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Vegetation of urban wastelands in Rotterdam and the effect of human disturbance

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Sixty wastelands of Rotterdam were described in terms of plant species composition, biodiversity and succession and they were analysed for multiple geological and geographical parameters. The sites were clustered according to species composition. Significantly different environmental variables between the clusters were selected for further analysis in order to identify which abiotic factors contribute most to the presence or absence of the species. Age, zonation and human activity have the highest explanatory value for the composition of the wasteland communities. Sites towards the periphery of the city have the lowest amount of human activities. The youngest sites are situated in the centre, the recycling rate of wastelands is the fastest in the centre and decreases towards the outskirts. On sites with two human activities the number of species was higher than on sites with one, three or four human activities. This can be explained with the intermediate disturbance hypothesis. Apparently, some disturbance is beneficial to the typical urban vegetation.

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INTRODUCTION

The vegetation is a mirror for processes in the landscape. Abiotic factors such as climate, soil, nutritional status and humidity influence these processes (Wittig 1991). The distribution of plants in cultivated land such as cities and pasture is under high human influence, but even there, climate and soil type determine which plants grow where (Rebele & Dettmar 1996). Most climatic parameters in the city differ from the parameters in the surrounding area. Depending on the size of the city, its temperature is usually 2-6 degrees higher as a result of a local greenhouse effect; the city forms a heat island. As a result, the winters are less severe than in the countryside and air pressure is different, which may even cause a 10% higher precipitation in the city (Wittig 1991). The vegetation in a city (the urban flora) consists of species of very different origin. Feral ornamentals, adventives (transported unintentionally in cargo), ruderals, plants that profit from artificial habitats (wall vegetation for example) and plants that profit from the urban heat island effect live together in the urban context (Reumer 2000). So, a typical flora can develop, with its own characteristic species, both indigenous and exotic. It can be considered a young and new ecosystem that consists of species of different ecological origin (Andeweg & Florusse 2002).

Together, abiotic parameters and the urban flora and fauna form the urban ecosystem. Abiotic factors are primarily based on geological, geographical and meteorological properties of any area, but, in the city, human influence (such as building constructions, infrastructure, drainage and heat production) is added as an important set of factors (Wittig 1991). Cities have their own specific biotopes. Typical urban biotopes are public and private gardens, verges, roof tops and wastelands. Urban wastelands are defined as sites supporting semi-natural vegetation that has developed on a deposited or artificial substrate, subsequent to previous development or disturbance and with little human influence since the moment the site was abandoned. Such sites include disused railways, demolition sites and derelict land (Gilbert 1994). Wastelands are thus previously developed land. All sites have in common that they are left alone for several years and are not managed (Brown 2002; Wittig 1991). As such, urban wastelands are usually subject to redevelopment (Münch 2001). Hence, wastelands get lost, while new ones are constantly being created; this is a typical feature of the ecological cycle in cities.

Despite redevelopment, wastelands can act as an important source of species, and they thus contribute substantially to the urban biodiversity (Rothe 1971; Reumer 2000). Although it seems contradictory, rebuilding should not be prevented, because wasteland floras are essentially short-lived, as in natural high-energetic systems. A common feature of many urban wastelands is the dominance of weedy, ruderal or pioneer plant species (Denters 1999). These species are generally better in colonising disturbed environments, but they are often outcompeted during succession. Thus, constant creation and destruction of wastelands favours their presence (Wittig 1991). The total amount of wastelands can be considered as one single system. It inevitably is a habitat that continuously changes its location: it is a ‘hopping’ ecosystem (Reumer & Andeweg 1998).

In western Europe the urbanisation rate is very high and as a result the contrast between countryside and city is fading. That is the reason why nature in and around cities is becoming more and more important (Muller 2003). Urban waste communities have not yet been studied in the Netherlands. Within the Rotterdam urban area, a proper knowledge of the presence of plant and animal species, of their distribution in the urban environment, and of the factors affecting their presence and their distribution is lacking. This hampers the introduction and evaluation of policy measures concerning wasteland management. Therefore, fundamental scientific research into the distribution of organisms in the urban environment in Rotterdam is needed. The research aim is to obtain data on the occurrence of plant species in the wastelands of Rotterdam, in order to identify the most important abiotic variables that determine the floral composition.

MATERIALS AND METHODS

Data collecting

The city of Rotterdam, situated in the western part of the Netherlands, has smaller towns merged to its eastern and western boundaries, forming an urban agglomeration of over 1.1 million residents. Rotterdam is strategically situated on the river Nieuwe Maas, in which the Rhine and Meuse join together and that reaches the North Sea some 25 kilometer west of the agglomeration. The altitude of Rotterdam ranges from 3 to 1.5 m below mean sea level and the city has an area of 304.24 km^2. The city is built on fluvial, estuarine, and lacustrine Holocene deposits. Sixty wastelands within the municipality of Rotterdam were sampled in the summer of 2003 in terms of plant species composition and were analysed for various geological and geographical parameters.

The nomenclature of the plant species follows Van der Meijden *et al*. (1996). Numbers and abundances of plant species were recorded with the Tansley approach (Appendix 1). This method is very useful for a quick and accurate judgement of the vegetation (Schaminée et al. 1995). The sites were walked around and across and every plant species encountered was noted. For all 60 sites, 20 environmental variables were described, measured, analysed and calculated (Appendix 2). Six of these variables will be explained in more detail below (a-f).

a One of the measured parameters was the degree of human influence (indicated in the tables as USAGE and considered a measure of disturbance) on the sites. The number of disturbance factors present in the sites decided upon the degree of human influence. Disturbance factors were (1) dumping of rubbish, (2) dumping of construction wastes, (3) parking of cars, (4) walking the dog, (5) trampling by commuters and (6) playing children.

b The age (AGE) of the sites was another variable taken into account. Succession takes place in the time the area lies fallow and is an important factor in the species composition of a site. Every successional stage has its range of own species. As the exact age of some sites is unknown, four age categories were created: 0-2 years, 3-5 years, 6-9 years and 10 years or more.

c Zonation (ZONE) of the city was also an important variable: the most characteristic and meaningful properties of cities are buildings and surface sealing. Buildings and ground sealing are not evenly distributed over the city. The concentration of buildings decreases more or less concentrically from the centre to the periphery (Sukopp 1973; Wittig 1991). Four zone types were recognized in Rotterdam, and the zone type all wastelands belonged to, was assessed. Zone A: a site in an area of the city which is heavily built and where the ground is completely sealed; zone B: sites surrounded by many buildings in an area without complete ground sealing; zone C: sites surrounded by houses and roads and open land; zone D: sites with almost no buildings and much open ground.

d Six soil samples were taken with a 25 cm long and 13 mm wide ground drill. All six samples were mixed in the field and stored in a bag and at -18oC until further analysis. After drying and weighting the samples, their grain sizes (MEANGR) were measured. With a grain size ruler, the smallest, largest and most frequent grain sizes were observed in μm.

e The conductivity (CONDUC) was measured according to Houba *et al*. (1995) in a supernatant solution that is in equilibrium with a soil suspension. We weighed 5.00 g of air-dry soil in a shaking bottle and added 100 ml of demineralised water with a dispenser. The bottles were shaken mechanically for one hour. Then the suspension was left to settle and the conductivity of the supernatant liquid was measured.

f Plant cover percentage (COVER) is expressed in steps of 5% presence based on the visual inspections of the sites.

Statistics & analysis

Two databases were composed; one with the nominal vegetation data, which was made ordinal and the other one with the environmental variables. All nominal variables were made ordinal, and the measured variables had a quantitative scale. We used SPSS 10.0 (SPSS Inc.) for analyses. This was done to perform a hierarchical clustering with the Ward's method and Euclidean distance, Anova, a testing of the residuals of significantly different environmental variables for their normal distribution, and a Pearson correlation between the significantly different abiotic factors. The last analysis done was a stepwise logistic regression. This method determines which abiotic factors contribute most to the presence or absence of the species (Bootsma 2000). The regression was the binary logistic regression with the forward enter method and the species data had to be in the form of presence/absence. The relation obtained between the vegetation and the abiotic factors of the sites was examined in more detail, using the abiotic factors that explained most of the variance in the species data. This detailed analysis was performed in two-fold, grouping the species into different categories; (1) a native vs. alien group and (2) a group with the three urban indications (urban-depending, urban-loving and urban-neutral species according to Denters 1999). The category 'alien species' is defined as the total of all neophytes, archeophytes, adventives and feral plants (Andeweg, pers.comm.).

The distribution of the sites was analysed, regarding the different categories of abiotic factors, by plotting them on the map of Rotterdam (Fig. 1). Different diagrams were made, containing the environmental variables and the species compositions. The mean numbers of species on a site within a category were plotted. The observed trends were analysed for their significance with Anova.

RESULTS

A total of 204 species have been found on the 60 wastelands described in this study (Appendix 3). Of these, 153 were Dutch native species and 51 were alien species. The Dutch native species were all common species for the Netherlands; no species were found that are on Red Data lists or the like. The alien species were also common species for the Netherlands and are mentioned in Heukel's flora (van der Meijden 1996), except for some ornamentals like *Alcea rosea*, *Aster tradescantii*, *Lobelia inflata* and *Petunia* sp. Of the 204 species, 36 species were urban indicator species (Appendix 3; Denters 1999).

Environmental conditions

A cluster-analysis was performed with the vegetation data. As a result, the 60 sites were divided into three groups (Table 1). Sites in cluster 1 mostly contained weeds (e.g. *Chenopodium ficifolium* and *Capsella bursa-pastoris*), cluster 2 was characterised by humidity indicators (e.g. *Stellaria media* and *Phragmites australis*) and the sites of cluster 3 were depleted in nutrients (e.g. *Festuca rubra* and *Rubus fruticosus*). The species shaded on the right-hand side of Table 1 were indifferent for the growing conditions of the sites (e.g. *Artemisia vulgaris* and *Urtica dioica*). Six variables were significantly different between the clusters; AGE, USAGE, CONDUC, ZONE, MEANGR and COVER. These six variables were tested for their correlation (Table 2), and were not strongly correlated with each other in the total dataset. Cluster 1 was found to have young sites, a low coverage by plants and a high conductivity (Tables 1 and 3). Sites in cluster 2 had a low human influence, were old, had a high

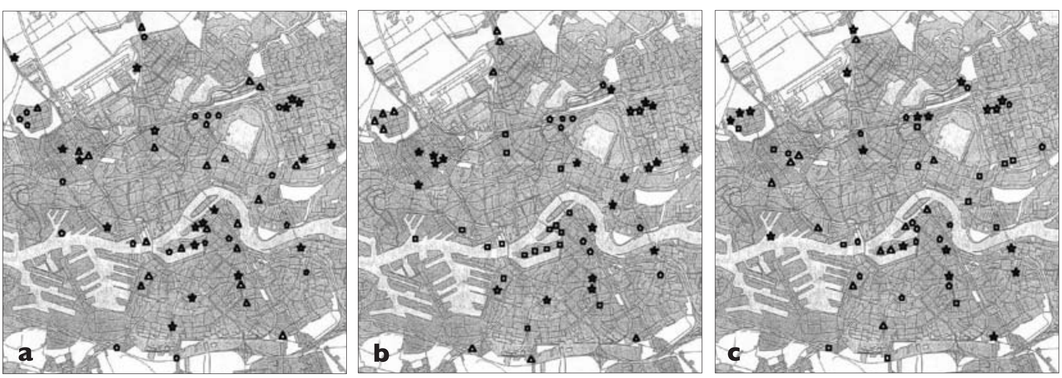

Figure 1 The distribution of the different sites over the city of Rotterdam. The triangle (Δ) represents cluster one sites, sites from zone D and sites with four humans activities (Map **a**, **b** and **c**, respectively). The pentagon (⬠) represents cluster two, zone C and three human activities. The star (☆) represents cluster three, zone B and two human activities. The square (❑) represents zone A and one human activity (Map **b** and **c**, respectively).

coverage by plants and the sites were situated in zone B. Sites in cluster 3 were characterised by an intermediate age and coverage and the sediment had a large mean grain size. The human activity on sites within clusters 1 and 3 was not different. Both cluster 1 and 3 had sites situated in zone C. Sites in clusters 1 and 2 have a low mean grain size.

Twenty-five species were selected for further analysis: five species specific for sites in cluster 1, six species of cluster 2 and four species growing on sites of cluster 3. Ten species were abundant within all three clusters (Table 1). A stepwise logistic regression was performed on these species, in order to discover those environmental variables that contribute most to the species' presence (Table 4). Only the four variables that explain most of the variance are presented in this Table 4. The two variables that are omitted (MEANGR and COVER) explained less than 0.5% of the variance. The percentage of variance explained by the first four variables ranges from 11.0% to 58.9% for the individual species. On average 27.3% of the total variance was explained. The AGE was selected for 15 species as the first explanatory variable, ZONE was selected 6 times and USAGE was selected 4 times. As the second explanatory variable, ZONE was selected for 10 species, USAGE 9 times, AGE 5 times and COVER 1 time. The USAGE was selected for 11 species as the third explanatory variable.

Table 1 Cluster analysis (Ward's method, Euclidean distance) divided the 60 wastelands in three clusters. This table shows how much of the sites within a cluster (in %) are occupied with the indicated plant species. Only the most frequent species are shown. Those are the species with a least occupancy of 30% within one cluster. Four species groups can be composed out of these clustered species: species of group 1 grow especially on sites within cluster 1, species of group 2 are more indicative of sites within cluster 2 and species of group 3 are representatives for sites within cluster 3. Group 4 contains general species, they are indifferent for their surroundings. The species that are shaded are placed in the four groups and are selected for further analysis.

names	cluster 1	cluster 2	cluster 3	names	cluster 1	cluster 2	cluster 3
Chenopodium ficifolium	95	30	35	*Artemisia vulgaris*	65	100	85
Polygonum aviculare	75	40	25	*Plantago lanceolata*	55	70	60
Sonchus oleraceus	70	30	20	*Medicago lupulina*	70	90	55
Capsella bursa-pastoris	55	20	20	*Lolium perenne*	55	70	75
Chenopodium album	50	5	5	*Equisetum arvense*	60	70	65
Plantago major	75	70	35	*Conyza canadensis*	70	85	60
Matricaria recutita	80	85	45	*Poa trivialis*	65	70	80
Melilotus albus	45	70	35	*Urtica dioica*	65	65	55
Potentilla anserina	15	70	30	*Tussilago farfara*	55	65	60
Oenothera biennis	20	60	30	*Trifolium repens*	45	60	50
Stellaria media	20	60	30	*Cirsium arvense*	70	75	70
Phragmites australis	5	55	20	*Crepis capillaris*	55	75	85
Potentilla reptans	15	55	15	*Rumex acetosa*	70	80	75
Phleum pratense	15	50	30	*Taraxacum officinale*	75	40	55
Senecio jacobea	30	60	75	*Diplotaxis tenuifolia*	65	40	50
Holcus lanatus	15	85	70	*Achillea millefolium*	25	60	45
Agrostis gigantea	25	15	60	*Trifolium pratense*	35	60	50
Festuca rubra	20	50	90	*Hordeum murinum*	50	25	55
Epilobium hirsutum	20	35	70	*Ranunculus repens*	25	55	40
Vicia sepium	20	35	60	*Convolvuluus arvensis*	40	35	50
Rubus fruticosus	25	30	55	*Cirsium vulgare*	40	40	35
				Symphytum officinale	20	45	35
				Glechoma hederacea	30	25	35
				Sisymbrium officinale	30	20	25

Human activity
Human activity was one of the environmental variables that explained most of the variance in the species data, together with zonation and age. Human activity, zonation and the differentiation of the species data in some biological groups (Appendix 1; native vs. alien and urban indications) were used to examine the relations in more detail.

Figure 1 shows the distribution of the clustered sites, the distribution of the sites according to the zonation and the distribu-

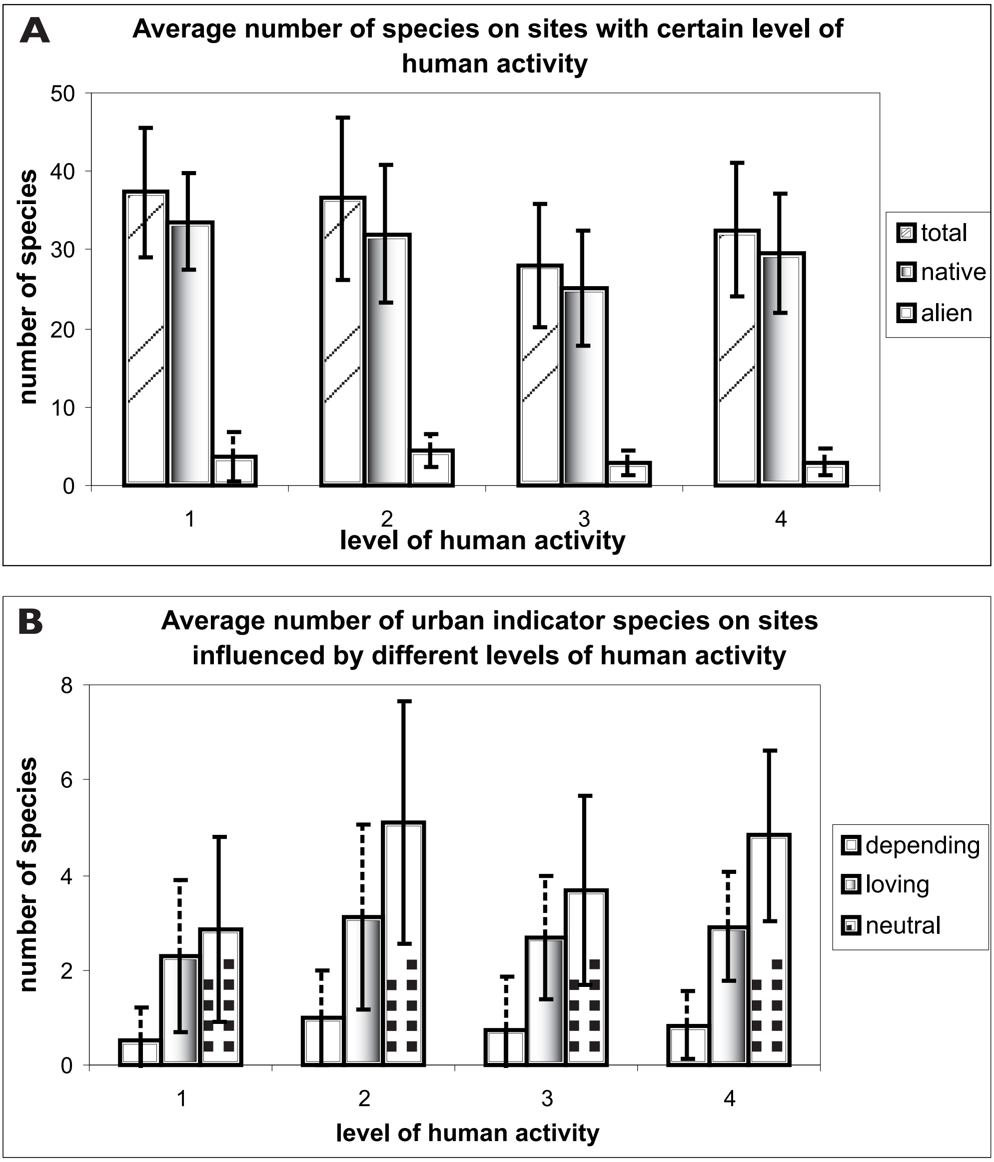

Figure 2 These diagrams show the average number of species on a site. The sites were judged for their level of human activity (Figure 1**c**). The species were classified in two biological groups (Appendix 3); native-alien (Figure 2A) and urban indicators (Figure 2B). The error bars indicate the standard deviation of the average number of species. The categories with an hatched error bar have no significant difference in average number of species on the sites between the four classes (p<0,05).

Table 2 Pearson correlation matrix of the selected variables.

all sites					
AGE	-0,18				
USAGE	-0,15	-0,22			
ZONE	0,04	-0,36	0,37		
MEANGR	-0,33	-0,14	0,38	0,39	
COVER	0,10	0,42	-0,44	-0,38	-0,55
	CONDUC	AGE	USAGE	ZONE	MEANGR

tion of human activity in Rotterdam. The clustered sites were distributed randomly; all three clusters were present in both centre and periphery of the city (Figure 1A). What could be seen from the human activity distribution was that sites with only one human activity (Figure 1C) were present within all clusters, but sites with one human activity were no sites of zone A, only of zones B, C and D. The sites with two human activities were present within all clusters and within all zones. Three human activities could be found on sites within all clusters, but not on sites with zone D. The sites with four human activities were present on the left side of the map, within all clusters, but not on sites with zone C.

Figure 2 shows that there is also a difference in average number of species on the sites between the four classes of human activity. The average of the total number of species is higher ($\bar{x}$=36) on a site with USAGE level 1 and 2 and is low ($\bar{x}$= 30) on sites with levels 3 and 4 (Figure 2A). Thus, the total number of species decreases with increasing human influence. The average number of native species is also higher ($\bar{x}$= 30) on sites with USAGE levels 1 and 2, and relatively low ($\bar{x}$= 28) on sites with levels 3 and 4. There is an average difference of 2 species on a site between high and low human influences. For alien species, the respective numbers are $\bar{x}$ = 5 and $\bar{x}$ = 3. The alien species thus also have an average difference of 2 species on a site with high and low human influences.

The average number of urban-neutral species fluctuates significantly from low on sites with levels 1 ($\bar{x}$= 3) and 3 ($\bar{x}$= 4) to high numbers on sites with level 2 and 4 (both with $\bar{x}$ = 5). The same fluctuations are shown for the average numbers of urban-loving ($\bar{x}$= 2) and urban-depending species ($\bar{x}$= 1), but the fluctuations are not significant (Figure 2B). The average number of wind-dispersed

Table 3 Mean values with their standard deviations of the environmental variables in the study areas. Each cluster contained 20 sites. * Indicates that the difference between the clusters is significant (Anova, p < 0.05).

	USAGE * (n$_o$. of factors)	AREA (m^2)	AGE * (classes)	SEA (distance in km.)	ZONE * (1-4)
Cluster 1	2,70 ± 0,9	597,00 ± 649,5	3,10 ± 1,4	31,96 ± 2,3	2,85 ± 1,1
Cluster 2	1,95 ± 0,1	657,25 ± 514,9	4,45 ± 1,8	31,01 ± 3,4	2,25 ± 1,1
Cluster 3	2,70 ± 1,1	749,25 ± 569,2	3,85 ± 1,5	32,45 ± 3,7	3,00 ± 0,9

	COVER * (%)	MOIST (%)	OM (%)	PH	CONDUC * (µS)
Cluster 1	67,25 ± 26,8	12,01 ± 11,3	7,43 ± 10,4	7,55 ± 0,4	102,95 ± 78,5
Cluster 2	83,75 ± 20,4	10,19 ± 7,8	5,21 ± 5,3	7,63 ± 0,2	69,65 ± 18,0
Cluster 3	75,25 ± 25,1	8,13 ± 4,8	4,49 ± 3,7	7,64 ± 0,3	65,50 ± 22,6

	RIVER (distance in km.)	SOIL (3 types)	MEANGR * (µm)	RANGR (µm)
Cluster 1	2,07 ± 1,7	2,3 ± 0,7	182,63 ± 94,0	856,55 ± 488,4
Cluster 2	2,31 ± 1,8	2,3 ± 0,7	177,38 ± 61,1	901,40 ± 499,4
Cluster 3	2,26 ± 1,9	2,4 ± 0,7	241,50 ± 139,6	1001,20 ± 516,1

Table 4 Environmental variables explaining the occurrence of 26 selected species. The total variance of each variable was determined with a stepwise logistic regression. The percentage of total variance in species data that is explained by the variable is given. In the last column the cumulative percentage of the variance explained by the four variables is given.

Species	1st	%	2nd	%	3rd	%	4th	%	total %
cluster1									
1. *Capsella bursa-pastoris*	age	23,1	zone	8,7	usage	6,7	meangrain	0,14	38,6
2. *Chenopodium album*	age	23,0	zone	17,1	usage	5,7	cover	0,30	46,1
3. *Chenopodium ficifolium*	age	17,5	usage	5,1	zone	1,3	cover	0,18	24,1
4. *Polygonum aviculare*	age	12,0	usage	7,6	zone	6,0	conduc	0,12	25,7
5. *Sonchus oleracea*	age	15,2	zone	4,0	usage	13,7	cover	0,15	33,1
cluster2									
6. *Melilotus albus*	zone	7,7	age	7,5	usage	5,5	cover	0,3	21,1
7. *Oenothera biennis*	age	18,6	usage	1,5	conduc	0,9	cover	0,4	21,3
8. *Phragmites australis*	usage	7,6	age	5,9	zone	4,9	cover	0,6	19,0
9. *Potentilla anserine*	zone	31,7	age	12,5	usage	7,4	cover	1,7	53,3
10. *Potentilla reptans*	age	5,9	zone	3,7	usage	2,2	cover	0,6	12,5
11. *Stellaria media*	age	11,3	zone	5,6	usage	1,9	cover	0,6	19,3
cluster3									
12. *Epilobium hirsutum*	usage	18,8	zone	12,5	age	11,3	cover	0,6	43,2
13. *Festuca rubra*	age	9,3	cover	0,7	zone	0,6	usage	0,3	11,0
14. *Rubus fruticosus*	age	10,6	usage	0,8	zone	0,8	conduc	0,7	12,8
15. *Vicia sepium*	usage	12,8	age	3,5	zone	2,0	conduc	0,3	18,5
all sites									
16. *Artemisia vulgaris*	age	37,2	zone	15,7	usage	5,8	meangrain	0,1	58,9
17. *Conyza canadensis*	age	9,2	zone	5,8	usage	1,3	cover	0,05	16,3
18. *Equisetum arvensis*	age	7,6	usage	7,1	zone	1,4	cover	0,4	16,5
19. *Lolium perrene*	age	12,7	zone	10,1	usage	5,7	cover	0,5	29,0
20. *Medicago lupulina*	zone	14,7	age	2,9	usage	2,2	conduc	1,6	21,5
21. *Plantago lanceolata*	age	21,9	usage	4,5	zone	3,9	meangrain	0,1	30,5
22. *Poa trivialis*	zone	9,0	usage	7,0	age	3,0	cover	0,2	19,1
23. *Trifolium repens*	zone	29,5	usage	17,2	age	5,2	cover	1,2	53,1
24. *Tussilago farfara*	usage	10,3	zone	8,5	conduc	1,0	Age	0,3	20,1
25. *Urtica dioica*	zone	9,2	usage	7,7	cover	0,5	conduc	0,3	17,7

species is high on sites with levels 1 and 2 (both $\overline{x} = 9$) and the numbers are lower on sites with levels 3 and 4 (both $\overline{x} = 8$).

DISCUSSION

Like in any other ecosystem, abiotic climate parameters and the flora and fauna present form the urban ecosystem. The abiotic factors are primarily based on geological, geographical and meteorological properties of an area, but in the city human influence is added as an important set of factors (Wittig 1991). The wastelands of Rotterdam were described in terms of species composition and biodiversity and they were analysed for multiple geological and geographical parameters and human influences.

The research question to be answered was: What are the most important abiotic variables that determine the nature of the waste communities? Sixteen species in three clusters as well as ten ubiquist species were selected for analysis (Table 1). There are differences in environmental variables between the clusters (Table 2). A stepwise logistic regression was necessary to determine what variables contributed most to the presence of the species (Table 4). Cover, conductivity and mean grain size had a low explanatory value for the occurrence of the selected plant species. Age, zonation and human activity have the highest explanatory value for the occurrence of the selected plant species. These are the variables that contribute most to the difference in species composition of the wasteland communities. The clustered sites were distributed evenly over the city (Fig. 1). In general, it can be said that the sites closest to the urban periphery show the lowest amount of human activities. The less buildings and ground sealing there are, the less human influence.

This study found that the total number of species on a site, the number of native species and the number of alien species all were highest on sites with intermediate disturbance. On sites with one or two human activities the number of species were higher compared to sites with three or four human activities (Fig. 2A). Also, the urban indicator species had the highest numbers of species on sites with two human activities (Fig. 2B). Different researchers found this same pattern: highest species numbers on intermediately disturbed sites (Maurer *et al*. 2000; Zerbe *et al*. 2002). In another paper concerning a similar matter, Lake & Leishman (2004) stated that invasion of natural ecosystems by exotic species is dependent on the amount of disturbance. Too much disturbance will decrease the number of species present, and a very low disturbance does not support a lot of species either.

Lake & Leishman (2004) investigated the effect of different disturbance types on natural ecosystems in terms of native and exotic plant species diversity. No exotic species were found on undisturbed control sites. Species richness was higher on intermediately disturbed sites, while native species richness decreased. Exotic species had invaded the disturbed sites abundantly. Species richness decreased at sites with high disturbance, but the native species richness decreased dramatically and the number of exotic species was somewhat lower as observed in intermediately disturbed sites.

All studies (Maurer et al. 2000; Zerbe *et al.* 2002; Lake & Leishman 2004; this report) share the conclusion of high numbers of species on intermediately disturbed sites. Huston (1979) developed the intermediate disturbance hypothesis. This hypothesis states that diversity will be highest at sites with an intermediate disturbance that prevents competitive exclusion, and that it will be lower at sites that have experienced either very high or very low disturbance (Huston 1979). Under conditions where the growth rates of competitors are low, that means a low rate of competitive displacement, diversity will be low at minimum disturbance. This is because the time period is sufficient to approach competitive equilibrium. An increase in the disturbance (sufficient enough to prevent competitive equilibrium) will allow maximum diversity, and the diversity will then decrease as the disturbance rises and some competitors are unable to recover (Huston 1979; Schwilk *et al.* 1997). The intermediate disturbance theory holds both for natural ecosystems (Zerbe *et al.* 2002; Lake & Leishman 2004) as for the 'hopping ecosystems' in man-made environments (Kowarik 1990; Maurer *et al.* 2000; this report). Apparently, some limited disturbance is beneficial to the typical urban vegetation found on wastelands.

CONCLUSION

1 Age, zonation and human activity have the highest explanatory value for the composition of the urban wasteland communities in Rotterdam.

2 There are several types of wasteland communities, and these communities are determined by the differences in abiotics of the sites.

3 Typical cosmopolitan species as well as typical urban species were found on the wastelands of Rotterdam.

4 The sites follow the concentric model. Sites towards the periphery of the city have the lowest amount of human activities. The youngest sites are situated in the centre, as the recycling rate of wastelands is faster in the centre and decreases towards the outskirts.

5 The number of species was higher on sites with two human activities in comparison to sites with one, three or four human activities. This can be explained by the intermediate disturbance hypothesis.

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APPENDIX 1

Tansley's nine points abundance scale, with the nominal scale abbreviations and the ordinal number for each category and the category explanations.

nominal scale	abbreviations	ordinal scale	
dominant	c	9	species dominant
co-dominant	cd	8	species dominant together with other dominant species
abundant	a	7	species is present everywhere, but not dominant
local abundant	la	6	species is only on a certain area within the site abundantly present
frequent	f	5	species is numerous
local frequent	lf	4	species is only on a certain area within the site frequently present
occasional	o	3	species is present, but scattered
rare	r	2	species is rare
sporadic	s	1	species very rare, only a few individuals present

APPENDIX 2

List of abiotic factors with their explanation and scale.

Abiotic factors	Explanation	Scale
Reason	Reason of lying fallow	Cleared land, demolition sites, forgotten building site, old railway yard
Usage	Number of human influence factors on a site	Six possible factors: rubbish dumping, dumping construction wastes, car parking, walking the dog, trampling by forensic people, playing children
Relief	Differences in altitude within a site	Measured in meters
Area	Size af a site	Measured in squared meteres
Age	Number of years a site has laid fallow	Divided in four age categories: 0-2, 3-5, 6-9, 10>
Sea	Distance towards the North Sea coast	Measured in kilometers
Zone	Place of a site within the city	The city was divided in four zones: zone A to D
River	Shortest distance to the riverbank	Measured in kilometers
Position	Position north or south of the river	Tow classes: north and south
Subsoil	Holocene sediment type a site is build on	Swale, sea, peat, channel or mud-flat sediments
Build	Type of deposited material for new buildings	Sand or garden material or a mixture
Soil	Substrate composition o the sites	Sand, loam and clay
Meangr	Mean grainsize of the sediment	Measured in micrometers
Ranggr	The range of grainsizes witin the sediment	Measured in micrometers
Cover	Percentage of vegetation cover	Estimated in steps of 5%
Sun	Percentage of direct sunlight during the day	Estimated in steps of 5%
OM	Percentage of organic matter in the sediment	Measured
pH	pH value of the sediment	Measured
Conduc	Conductivity of the sediment	Measured
Moist	Percentage of moist in the sediment	Measured

APPENDIX 3

Species list, with their biological indications; native vs. alien plant species and the different urban indications.

nr	Species names	native	alien				urban indicators		
			neophyte	wild	adventive	archeophyte	depending	loving	neutral
1	*Acer campestre*	x							
2	*Acer pseudoplatanus*		x						
3	*Achillea millefolium*	x							
4	*Agrostis gigantea*	x							
5	*Agrostis stolonifera*	x							
6	*Alcea rosea*			x					
7	*Alchemilla mollis*			x					
8	*Alliaria petiolata*	x							
9	*Alnus glutinosa*	x							
10	*Amelanchier lamarckii*		x						
11	*Ammi majus*				x		x		
12	*Ammi visnaga*				x				
13	*Anagallis arvensis*	x							
14	*Anethum graveolens*			x					
15	*Anisantha sterilis*	x							
16	*Anisantha tectorum*	x							
17	*Anthriscus sylvestris*	x							
18	*Anthyllis vulneraria*	x							
19	*Arctium lappa*	x							
20	*Arctium minus*	x							
21	*Arrhenatherum elatius*	x							
22	*Artemisia vulgaris*	x							
23	*Aster tradescantii*			x					
24	*Bellis perennis*	x							
25	*Betula pendula*	x							
26	*Bidens tripartita*	x							
27	*Brassica nigra*	x							
28	*Brassica oleracea*			x					
29	*Brassica rapa*		x						
30	*Bromus hordeaceus*	x							
31	*Buddleja davidii*		x				x		
32	*Buxus sempervivum*			x					
33	*Capsella bursa-pastoris*	x							x
34	*Cardamine flexuosa*	x							
35	*Carduus crispus*	x							
36	*Carex hirta*	x							
37	*Centaurea cyanus*								
38	*Centaurea jacea*	x				x			
39	*Chamerion angustifolium*	x							
40	*Chaenorinhum minus*	x							
41	*Chenopodium album*	x							x
42	*Chenopodium ficifolium*	x							
43	*Cirsium arvense*	x							
44	*Cirsium vulgare*	x							
45	*Consolida hispanica*			x					
46	*Convolvulus arvensis*	x							
47	*Conyza canadensis*		x						x
48	*Corispermum intermedium*		x				x		
49	*Cornus sanguinea*	x							
50	*Coronopus didymus*		x						
51	*Corylus avellana*	x							

APPENDIX 3 (continued)

Species list, with their biological indications; native vs. alien plant species and the different urban indications.

nr	Species names	native	alien				urban indicators		
			neophyte	wild	adventive	archeophyte	depending	loving	neutral
52	*Cotoneaster sp*			x					
53	*Crataegus monogyna*	x							
54	*Crepis capillaris*	x							
55	*Dactylis glomeratus*	x							
56	*Diplotaxis muralis*	x					x		
57	*Diplotaxis tenuifolia*	x						x	
58	*Dipsacus fullonum*	x							
59	*Elytrigia repens*	x							
60	*Eupatorium cannabinum*	x							
61	*Euphorbia helioscopia*	x							
62	*Euphorbia peplus*	x							
63	*Epilobium ciliatum*		x					x	
64	*Epilobium hirsutum*	x							
65	*Epilobium parviflorum*	x							
66	*Epilobium* sp.	x							
67	*Equisetum arvense*	x							
68	*Equisetum palustre*	x							
69	*Erigeron annuus*		x						
70	*Erophila verna*	x							
71	*Eruca vesicaria*				x				
72	*Erysimum cheiranthoides*	x					x		
73	*Fallopia convolvulus*	x							
74	*Festuca arundinacea*	x							
75	*Festuca rubra*	x							
76	*Fraxinus excelsior*	x							
77	*Galinsoga quadriradiata*		x					x	
78	*Galium aparine*	x							
79	*Geranium* sp.	x							
80	*Geranium dissectum*	x							
81	*Geranium purpureum*		x				x		
82	*Glechoma hederacea*	x							
83	*Gnaphalium uliginosum*	x							
84	*Helianthus annuus*			x					
85	*Heracleum sphondylium*	x							
86	*Hirschfeldia incana*		x						
87	*Holcus lanatus*	x							
88	*Hordeum murinum*	x							x
89	*Hypericum perforatum*	x							
90	*Hypochaeris radicata*	x							
91	*Hyssopus officinalis*			x					
92	*juncus articulatus*	x							
93	*Juncus bufonius*	x							
94	*Juncus compressus*	x							
95	*Juncus effusus*	x							
96	*Lactuca sativa*			x					
97	*Lactuca serriola*	x						x	
98	*Lamium album*	x							
99	*Lamium purpureum*	x							
100	*Lapsana communis*	x							
101	*Lappula squarrosa*								
102	*Lathyrus pratensis*	x			x				

APPENDIX 3 (continued)

Species list, with their biological indications; native vs. alien plant species and the different urban indications.

nr	Species names	native	alien				urban indicators		
			neophyte	wild	adventive	archeophyte	depending	loving	neutral
103	*Leontodon autumnalis*	x							
104	*Leontodon saxatilis*	x							
105	*Lepidium ruderale*	x					x		
106	*Leucanthemum vulgare*	x							
107	*Linaria vulgaris*	x							
108	*Lobelia inflata*			x					
109	*Lolium perenne*	x							x
110	*Lotus* sp.	x							
111	*Lycopus europaeus*	x							
112	*Lysimachia punctata*			x					
113	*Lythrum hyssopifolia*				x		x		
114	*Lythrum salicaria*	x							
115	*Malva moschata*	x							
116	*Malva sylvestris*	x							
117	*Matricaria discoidea*		x						x
118	*Matricaria recutita*	x							
119	*Matricaria* sp.								
120	*Medicago lupulina*	x							
121	*Medicago sativa*			x					
122	*Melilotus albus*	x						x	
123	*Melilotus altissimus*	x						x	
124	*Melilotus officinalis*	x							
125	*Myosotis arvensis*	x							
126	*Oenothera biennis*		x					x	
127	*Papaver rhoeas*				x				
128	*Persicaria maculosa*	x							
129	*Petasites hybridus*	x							
130	*Petunia* sp.			x					
131	*Phalaris arundinacea*	x							
132	*Phleum pratense*	x							
133	*Phragmites australis*	x							
134	*Plantago lanceolata*	x							
135	*Plantago major*	x							x
136	*Poa annua*	x							x
137	*Poa trivialis*	x							
138	*Polygonum aviculare*	x							x
139	*Populus nigra*	x							
140	*Potentilla anserina*	x							
141	*Potentilla norvegica*				x				
142	*Potentilla reptans*	x							
143	*Prunela vulgaris*	x							
144	*Pulicaria dysenterica*	x							
145	*Quercus robur*	x							
146	*Rapistrum rugosum*	x	x					x	
147	*Ranunculus repens*	x							
148	*Ranunculus sceleratus*	x							
149	*Rorippa palustris*	x							
150	*Rorippa sylvestris*	x							
151	*rosa* sp.	x							
152	*Rubus fruticosus*	x							
153	*Rumex acetosa*	x							

APPENDIX 3 (continued)

Species list, with their biological indications; native vs. alien plant species and the different urban indications.

nr	Species names	native	alien				urban indicators		
			neophyte	wild	adventive	archeophyte	depending	loving	neutral
154	*Rumex acetosella*	x							
155	*Salix caprea*	x							
156	*Salix* sp.	x							
157	*Sambucus nigra*	x							
158	*Scrophularia auriculata*	x							
159	*Sedum acre*	x							
160	*Sedum reflexum*	x							
161	*Senecio inaequidens*		x					x	
162	*Senecio jacobea*	x							
163	*Senecio vicosus*	x						x	
164	*Senecio vulgaris*	x							x
165	*Silene dioica*	x							
166	*Silene latifolia*	x							
167	*Sinapsis arvensis*	x							
168	*Sisymbrium officinale*	x							x
169	*Solanum dulcamara*	x							
170	*Solanum lycopersicum*		x						
171	*Solanum nigrum schultesii*		x				x		
172	*Solidago gigantea*		x					x	
173	*Sonchus asper*	x							
174	*Sonchus oleraceus*	x							
175	*Stachys palustris*	x							
176	*Stellaria aquatica*	x							
177	*Stellaria media*	x							x
178	*Symphoricarpos albus*			x					
179	*Symphytum officinale*	x							
180	*Tanacetum vulgare*	x							
181	*Taraxacum officinale*	x							x
182	*Thlaspi arvense*	x							
183	*Thymus vulgaris*			x					
184	*Tilia* sp.			x					
185	*Tragopogon pratensis pratensis*	x							
186	*Trifolium arvense*	x							
187	*Trifolium dubium*	x							
188	*Trifolium pratense*	x							
189	*Trifolium repens*	x							
190	*Tripleurospermum maritimum*	x							
191	*Triticum aestivum*			x					
192	*Tropaeolum majus*			x					
193	*Typha latifolia*	x							
194	*Tussilago farfara*	x							
195	*Ulmus* sp.	x							
196	*Urtica dioica*	x							
197	*Verbena officinalis*	x						x	
198	*Veronica arvensis*	x							
199	*Vicia cracca*	x							
200	*Vicia sepium*	x						x	
201	*Viola canina*		x						
202	*Viola rupestris*		x						
203	*Vulpia muyros*	x					x		
204	*Xanthium strumarium*		x						

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