

# Landscape indices describing a Dutch landscape

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Keywords: pattern indices, land use development, quantification of changes in landscape pattern, dominance index, shape index, rate of change

## Abstract

The data set of a human modified Dutch landscape was used to evaluate whether landscape pattern indices developed in the United States are fit to describe a Dutch landscape. The grid based data set contains the development of land use over the period 1845–1982. The indices were divided in two groups: pattern indices and change indices. In the first group the proportion of each land use type (P), patch number (N), mean patch size (A) and two indices of patch shape (S1 and S2) were tested; in the second group the rate of change (C) was tested.

Not all indices considered in this case study are suitable for the Dutch landscape. The dominance index (D) seems not to be sensitive enough to respond in a clear way to changes in the landscape studied. Shape index seems to be a complicated index, particularly in a human modified landscape like the Dutch, where the shape of natural patches is fixed by their man-made neighbours. The trends observed in the two shape indices considered in this study are not satisfactory since each index considers another aspects of shape (either the interior-to-edge ratio or the complexity of the patch perimeter).

None of the indices appears to give information on changes in the geographical position of the patches, which implies that nothing can be induced with respect to the real landscape dynamics.

The indices have to be considered in combination to produce meaningful information. The combination of proportion of each land use (P) and the data of the transitions shows how the development in land use has been. Number of patches (N) together with the mean size of patches (A) gives a good indication of the pattern development.

Further research is necessary to develop a useful method how to quantify the change in landscape pattern and to give an ecological meaning to the index value in relation to the process of changing pattern.

## Introduction

Landscape pattern is a mixture of natural and human-managed patches that vary in size, shape, and arrangement and is the result of complex interactions of physical, biological, and social forces (Burgess and Sharpe 1981; Forman and Godron 1986; Krummel *et al.* 1987; Turner 1987c, 1990).

On its turn, landscape pattern may influence a variety of ecological processes.

It is known that changes in area, shape and connectivity of the patches cause changes in species richness, distribution and persistence of populations, and probability of disturbance (Fahrig and Merriam 1985; Franklin and Forman 1987; Freeman and Merriam 1986; Van Dorp and Opdam 1987).

It may therefore be stated that understanding the ecological principles of changing pattern is important for nature conservation and landscape planning.

The first step to understand the ecological principles is quantification of change in landscape pattern.

This quantification can be done in several ways: first, by describing the change in words, secondly, by means of maps and graphic illustrations, and thirdly, by means of indices. This last method has recently developed and gives opportunity to treat the data statistically and to compare patterns on different scales.

Several indices are already developed (*e.g.*, Iverson 1988; Forman and Godron 1986; Turner and Ruscher 1988; O'Neill *et al.* 1988). Many of these indices are applied on data sets that cover larger areas in the United States. Whether these indices can be used in small areas with fine-grained pattern is unclear, nor has there been reported any comparison between the various indices.

The aim of this paper is to evaluate whether indices developed in the United States can describe a Dutch landscape. Therefore several indices are calculated, irrespective of their ecological meaning. A Dutch data set is used, which covers the change in land use over a period of about 140 years in a relatively small area with a fine-grained pattern.

First the indices treated in this study will be focussed on. Then study area and land use development will be described. Finally the observed trends in values of the indices will be discussed separately and in combination.

## Indices of landscape pattern

### Introduction

In this paper two groups of indices are distinguished: pattern indices and change indices. Pattern indices describe the mosaic of a landscape of one area or at one moment. These indices are the so-called condition parameters. Some of these indices give information on the contents of the mosaic (*e.g.*, proportion of each legend type), other indices give information on the shape of the mosaic (*e.g.*, mean

size or shape of the patches). Change indices are indices that give information on changes in the mosaic through time, the so-called process parameters. They are calculated using the values of a pattern index at different times (*e.g.*, rate of change).

### Pattern indices

Five pattern indices are considered:

1. P = the proportion of each legend type,
2. N = number of patches,
3. A = mean size of patches,
4. S = mean patch shape index,
5. D = dominance index.

Changes of P in time give information on the increase or decrease in area of a legend type. The index gives no information on changes in geographical position. So, when the position of a legend type is changed entirely but the proportion of the legend type has remained equal, P will have the same value.

Number of patches (N) and mean size of patches (A) are direct information on the landscape pattern.

Dominance index (D) measures the extent to which one or a few legend types dominate the landscape (O'Neill *et al.* 1988). It is calculated by

$$D = \ln c + \sum (P_k * \ln P_k)$$

where c is the total number of legend categories and P<sub>k</sub> is the proportion of the landscape in category k. The index gives no information on which legend type is dominant. Large values of D indicate landscapes that are dominated by one or a few land use types in a further heterogeneous landscape. A value close to 0 indicates the land use types cover equal surfaces.

Shape index can be expressed in a meaningful way by the area and perimeter of a patch since community and population characteristics differ between patch interior and patch edge (Fahrig and Merriam 1985; Forman and Godron 1986; Freemark and Merriam 1986; Howe 1984; Van Dorp and Opdam 1987). Although a large number of indices based on the perimeter-to-area ratio is available (*e.g.*, Davis 1986; Forman and Godron 1986; Iverson 1988), in this case study only two relatively simple indices have been selected. Most other shape indices can be considered as derived from these.

The first shape index ( $S1$ ) is calculated as the average of the perimeter-to-area ratio (Iverson 1988) of all patches of a legend type:

$$S1 = 1/Ni1 * \Sigma (li/ai)$$

where  $Ni1$  is the number of patches of legend category  $i$  in map 1,  $li$  the perimeter and  $ai$  the area of each patch in category  $i$ . The index measures mean perimeter-to-area ratio of a legend type. A high value of  $S1$  indicates relatively many patches with small interiors.

The second shape index ( $S2$ ) is based on the fact that an isodiametric patch (circular or square) contains the most patch interior (Forman and Godron 1986). Shape index  $S2$  is calculated as the deviation of a registered patch from an isodiametric patch with the same area (Forman and Godron 1986). So this shape index is calculated as the average of this deviation for all the patches of a legend type:

$$S2 = 1/Ni1 * \Sigma (li/4\sqrt{ai})$$

where  $Ni1$  is the number of patches of category  $i$  in map 1,  $li$  the perimeter and  $ai$  the size of each patch in the category. If the landscape is composed of isodiametric patches,  $S2$  will be small, approaching 1.00. The more  $S2$  deviates from 1.00 the more the patches deviate from a isodiametric shape. Shape index 2 is comparable with the particular fractal dimension used by O'Neill (1988) and Turner (1987). Fractal dimension also is a measure of the complexity of patch perimeter as compared to a perfect square or circle (Iverson 1988).

### Change indices

One change index is considered: rate of change of each legend type in each period ( $C$ ). This index is calculated in terms of ha/year/km<sup>2</sup> (Sharpe *et al.* 1982) by the formula

$$C = ((pk2 - pk1)/(t2 - t1))/n$$

where  $(pk2 - pk1)$  is the difference in ha of category  $k$  in the period of time 1–time 2;  $t2 - t1$  is the difference in years between time 2 and time 1 and  $n$  is the total surface area in square km of the study area. The index ( $C$ ) indicates the rate of increase or decrease in area of that legend type and gives no in-

formation on the rate of change in geographical position.

### Study area and development of land use

The study area is a well documented area in the northern part of the Veluwe region, in the central Netherlands (Fig. 1). This part of the Netherlands is geomorphologically characterized by ice-pushed ridges and fluvio-glacial deposits, partly covered by Pleistocene and Holocene aeolian sands (Koster 1978). Nutrient-poor sandy soils, thick humous pluggen soils and humous-rich podzolic soils are the main soil types to be distinguished.

Originally, the landscape of the Veluwe was covered by mixed deciduous forest. Due to occupation and reclamation of forest for agricultural purposes in the period AD 800–1100 the forest area gradually decreased to make place for heathland (Vervloet 1977). At some places even aeolian drift sand areas originated, due to the combined effect of anthropogenic influences (growing population) and a cli-

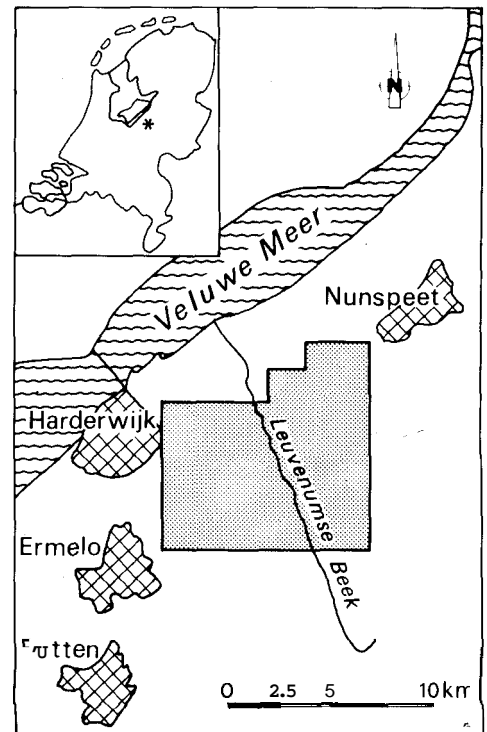


Fig. 1. The asterisk resp. the fine pointed area illustrate the position of the sample area in the Netherlands.

matic warming in the Early Middle Ages (11th–14th century, cf. Lamb 1984).

After deforestation the agricultural system changed from a stock-farming system into a system of arable farming known as 'potstal-system' (Pape 1970). This is a mixed farming system characterized by small fields and extensive areas of common heathlands. To fertilize the originally humus-poor podzolic soil the fields were almost yearly supplied with a mixture of manure and sods, litter or sand. Manure was collected from cattle and sheep grazing the extensive areas of common heathlands. The heathland was also used to gather sods, litter and sand (Vervloet 1977).

Due to intensive use of the heathlands vegetation cover locally disappeared and extensive drift-sand areas arose. Although already reported in the 10th and 11th century, the problem of drifting sand is reported more frequently since the 15th century. For long times the techniques used for stabilizing blown sands were hardly successful. At the end of the 19th century the Dutch State became concerned with the defence against drifting sands. By planting (mainly) pine-forest and drift-sand areas decreased in size and number (Vervloet 1977).

With the introduction of artificial fertilizers and cheap wool from Australia at about the same time the use of sheep and sheep-manure was no longer necessary. The extensive heathlands were no longer an essential part of the agricultural system. At that time only 500 km<sup>2</sup> of woodland (1 percent of the nation's area) was left (Harms and Opdam 1990). Large heathland re-forestation programs were started resulting in the present landscape of the Veluwe which is covered by coniferous plantations and has small relict-patches of heathland and drift-sand areas (Vervloet 1977).

## Methods

Eight topographical map editions from 1845 to 1982 at the 1:50,000 scale were studied. The period between the editions is about 20 years. In an area of 10 x 10 km (Fig. 1) land use pattern is quantified. To do so a lattice with square gridcells of 200 x 200 m<sup>2</sup> was superposed over the maps. The orientation

of the lattice is chosen north-south, because the change in pattern is caused by altering land use rather than by natural succession and natural forces (e.g., geomorphological orientation, wind direction). The result is a total number of 2175 gridcells.

The maps are sampled using the method of modal sampling (Webster 1977), where a gridcell gets the value of the land use type with the largest area in that gridcell. When this method did not satisfy point sampling (Webster 1977) is used.

Five main land use types were identified: 1. forest (no difference is made between coniferous and deciduous forest), 2. heathland, 3. drift-sand, 4. agricultural land (no difference is made between meadows and cropland) and 5. urban (all built areas exclusive isolated farmhouses).

The sampled data are digitized using the GIS program MAP250 (Van den Burg et al. 1985). Transitions of the land use types were calculated also using this GIS program.

For the shape indices size and perimeter of the patches were used, where a patch is defined as a group of contiguous, adjacent cells of the same land use type (adjacent = horizontally, vertically and diagonally).

The second shape index (S2) is based on a formula given by Forman and Godron ( $S = li/2\sqrt{ai\pi}$ ). Because this formula is based on polygonal format in this case study the formula is adjusted for gridcell data. So the average of this shape index (S2) is calculated by:

$$S2 = 1/Ni1 * \sum (li/4\sqrt{ai})$$

where Nil is the number of patches of land use category i in map 1, li the perimeter and ai the size of each patch in that category.

Correlations between the indices are calculated with Spearman's correlation coefficient with a = 0.05.

## Results

First, the results of the separate indices will be discussed, then combinations of indices will be made to evaluate the additional value of the combination.

**Table 1.** Land use development during the period 1845–1982. **F** = forest, **H** = heathland, **S** = drift-sand, **A** = agricultural land and **U** = urban.

	1845	1875	1898	1913	1931	1957	1972	1982
<b>PROPORTION OF LAND USE TYPES</b>								
<b>Forest</b>	0.17	0.31	0.34	0.41	0.54	0.55	0.64	0.64
<b>Heathland</b>	0.66	0.56	0.42	0.38	0.25	0.22	0.15	0.12
<b>Drift-Sand</b>	0.08	0.03	0.12	0.08	0.06	0.04	0.03	0.04
<b>Agricultural</b>	0.09	0.10	0.12	0.13	0.15	0.16	0.14	0.14
<b>Urban</b>	0.00	0.00	<b>0.00</b>	0.01	0.01	0.03	0.04	0.06
<b>TRANSITIONS (%)</b>								
<b>F -&gt; F</b>	91.8	80.8	87.0	86.4	88.3	97.9	95.1	
<b>F -&gt; H</b>	4.4	8.2	8.9	10.2	6.1	0.6	1.2	
<b>F -&gt; S</b>	0.3	4.7	0.9	0.6	0.4	0.3	0.5	
<b>F -&gt; A</b>	3.5	6.3	3.2	2.6	4.1	0.8	1.1	
<b>F -&gt; U</b>	0.0	0.0	0.0	0.2	1.0	0.4	2.0	
<b>H -&gt; F</b>	17.9	12.6	12.8	38.5	25.1	34.0	12.9	
<b>H -&gt; H</b>	81.7	68.6	80.2	49.1	67.5	61.3	74.2	
<b>H -&gt; S</b>	0.1	15.5	3.7	2.3	0.9	0.4	10.2	
<b>H -&gt; A</b>	0.3	3.3	3.3	10.0	4.8	3.5	2.1	
<b>H -&gt; U</b>	0.0	0.0	0.0	0.1	1.7	0.8	0.6	
<b>S -&gt; F</b>	46.2	13.0	39.6	23.1	6.3	10.5	3.5	
<b>S -&gt; H</b>	13.0	23.2	10.6	17.9	29.4	29.1	5.3	
<b>S -&gt; S</b>	39.1	63.8	49.8	59.0	60.3	59.3	91.2	
<b>S -&gt; A</b>	1.8	0.0	0.0	0.0	0.0	1.2	0.0	
<b>S -&gt; U</b>	0.0	0.0	0.0	0.0	4.0	0.0	0.0	
<b>A -&gt; F</b>	6.3	14.1	9.2	14.2	3.7	13.4	3.3	
<b>A -&gt; H</b>	2.9	4.4	2.0	2.2	4.3	0.9	0.0	
<b>A -&gt; S</b>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
<b>A -&gt; A</b>	90.7	81.6	88.0	79.3	82.5	74.4	86.6	
<b>A -&gt; U</b>	0.0	0.0	0.8	4.0	9.5	11.4	10.0	
<b>U -&gt; F</b>	0.0	0.0	0.0	0.0	7.1	11.3	4.3	
<b>U -&gt; H</b>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
<b>U -&gt; S</b>	0.0	0.0	0.0	0.0	0.0	10.0	0.0	
<b>U -&gt; A</b>	0.0	0.0	0.0	100.0	57.1	17.7	21.5	
<b>U -&gt; U</b>	0.0	0.0	0.0	0.0	35.7	71.0	74.2	

### Pattern indices

Large changes in cover (**P**) are recorded for forest, heathland, drift-sand and urban, little change is recorded for agricultural land (Table 1). Forest and urban area increase, the area of heathland and

drift-sand decreases. The increase of the urban area starts after 1931.

Figure 2 shows an increase of the average number of patches (from **35** to **78**) and a decrease of the mean size of all patches (from **249** to 112 ha). The increase respectively decrease of mean size of forest

Table 2. Pattern indices for each land use type (standard deviation between brackets).

	1845	1875	1898	1913	1931	1957	1972	1982
NUMBER OF PATCHES								
Forest	16	13	14	5	14	7	6	7
Heathland	5	11	16	21	31	35	19	20
Drift-Sand	3	1	9	9	9	6	6	15
Agricultural	11	12	15	13	13	10	14	19
Urban	0	0	0	1	6	19	14	17
MEAN SIZE OF PATCHES (ha)								
Forest	92.0 (279.3)	210.8 (608.3)	212.6 (603.8)	713.6 (1568.8)	334.6 (1084.8)	680.0 (1640.2)	928.7 (2062.0)	790.9 (1880.5)
Heathland	1147.2 (1583.6)	437.5 (874.6)	228.8 (479.4)	158.7 (380.9)	69.4 (165.2)	55.8 (146.4)	70.1 (120.1)	53.4 (100.1)
Drift-Sand	224.0 (226.7)	276.0 (0.0)	117.8 (141.2)	76.9 (97.0)	56.0 (77.1)	57.3 (54.9)	38.0 (33.1)	24.8 (29.1)
Agricultural	74.5 (104.2)	68.0 (93.6)	66.9 (87.2)	84.6 (104.2)	100.3 (144.1)	140.4 (226.0)	86.0 (165.6)	63.6 (143.8)
Urban	0.0	0.0	0.0	8.0 (0.0)	9.3 (6.0)	13.1 (14.4)	50.2 (26.6)	30.4 (62.4)
SHAPE INDEX 1 (m/ha)								
Forest	149.1 (57.8)	134.5 (53.9)	127.9 (59.0)	130.9 (63.3)	151.9 (66.6)	103.9 (60.9)	106.1 (71.3)	113.4 (71.9)
Heathland	86.4 (76.2)	108.9 (70.9)	116.4 (60.9)	123.9 (65.1)	136.5 (55.4)	140.0 (56.9)	118.7 (55.8)	129.5 (53.8)
Drift-Sand	74.0 (65.8)	39.1 (0.0)	88.8 (47.9)	113.0 (66.5)	112.8 (68.4)	114.1 (68.4)	111.4 (48.7)	161.2 (54.5)
Agricultural	135.5 (69.8)	130.1 (66.6)	124.6 (66.0)	103.3 (54.8)	96.4 (44.3)	97.5 (52.6)	121.9 (53.2)	141.3 (54.1)
Urban	0.0	0.0	0.0	150.0 (0.0)	161.1 (37.5)	165.5 (39.3)	151.8 (38.1)	142.5 (45.1)
SHAPE INDEX 2 (m/4√ha)								
Forest	1.26 (0.53)	1.72 (1.02)	1.57 (0.71)	2.07 (1.99)	1.50 (1.05)	1.84 (1.38)	1.86 (1.24)	1.84 (1.28)
Heathland	1.53 (0.57)	1.58 (0.64)	1.43 (0.49)	1.32 (0.60)	1.37 (0.53)	1.21 (0.36)	1.32 (0.30)	1.31 (0.39)
Drift-Sand	1.42 (0.41)	1.63 (0.00)	1.42 (0.32)	1.26 (0.25)	1.12 (0.43)	1.31 (0.26)	1.31 (0.28)	1.41 (0.49)
Agricultural	1.33 (0.58)	1.36 (0.42)	1.36 (0.37)	1.44 (0.37)	1.56 (0.45)	1.59 (0.44)	1.54 (0.63)	1.45 (0.50)
Urban	0.00	0.00	0.00	1.06 (0.00)	1.11 (0.17)	1.21 (0.30)	1.35 (0.54)	1.32 (0.44)

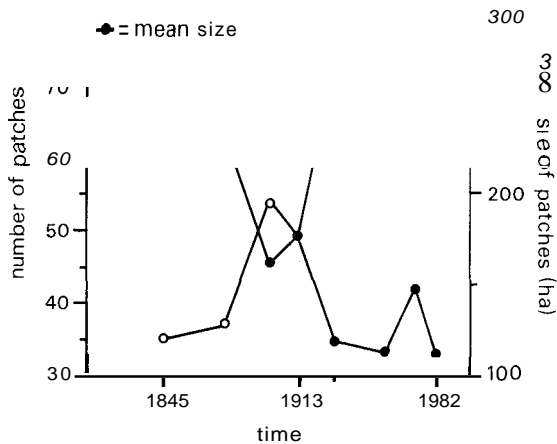


Fig. 2. Number and mean size of all patches.

and of heathland and drift-sand patches is enormous, whereas for agricultural patches little fluctuation in mean size is recorded (Table 2). Remarkable is the high standard deviation of this index (Table 2) due to the great differences in size of the patches (a few very large patches and several very small patches).

Comparing the two shape indices (Fig. 4) large differences in results are observed and no correlation between these indices is found. Shape index 1, calculated as the perimeter-to-area ratio, shows a general trend of decrease until 1931, after that time the index increases except for 1972. Shape index 2, calculated as the deviation of the observed patch from a square patch, shows an increase until 1913, then a period of decrease follows and after 1972 again an increase is recorded. Figure 4 shows also the differences of the two indices for the land use types separately. Sometimes shape index 1 seems to behave in the opposite direction of shape index 2 (*e.g.*, Fig. 4, agricultural land).

These results are surprising. Where they should theoretically indicate the same trend they do the opposite in some periods. An explanation for this phenomenon is the size dependency of shape index 1 and the size independence of shape index 2.

In Fig. 3 the differences between shape index 1 and 2 are shown by means of an arbitrary patch that changes in size and shape through time. In period I–III, when the patch becomes greater and the patch shape becomes more complex, shape index 1

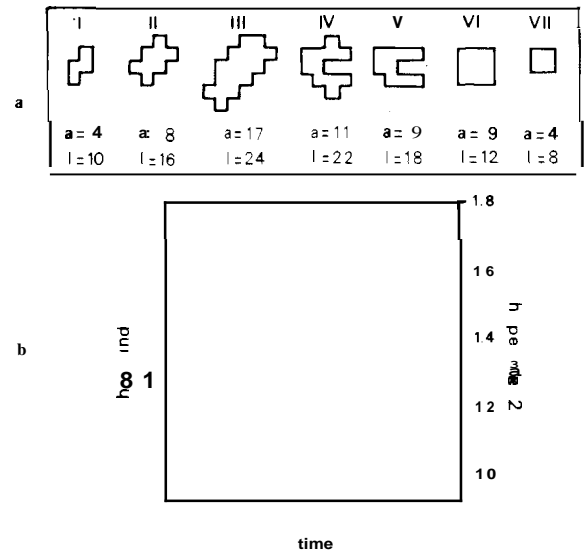


Fig. 3. Development of an arbitrary patch (a) and its corresponding shape indices (b).

decreases and shape index 2 increases. In period IV–V shape index 1 remains stable whereas the complexity of the perimeter decreases. In period V–VI, when the patch size remains stable and patch shape develops from complex to a square shape, both indices decrease. On the strength of this exercise it seems justified to conclude that the indices have a different ecological meaning: changes in shape index 1 indicate changes in the patch interior whereas shape index 2 indicates changes in the complexity of the perimeter.

Like all shape indices mentioned in literature each of these indices covers just one of the aspects of the ecological value of a patch, *i.e.* the interior or the perimeter. Therefore it is possible that patches with different shape have the same index value (Fig. 3: patch 11, IV, V and VII have the same S1 index value and patch VI and VII have the same S2 index value).

One additional remark should be given regarding the shape index. In The Netherlands most patches of semi-natural land use types (*e.g.*, drift-sand) are relict patches. Therefore, the shape of these patches is fixed by their human modified neighbour patches. So, particularly in a human modified landscape like the Dutch landscape no difference will be observed between the shape of semi-natural and human modified patches. Iverson (1988) also found that

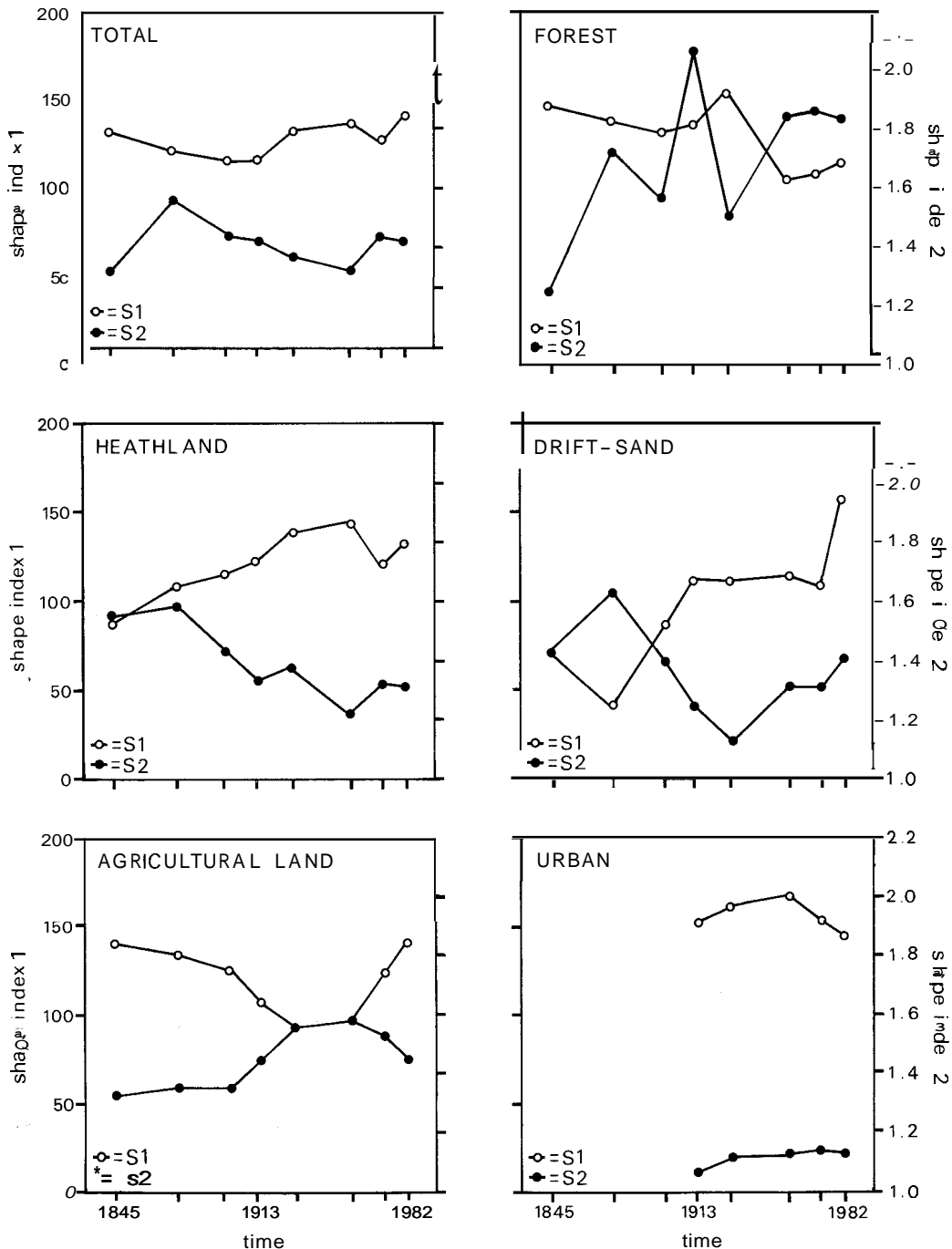


Fig. 4. Shape index 1 and 2 of all patches (total) and for each land use type separately, where S1 is mean perimeter-to-area and S2 is mean deviation from an isodiametric patch.

forest perimeters are often straight lines adjacent to agricultural land. His conclusion on that point is: the complex 'natural' boundary does not exist (where human activity has created the boundary)

For the dominance index (D) the results of the analysis are not very clear (Fig. 5). Where the possible range of this index for this case study has value from 1.61–0.00 the recorded values are between

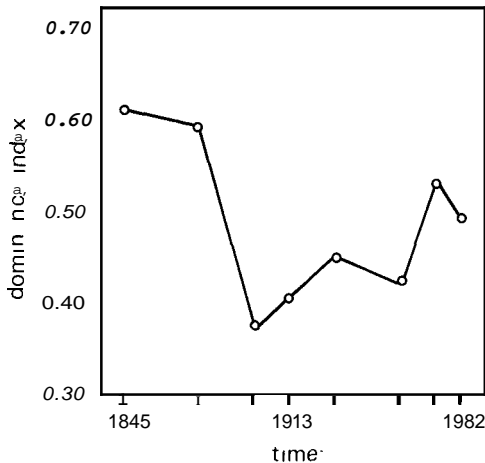


Fig. 5. Changes in the degree to which one or few land uses dominate the landscape (= dominance index) during the period 1845–1982.

0.61 and 0.37. The lowest values are found in the period 1898–1972, the period of re-afforestation. But the values in this transient stage hardly differ from the values at the beginning or the end of the period studied, when heathland has a cover of 66% and forest has a cover of 64%, respectively. So, the trend indicated by the proportion of each land use type (P) is not reflected in the dominance index. This may be caused by the fine-grained pattern of the study area, where a variety of land use types is always present. This statement is confirmed by the fact that no significant correlation is found between dominance index and proportion of each land use type.

### Change index

The highest total rate of change is found in the period 1913–1931 (Fig. 6), when re-afforestation of drift-sand as well as of heathland take place. In the period 1931–1957 the total rate of change is remarkably low, probably due to the combined effect of World-War II and the economic recession before and after World-War II. For the particular land use types the index shows large fluctuations and no significant correlation is found between the index of the land use types separately. This is in contradiction to the change in proportions of the land use types (P), which are significantly correlated for

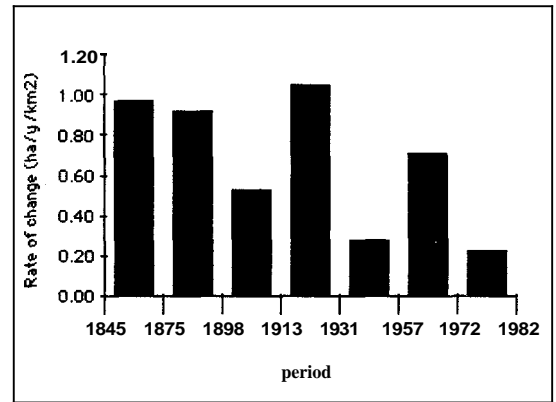


Fig. 6. Total rate of change in different periods between 1845–1982. The height of a bar equals the average amount of land changed between the years indicated.

several land use types (e.g., forest and heathland). Obviously, the rate of increase or decrease of a land use type is determined by the transition of several land use types into that type, whereas sometimes the increase of the proportion of a land use type is correlated with the decrease of one other land use type.

### Combination of indices

Proportion of each land use type (P) alone gives no sufficient information on the way land use development take place. First, the index gives no information on the change in geographical position of the land use types (same cover of a land use type gives the same P value). Secondly, the index does not indicate how the land use types are replaced by each other. The first problem can be dealt with by including information derived from the GIS data set. Using the utilities of the GIS for each land use type, two different proportion-indices can be calculated: a. the proportion of gridcells which have the same land use type as in a previous map and b. the proportion of new gridcells of the land use type.

The way a land use type is replaced by other land use types is to be reconstructed from the combination of proportion of land use type (P) and the transition percentages (Table 1). This together with the rate of change makes the information on the land use development more complete. For the present study the combination of the indices P and C and the transition percentages gives the following infor-

mation. The increase of the forest area is due to transitions from drift-sand and heathland, by which the transition from drift-sand to forest has the highest percentage and the most rapid change in the period before 1913 (drift-sand re-afforestation) and the transition from heathland to forest (heathland re-afforestation) has the highest percentage and the most rapid change in the period after 1931 (Table 1 and 2). The increase of the urban area is in some degree at the expense of forest and heathland area, but for the largest part it is due to transition from agricultural land to urban. The latter transition is due to the increase of number of buildings in the agricultural conglomerations, the first to the enlargement of the cities.

Number of patches (N) together with mean size of the patches (A) gives better information on the way the pattern develops than the two indices separately (Table 2). In the study area a general trend of increase of number of patches and of decrease of the mean size of the patches is recorded (Fig. 2). This gives the indication that the landscape pattern in the study area is fragmented.

The dominance index (D) alone gives no information on which particular legend type is dominant. Therefore the index should be used together with the proportion of each legend type (P). However for the study area this combination gives little extra information because according to the dominance index no land use type is dominant during the period studied.

As indicated above, the two shape indices calculated in this case study deal with different ecological aspects (size of the patch interior and complexity of the patch perimeter). Therefore the two indices should be considered together.

The standard deviation of the mean size of the patches and the two shape indices (Table 2) give a picture of the variability in area and shape of the patches and so an indication of the landscape type. Large standard deviations mean a heterogeneous landscape with large and small patches with great differences in shape.

## Conclusions

It is necessary for good understanding of the ecological consequences of changes in landscape pat-

tern to describe the pattern with suitable indices. But not all indices considered in this case study are suitable. Beside, the indices do not give enough information on changes in the geographical position of the patches, and several indices have to be considered in combination with other indices to get meaningful information. For instance, the dominance index (D) seems not to be sensitive enough for changes in dominance in a landscape with several legend types present and with a 'dominant' legend type that does not reach above a proportion of 0.70. In the beginning as well as at the end of the study period one of the legend types seems to be dominant according to proportion (P is greater than 0.60 while the other land use types have a proportion less than 0.20). Still the dominance index in these times differs not much from other times when the recorded proportions have more equal values.

The indices proportion of each land use type (P) and rate of change (C) give no information on the change in geographical position of the land use types. So nothing is known about the landscape dynamics.

About the shape index two remarks have to be made. First in a human modified landscape, like the Dutch landscape, the shape index can give no information whether a patch has a semi-natural or a human modified shape because the shape of natural patches is mostly fixed by their human modified neighbour patches. Secondly, for the ecological interpretation of the shape index it is better to calculate the index by both the interior-to-edge ratio and the complexity of the patch perimeter. But such an index is not found in literature. Efforts should be made to design a new index accordingly.

Sometimes, the standard deviation of indices gives an addition to the index value. For instance, the standard deviation of the mean size of the patches and the two shape indices gives a picture of the variability in area and shape of the patches and so an indication of the heterogeneity of the landscape.

Useful information on the development of land use and pattern is given by several combinations of indices. So, the combination of proportion of each land use type (P) and the data of the transitions shows how the development in land use has been. The number of patches together with the mean size

of patches gives a good indication of the pattern development.

Nevertheless continued research will be necessary to develop a useful method how to quantify the change in landscape pattern. New indices giving information on the change in geographical position of the patches has to be formulated, a new shape index including the aspect of patch interior as well as the aspect of complexity of the perimeter has to be developed, and last but not least an ecological meaning has to be given to the index value in relation to the process of changing pattern.

### Acknowledgements

I gratefully thank Josef Fanta, Frans Klijn and Bas Pedroli for their valuable comments of early drafts of the manuscript.

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