richness between unmown and mown stands

	Unmown (LS mean) ( <i>n</i> = 19)	Mown (LS mean) ( <i>n</i> = 15)	Probability unmown = mown
Total species	67.3	91.3	0.0404
Natives	33.7	63.7	0.0004
Aliens	33.6	21.6	0.2076
Trees	17.7	17.9	0.9317
Shrubs	4.6	11.3	0.0008
Herbs	14.5	62.1	0.0527

mental heterogeneity, indeed do hold more species than smaller patches. However, isolation seems to be unimportant in determining species richness in these urban forests. Although they may be distant from other forested patches, urban patches are not isolated from species sources. Many species within the urban matrix have ready access to these stands. These compensate, at least numerically, for any losses resulting from isolation from other forests. Even the richness of native herbs and shrubs is not significantly reduced by isolation within the urban context. One concludes from these data that the theory of island biogeography (McArthur and Wilson 1967) should not be considered as a model for predicting richness in urban forest patches.

The observed relationship between species richness and area, although important, does not clarify the role of patch shape. Only the largest unmown patch sampled was large enough to contain a 2.3 ha circle, therefore large enough to contain mesic species. This patch was in fact much richer in species than the others, particularly in native species (Fig. 2) and in herbs (Fig. 3). Indeed, there were four native shrubs and 31 native herbs found in this patch which were not present in any other stand sampled. Of these, Curtis (1959) found one of the shrubs and 17 of the herbs to occur most commonly in forests or other shaded habitats.

### *Environmental heterogeneity*

The observed species/area relationship could be at least partially the result of a greater variety of en-

vironmental conditions in larger patches. Slope, the other measure of heterogeneity used, only appeared in a few of the regression models and was usually negatively related to richness. However, slope was positively related to the number of tree species on mown stands (Tables 3 and 4). In this case slope may be a better indicator of human activity than of environmental heterogeneity; stands of trees on flatter sites are more likely to be thinned to make room for picnic tables and other facilities.

Structurally heterogeneous patches are not more species rich than their homogeneous counterparts (Fig. 2 and Table 5). The richness of the heterogeneous patches is enhanced by their unmown segments and does not exceed that of homogeneous unmown patches of about the same size. However, richness of both heterogeneous and unmown patches is significantly greater than that of mown patches, which more closely resemble the interstitial forest. Thus, protecting even a very small area of forest from mowing will preserve many species. By maintaining some unmown areas within a mown park, fewer species, particularly native shrubs and herbs, are lost (Table 2 and Figs 2 and 3).

### *Human intervention*

Disturbance clearly has a significant negative impact on species richness (Tables 3 and 4). Most of this effect is likely to be attributable to mowing, since mown and unmown stands differ significantly in structure (Table 1) and richness (Table 6). However, the negative correlations between disturbance and several species richness values on mown and unmown stands respectively (Table 3) is likely to be the result of trampling alone. Natives, particularly shrubs and herbs, seem most susceptible to the effects of trampling and mowing.

On the other hand, species richness, particularly of aliens and trees, is significantly enhanced by the deliberate planting of introduced species. Even though cultivation does not compensate numerically or ecologically for lost natives, it has become the primary determinant of richness of all groups of species on mown stands (Tables 3 and 4). The number of cultivars is even the best predictor of native

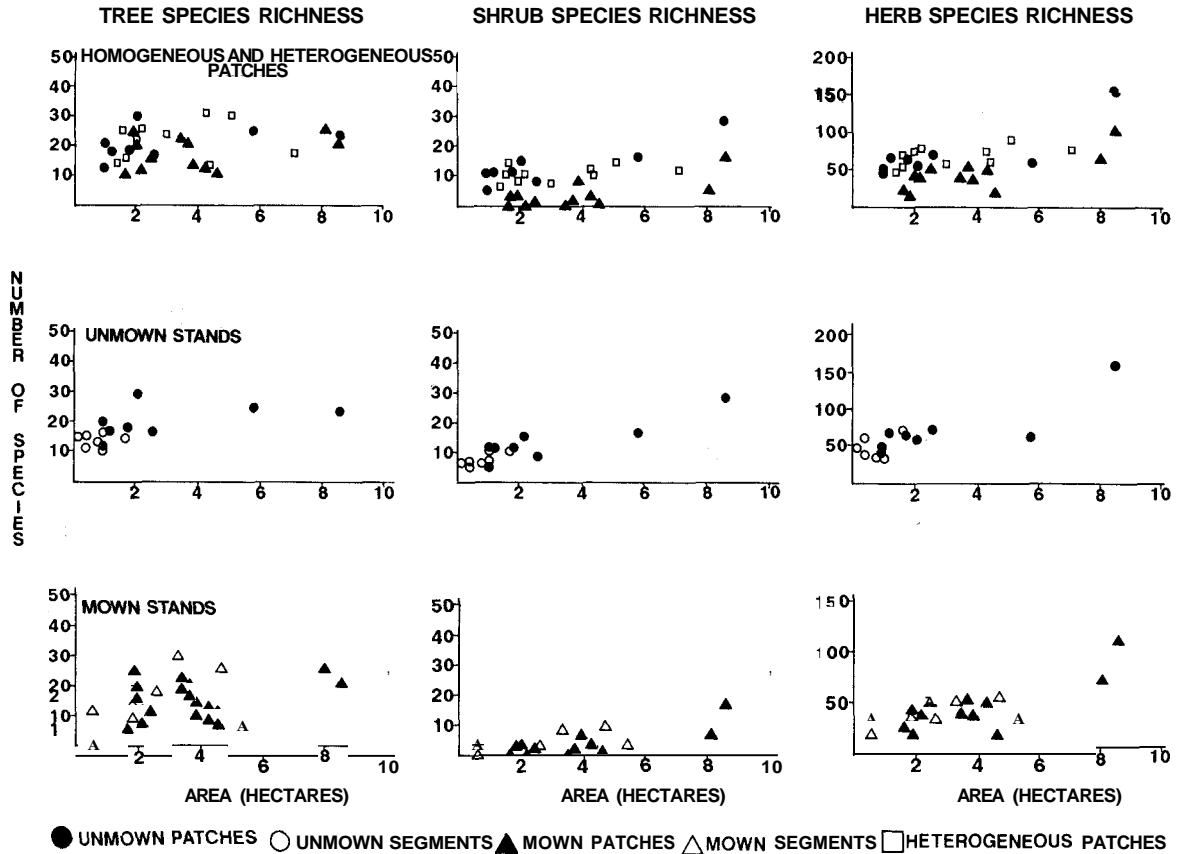


Fig. 3. Plots of species richness by individual stand area for different lifeforms.

species richness on mown stands (Table 4). This appears to support Whittaker's (1977) hypothesis that adding species to a community creates opportunities for other species as well.

### Landscape diversity

Tree species richness within these forest patches has nearly doubled by the introduction of cultivars during the nearly 140 years of urbanization (Table 2). Likewise, cultivated shrubs have increased shrub richness by 50%. However, alien herbs are the single largest group of introduced species. Most of these are weedy species which were not deliberate introductions. Although all of the alien tree and shrub species encountered were initially introduced deliberately, some have become naturalized and now behave as weeds.

The implications of the species/area relationship to landscape diversity bear examining. Clearly loss of unmown upland forest will result in species loss from the cities and probably has already done so. Although individual heterogeneous patches may be as species rich as unmown patches, they apparently simply contain more of the common native species than do mown stands. Their total richness in aggregate is still less than that of unmown stands (Table 2). Thus, increasing conversion of unmown to mown forest would result in further loss of native species from the landscape.

An analysis of richness by lifeforms indicated that tree species were least affected by mowing (Fig. 2 and Table 2). This may be the result of the greater longevity of trees, of the difficulty of removing mature trees, and of the deliberate planting of trees. Many of the planted species are natives, so that native tree species still outnumber alien tree species

even on the most disturbed sites.

Shrubs are likely to be lost from mown stands (Fig. 3 and Table 2). Native shrubs appear less likely to be planted than native trees. The result is that the richness of alien shrub species on mown stands nearly equals that of native shrubs (Table 2). Maintaining small unmown segments within heterogeneous patches helps to maintain shrub species richness in the landscape, as indicated by the richness of native shrubs on heterogeneous patches (Table 2).

Native herb richness suffers greatly from mowing (Table 2). The unmown forest habitat is critical for the survival of many herbaceous species. Heterogeneous patches preserve native herb richness to a certain extent, but a large unmown stand size is needed to include mesic species. The marked increase in herb richness by the inclusion of the largest unmown stand demonstrates this (Fig. 2). Heterogeneous patches with small unmown segments will ultimately do little to maintain the richness of native herbs in the landscape.

Clearly, the best situation for preserving landscape diversity is to leave the fragmented forest unmown. This will increase between habitat (beta) diversity (Whittaker 1977) and maximize the contrast between forest patches and the interstitial forest. However, the dense understory must be removed to provide space for picnicing and recreation. Retention of even small unmown forested parts of an urban park will help maintain species richness and preserve native species. If it is necessary to mow the entire area, shrubs can be planted to replace some of the species most affected and provide habitat for birds and other wildlife.

The preservation of shade tolerant native forest herbs requires more extreme measures. Preservation of patches of unmown upland forest large enough to contain at least a 2.3 ha circle (Levenson 1981) would be necessary. Site planning could accomplish this goal within a larger heterogeneous patch if shape is considered. However, large unmown forested patches may not meet other open space needs. In the Twin Cities forests, the understories are too dense and prickly to make human use pleasant. With increasing demand for usable open space within urban areas, such a land-consumptive option may not be desirable.

An alternative would be to utilize horticultural techniques to increase species richness. Creating a habitat for mesic herbs that is also compatible with human recreation and educational needs is certainly possible, as demonstrated by the Eloise Butler Wildflower Garden in Minneapolis. Most species on display in this garden were present in the unmown stands sampled for this study. As undisturbed forest land becomes more scarce, artificial habitats may become increasingly important for preservation of local species richness as well as landscape richness. Garden paths facilitate human travel with less damage to the forest herbs than would be possible in an unmanaged forest. Such landscaping may well be more aesthetically pleasing to most people than a natural woodland with its brambles and dense shrubs, and signs can enable visitors to learn the names of the plants. Whittaker (1977) proposed that an increase in plant species diversity may be more readily achieved than an increase in animal diversity because of the small amount of space needed by many individual plants; plants can partition habitat into a fine pattern. Thus, the species richness of such a garden would be limited to some extent by its size, but mostly by funding and the creativity of the gardeners. Both of these factors have greater potential for increase within a city than does undisturbed forested area.

## Conclusions

Species richness of unmown urban forests is primarily a function of their size. Species richness of mown forested stands is more importantly a function of the number of cultivars planted. Most of the variables which improve the ability of the regression models to predict species richness are indicators of human disturbance.

Isolation does not appear to influence species richness of forested patches within a matrix of urban land uses. This is probably because yard and street tree populations serve as seed sources for urban forest patches.

Mowing, an important form of forest disturbance in the city, greatly reduces species richness, especially of native shrubs and herbs. Structurally

heterogeneous patches, even with small unmown segments, may promote the survival of some native species, particularly shrubs. Such heterogeneous patches are not, however, more species rich than unmown patches of a comparable size, although they are significantly richer than mown patches. Moreover, species richness in these heterogeneous patches appears to be elevated simply by the inclusion of the species richer unmown segment.

These findings have important implications for design and management of urban open space. Urban landscape diversity would best be maintained or enhanced by either preservation of large areas of unmown mesic forest habitat or by deliberate planting of mesic forest herbs and shrubs in a carefully landscaped environment.

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