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IMPACT OF STARCH SEWAGE ON PHYTOCENOSES OF A FRESH PINE FOREST AND A CLEARING.
I. VEGETATIONAL CHANGES AS AN EFFECT OF SEWAGE FERTILIZATION[1]

ABSTRACT: Changes in composition and structure in ground flora of pinewood and clearing phytocenoses as a result of intensive ten-year-fertilization with starch sewage was the subject of the study. Two-directional changes were observed, namely (1) invasion of anthropogenic vegetation (Chenopodietea, Molinio-Arrhenatheretea, Epilobietea angustifolii, Artemisietea), and (2) degeneration of native ground flora (*Peucedano-Pinetum*). Vegetation-habitat relationships in fertilized biocenoses were revealed using phytoindication method.

KEY WORDS: plant invasion, vegetation degeneration, ground flora, fresh pine forest, clear cutting, fertilization, starch sewage.

1. INTRODUCTION

The necessity of protection of both terrestrial and aquatic ecosystems against eutrophication requires very efficient sewage purification of municipal and food industry sewage. One of the methods applied is the direct utilisation of sewage rich in organic and mineral compounds in soil-vegetation environment. Emploing terestial (forest) ecosystems as sewage treatment works seems to result from economical, rather than ecological reasons.

Ecological solution to organic sewage problem are so-called hydrobotanical sewage treatment works where working agents are hydrophytes (Brix 1987, Timofeeva and Stom 1988, Brix and Schierup 1989, Conley et al. 1991, Cooper and Hobson 1991, Hammer 1991, Moshiri 1993), or even peat (Aspleund et al. 1976, Brown and Farnham 1976, Counal and Lalancette 1976, Loxham 1980).

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[1] The study was performed within the Project CBR 04.09/D.

Current problems associated with organic wastes and sewage utilization have still commonly been solved by purification in the soil-vegetation environment. Although controversial, sewage treatment is sometimes regarded as a kind of fertilization. Disturbances in ecosystem, eutrophication, and consequent element leaching are the main ecological problems associated with sewage fertilization.

The studies on use of fertilizers in forestry practice lasting over 100 years have mainly been focused on stand productivity (e.g. Baule and Fricker 1973, Paavilainen and Päivänen 1995). However, ground flora of fertilized forest ecosystems has become subject of interest more and more frequently (Guzikowa et al. 1976, Zaręba 1978, Fałtynowicz 1982, Dyguś 1991a, b, 1995, 1996a, b, 1997b, Vasander et al. 1993). Ground flora and soil environment are of special importance in case of using forest habitat as a soil-vegetation sewage treatment works.

The objective of this study was: (1) estimate changes in composition, structure and succession of pinewood and clearing phytocenoses, (2) to recognize degeneration dynamics of native ground flora and (3) to evaluate relationships in "vegetation-habitat" system of forest affected by starch sewage.

2. STUDY SITE

The studies were carried out in a soil-vegetation starch sewage treatment works. The area comprises 216 hectares of fresh pine forest. It is situated in Iława forest district (East Pomeranian Lake District, North Poland) (Kondracki 1981).

Brown and podzolic soils dervided from sandr sands of fluvioglacial origin occur on the area of the forest sewage treatment works.

Seven kilometres long below-ground pipe conveyed sewage from the starch factory to the 11 000 m^3 retarding reservoir. Furthermore, sewage were pumped into the permanent sprinkling machine (pipe line system and rotated sprinklers of 36x36 m spacing) which distributed sewage onto the area of the treatment works.

Three types of plots were established within the fresh pine forest treated with starch sewage:

1. managed forest area (192 ha) fertilized with a base dose of sewage equal to 300 mm per year i.e. 3000 m^3 ha^{-1} year^{-1}

2. experimental forest area (18 ha), where four different doses were applied: 150, 300, 450 and 600 mm per year, i.e. 1500, 3000, 4500, 6000 m^3 ha^{-1} year^{-1}.

3. experimental plantation area established on a clear cut pine forest area (6 ha) where 16 species of trees were planted and three different sewage doses were applied: 150, 300, 450 mm, i.e. 1500, 3000, 4500 m^3 ha^{-1} year^{-1}.

Each type of plot was fertilized twice a year: in early spring (March-April) and autumn (September-December). During the growing season (May-August) all the areas were sprinkling with 300 mm (3000 m^3 ha^{-1} year^{-1}) of lake water. Control plots included forest units not sprinkled with sewage nor water and pine bufer zone of the sewage treatment works.

Starch sewage are mainly contamined with organic compounds (carbohydrates and proteins) and mineral substances. High values of BOD$_5$ index indicate high pollution level (Table 1).

Designers of the sewage treatment works have assumed that sewage supplied to oligotrophic pine habitat would enrich soil environment, increase wood increment and, at the same time the sewage would be purified. This would protect surface and ground water against pollution.

3. MATERIAL AND METHODS

Phytosociological and successional studies were conducted in area of the sewage treatment works, in 1984–1989 and 1994. Permanent study plots were established in each type of phytocenoses. In the pinewood phytocenosis 25 plots, each of an area of 100 m^2 (10x10 m), were delimited while in the clearing phytocenosis – 20 plots of 16 m^2 each (4x4 m). The plots were situated in each type of sewage treatment (see Section 2). Every year, phytosociological records were made in the middle of the growing season (July, August). The **Braun-Blanquet method** (1951, 1964) commonly applied in phytosociology, was employed in this study, whereas in the successional studies **Pawłowski**'s method (1977b) was used.

Table 1. Physico-chemical composition of starch sewage conveyed to forest treatment plant

Index	Mean for 1984–1990
Dry residue total (mg l^{-1})	3972
– volatile matter (organic) (mg l^{-1})	2928
– solid fractions (inorganic) (mg l^{-1})	1044
Suspension total (mg l^{-1})	667
K (mg l^{-1})	299
$N_{tot.}$ (mg l^{-1})	167
$N_{org.}$ (mg l^{-1})	125
$N\text{–}NH_4$ (mg l^{-1})	40
$N\text{–}NO_3$ (mg l^{-1})	2
Cl (mg l^{-1})	181
$S\text{–}SO_4$ (mg l^{-1})	155
Ca (mg l^{-1})	85
P_2O_5 (mg l^{-1})	75
Mg (mg l^{-1})	32
Na (mg l^{-1})	17
BOD_5 (mg O_2 l^{-1})	1652
Oxidizability (mg O_2 l^{-1})	889
ChOD (mg O_2 l^{-1})	2285
pH	5.8

Dynamics of successional changes was estimated using systematical values of group of species (D) according to **Scamoni** (1967) and **Pawłowski** (1977a, b) after Tüxen and Ellenberg (1937).

Quantitative changes in degeneration of native ground flora were assessed according to **Olaczek**'s (1974) concept based on the ratio of number of typical species – euphytes (E) to the number of foreign species – allophytes (A).

The system of degenerative stages proposed by **Faliński** (1966) was employed to describe both trait and intensity of degeneration.

Ellenberg's method (1950, 1952, **Ellenberg** et al. 1974, 1992) of bioindication was used for assessment of site conditions. Certain estimates for vascular plants were given after **Zarzycki** (1984) and for mosses - owing to the lack of data from Poland - after **Landolt** (1977).

The following soil properties were considered on the basis of an analysis of indicator values for particular species: moisture (W), fertility – mainly nitrogen content (N), soil pH (R), texture (D) and humus and organic matter content in the soil (H). Five degree scale of species index values was applied; 1– denoted the lowest value, 3 – medium range, 5 – the highest value of the index; 2 and 4 were respective medial values; e.g. W_1 – very dry soils, W_3 – fresh soils, W_5 – wet soils; R_1 – very acid soils, R_3 – acid soils, R_5 – neutral and alkaline soils etc. (Zarzycki 1984).

Latin nomenclature of vascular plant follows "Flora Europea" (Tutin 1964–1980). Moss nomenclature was given after Szafran (1957, 1961) and units of syntaxonomic groups – after Matuszkiewicz (1984).

4. RESULTS

4.1. STRUCTURAL AND FLORAL CHANGES OF GROUND VEGETATION AS AN EFFECT OF FERTILIZATION

4.1.1. Pinewood phytocenosis

Prior to the fertilization, the sewage-affected pine forest was represented by the subcontinental *Peucedano-Pinetum* Mat. (1962) 1973 association. The following species distinguish this association: *Convalaria majalis, Polygonatum odoratum, Solidago virgaurea, Peucedanum oreoselinum* and *Scorzonera humilis.*

Tree layer (a_1) has still been consisted of *Pinus silvestris* (conopy cover about 60%). Shrub layer (b) was poorly developed, constituting mainly of *Juniperus communis*. Prior to the sewage application (1984), mostly dwarf shrub-moss or grass-moss forms of ground flora layer occurred. The cover coefficient amounted to about 70 and 60% for herb (c) and moss layer (d), respectively (Table 2). Forty seven species of ground flora, including 13 moss species were recorded at the begining of the experiment.

Species of a narrow ecological range, i.e. those distinguishing *Peucedano-Pinetum* association and Dicrano-Pinion alliance diminished during first 2–3 years of the experiment, majority of them were mosses. After 5-year treatment, species of a wide ecological range, i.e. species characteristic of the Vaccinio-Piceetea class and accompanying flora disappeared as well.

Succession tended towards anthropogenic communities. Secondary ground flora – resembling vegetation of riparian sites developed with almost full cover. Nitrophilous species were the most frequent in the newly developed secondary ground flora. These species belonged to synanthropic communities from the Chenopodietea class and semi-natural ones including: meadow (Molinio-Arrhenatheretea), clearing (Epilobietea angustifolii) and ruderal (Artemisietea) communities. *Urtica dioica, Rubus idaeus, Stellaria media, Senecio sylvaticus* were dominants at this stage of transformations. Patches of these species formed characteristic mosaic pattern of distribution.

Ten years sewage treatment led to complete regression of pinewood ground flora. Even, more intensive expansion was observed in case of *Urtica dioica. Galium aparine, Stellaria media, Rubus idaeus, Poa pratensis* and mosses *Catharinea undulata, Mnium affine* occurred fairly frequently. Initial stage of the dwarf shrub-brushwood Sambuco-Salicion community with occurrence of Sambucus nigra was recorded.

After 10 years of the experiment, ruderal (Artemisietea), riparian and alder

Table 2. Structural and floral changes of vegetation in the pinewood phytocoenosis

	Species		Before fertilization		After fertilization	
			S	P	S	P
V–P	*Pinus sylvestris* L.	a_1	V	6250	V	6120
V–P	*Pleurozium schreberi* (Wild.) Mnkm.	d	V	4380	II	10
V–P	*Vaccinium myrtillus* L.		V	4120		
V–P	*Dicranum undulatum* Ehrh.	d	V	2250		
V–P	*Vaccinium vitis-idaea* L.		V	300		
V–P	*Deschampsia flexuosa* (L.) Trin.		V	3020		
	Anthoxanthum odoratum L.		V	250		
V–P	*Trientalis europaea* L.		V	160		
V–P	*Melampyrum pratense* L.		V	30		
V–P	*Convallaria majalis* L.		V	10		
	Dryopteris carthusiana (Vill.) H. P. Fuchs		V	10		
	Quercus robur L.	c	V	10		
	Calamagrostis arundinacea (L.) Roth		V	50	II	10
V–P	*Hylocamium splendens* (Hedw.) Br. eur.	d	IV	20		
	Juniperus communis L.	b+c	III	20		
S–S	*Festuca ovina* L.		III	50		
V–P	*Ptilium crista-castrensis* (Hedw.) De Not.	d	II	50		
	Polytrichum commune L.	d	II	100		
	Polytrichum attenuatum Menz.	d	II	50		
N–C	*Calluna vulgaris* (L.) Hull		II	50		
	Lazula pilosa (L.) Willd.		II	40		
	Rumex acetosella L.		II	30		
A	*Urtica dioica* L.				V	7640
Ch	*Stellaria media* (L.) Vill.				V	650
Ea	*Rubus idaeus* L.				IV	220
Ag	*Bilderdykia dumetorum* L. Dumort.				IV	180
Ag	*Galium aparine* L.				V	410
Fs	*Catharinea undulata* Web. et Mohr.	d			IV	180
M–A	*Poa pratensis* L.				III	170
Ag	*Solanum dulcamara* L. Dumort.				III	140
Ea	*Galeopsis tetrahit* L.				II	10
Ea	*Epilobium angustifolium* L.				II	30
	Mnium affine Bland.	d			II	20
Ea	*Senecio sylvaticus* L.				II	20
	Rhodobryum roseum (Weis) Limpr.	d			II	20
	Oxalis acetosella L.				II	20
Fs	*Mnium hornum* L.	d			II	20
	Pohlia nutans Lindb.	d			II	10
	Brachythecium rutabulum (Hedw.) Br. eur.	d			II	30
Ag	*Brachtythecium velutinum* (Hedw.) Br. eur.	d			II	20

Species			Before fertilization		After fertilization	
			S	P	S	P
Ea	*Galeopsis bifida* Boenn.				II	10
A	*Myosoton aquaticum* (L.) Moench				II	10
M–A	*Molinia coerulea* (L.) Moench				II	10
	Geranium robertianum L.				II	10
Ea	*Sambucus nigra* L.	b+c			II	10
Ag	*Lycopus europaeus* L.				II	10
	Eurhynchium swartzii (Turn.) Hobkirk	d			II	10
A	*Eupatorium cannabinum* L.				II	10

Explanations: S – phytosociological constancy; P – cover coefficient; V–P – Vaccinio-Piceetea; N–C – Nardo-Callunetea; S–S – Sedo-Scleranthetea; A – Artemisietea; Ch – Chenopodietea; Ea – Epilobietea angustifolii; Ag – Alnetea glutinosae; M–A – Molinio-Arrhenatheretea; Fs – Fagetalia sylvaticae; Pm – Plantaginetea majoris; a_1 –tree layer, b – shrub layer, c – herb layer, d – moss layer. The species with S = I or P < 10 are neglected.

carr vegetation (Alnetea glutinosae, Alno-Padion, Circaeo-Alnetum) determined the direction of ground flora transformations (Table 2, Fig. 1).

4.1.2. Clearing phytocenosis

Six hectares of the pine forest was cut off in 1979–80, and experimental tree plantation was established on the cut area (1982–83). Phytosociological observations started five years after felling. After this period few species of ground flora typical of pine forest survived. Composition of ground flora of the clearing was mainly supplemented by species from the Epilobietea angustifolii, Nardo-Callunetea and Sedo-Scleranthetea classes (Table 3).

In first two years of the experiment, floral composition of the clearing phytocenosis was significantly altered in the tree plantation. Species distinguishing the *Peucedano-Pinetum* associacion and pinewood mosses diminished. Other species of the Vaccinio-Piceetea class reduced their cover. On the other hand, nitrophytes from the Epilobietea angustifolii class as *Senecio sylvaticus, Calamagrostis epigeios, Epilobium angustifolium, Rubus idaeus* became more abundant. Second group of nitrophytes consisted of species from the Chenopodietea class: *Conyza canadensis, Chenopodium album* and others. A further decrease in pinewood species took place in third and especially in fourth year of the sewage application. *Vaccinium accinium myrtillus* and *Trientalis europea* occurred only sporadically. Species accompanying pinewood vegetation, mainly those from the Nardo-Callunetea and Sedo-Scleranthetea classes disappeared almost completely. Nitrophilous communities from the Epilobietea angustifolii, Artemisietea and Chenopodietea classes still predominated after five years of fertilization.

Even more evident changes were found after ten years of the sewage treatment applied to the clearing phytocenosis. Species of pinewood ground flora including species from the Nardo-Callunetea and Sedo-Scleranthetea classes which had occurred before the experiment, disappeared completely. Species from the Epilobietea angustifolii class still occurred, with *Calamagrostis epigeios* being the most invasive species from this group. In-

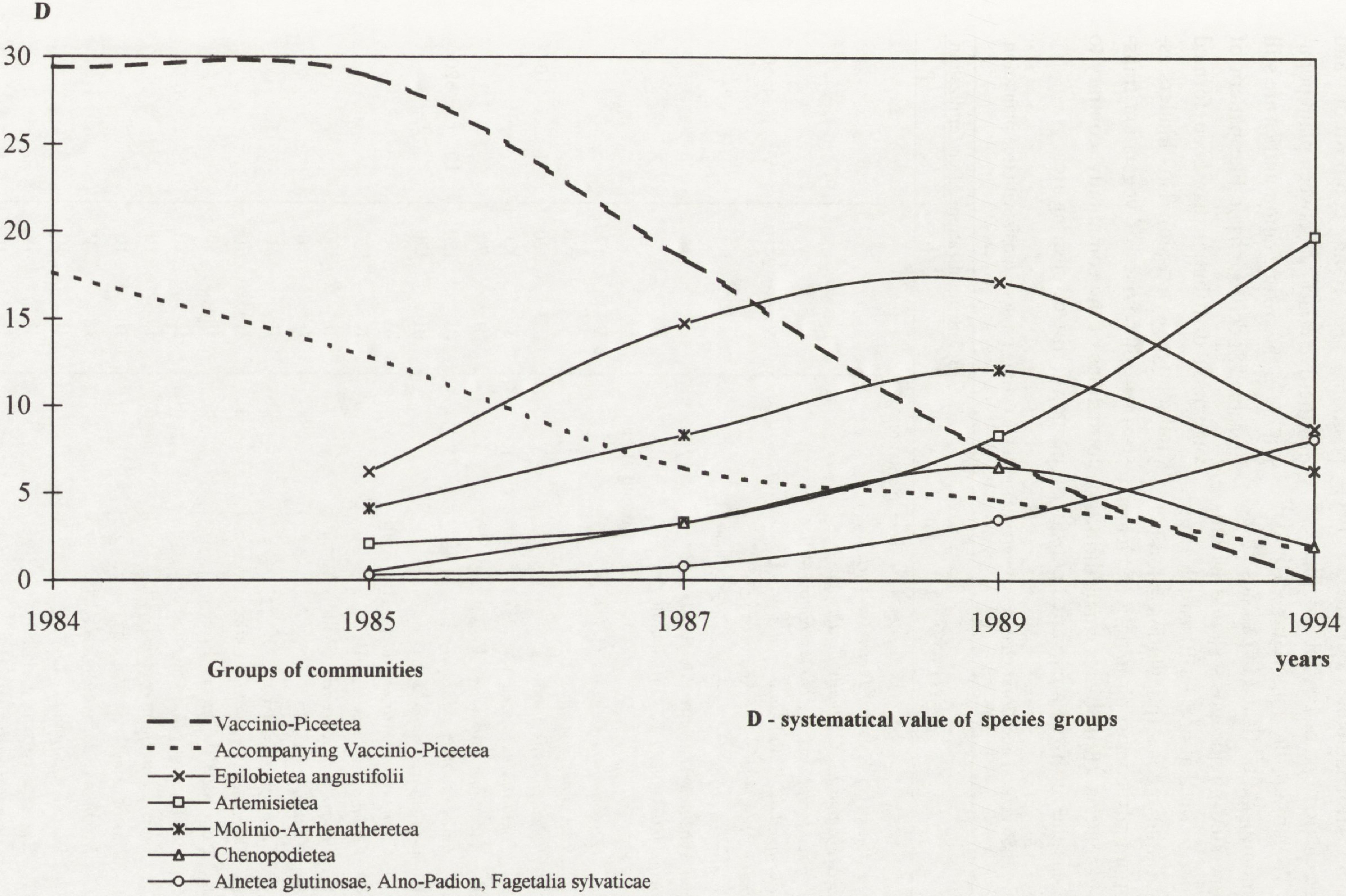


Fig. 1. Directions of vegetation changes in fertilized pinewood phytocenosis

vasion of species from the Artemisietea, Molinio-Arrhenatheretea and Alnetea glutiosae classes took place (Table 3, Fig. 2).

To sum up, the importance of initial communities established in patches of the degenerated phytocenosis should be emphasized. In the non-fertilized clearing area, initial species (populations) formed a community consisting mainly of clearing vegetation (Epilobietea angustifolii), whereas the fertilized area varied considerably with regard to syntaxonomic composition. The floral composition and quantitative relations between plant populations of the treated communities are still unstable. Specific mosaic-like pattern of vegetation distribution has been formed (anthropogenic mosaic). This hinders assessment of courses of vegetation transformations of the community, contrary to the non-fertilized clearing area.

Table 3. Structural and floral changes of vegetation in the cutting phytocoenosis with tree plantation

	Species		Before fertilization		After fertilization	
			S	P	S	P
	Tree plantation					
	Picea abies (L.) Karsten, *Pinus sylvestris* L. *Quercus robur* L., *Carpinus betulus* L. *Acer pseudoplatanus* L., *Ulmus minor* Miller *Betula pendula* Roth, *Alnus glutinosa* (L.) Gartner *Populus balsamifera* L. "Androscoggin" *Fraxinus excelsior* L., *Larix decidua* Miller *Fagus sylvatica* L., *Salix alba* L. *Populus balsamifera* L. "Fritzipantley"	b+c	V	2410	V	4550
	Ground flora					
V–P	*Deschampsia flexuosa* (L.) Trin		V	6170		
V–P	*Vaccinium myrtillus* L.		V	880		
	Pohlia nutans Lindb.		III	320	II	10
V–P	*Trientalis europaea* L.		V	320		
V–P	*Vaccinium vitis-idaea* L.		III	70		
	Anthoxanthum odoratum L.		III	150	III	320
V–P	*Convallaria majalis* L.		III	120		
	Calamagrostis arundinacea (L.) Roth.		III	40		
N–C	*Calluna vulgaris* (L.) Hull		II	120		
V–P	*Pleurozium schreberi* (Willd.) Mnkm.	d	II	380		
S–S	*Festuca ovina* L.		II	50		
N–C	*Carex pilulifera* L.		II	10		
V–P	*Dicranum undulatum* Ehrh.	d	II	70		
S–S	*Ceratodon purpureus* Brid.	d	II	30		
S–S	*Polytrichum piliferum* Schreb.	d	II	20		
	Polytrichum juniperinum Willd.	d	II	10		
N–C	*Carex ericetorum* Pollich		II	10		
N–C	*Danthonia decumbens* (L.) DC.		II	20		
	Veronica officinalis L.		II	10		
S–S	*Rumex acetosella* L.		II	10		
	Juniperus communis L.		II	10		
	Viola riviniana Reichenb.		II	10		

Species			Before fertilization		After fertilization	
			S	P	S	P
S–S	*Rhacomitrium canescens* (Timm) Brid.	d	II	10		
S–S	*Tortula ruralis* Ehrh.	d	II	10		
A	*Utrica dioica* L.				V	5160
Ea	*Epilobium angustifolium* L.				V	510
Ea	*Calamagrostis epigeios* (L.) Roth		IV	770	IV	1270
Ag	*Galium aparine* L.				V	750
	Elymus repens (L.) Gould				V	980
M–A	*Poa pratensis* L.				IV	410
Ea	*Rubus idaeus* L.		III	70	IV	250
Ag	*Bilderdykia dumetorum* (L.) Dumort.				II	10
A	*Artemisia vulgaris* L.				III	40
Ea	*Galeopsis tetrahit* L.				II	30
Ea	*Galeopsis speciosa* Miller				II	20
	Cirsium arvense (L.) Scap.				III	30
M–A	*Cirsium oleraceum* (L.) Scap.				II	40
Ch	*Stellaria media* (L.) Vill.				II	20
M–A	*Taraxacum officinale* Wiggers				II	20
Pm	*Agrostis capillaris* L.		III	60	II	50
Pm	*Agrostis stolonifera* L.		II	10	II	60
Ea	*Senecio sylvaticus* L.		III	350	II	10
Fs	*Milium effusum* L.				II	20
Ag	*Solanum dulcamara* L.				II	10
Ch	*Conyza canadensis* (L.) Cronq.				II	10
Ch	*Matricaria perforata* Merat				II	10
A	*Silene alba* (Miller) E. H. L. Krause				III	20
A	*Oenothera biennis* L.				II	10
Ch	*Chenopodium album* L.				II	10

Explanations: see Table 2.

4.2. DEGENERATION OF NATIVE GROUND FLORA AFFECTED BY SEWAGE FERTILIZATION

4.2.1. Pine forest phytocenosis

Phytosociological data revealed that quantity and quality of native ground flora was subject to degenerative transformations in the phytocenosis considered.

An index based on percentage of euphyte (E) to allophyte (A) numbers is a relatively precise measure of quantitative degeneration of plant communities. Changes in the index values estimated for the fertilized phytocenosis were the most pronounced when: (1) number of euphytes (E) decreased without any significant increase in allophyte number (A) (initial stage of degeneration); and (2) when low but stabile number of euphytes (E) was recorded and number of allophytes significantly increased (terminal stage of degeneration). The differences in the values amounted up to several thousand before the experiment to merely tens

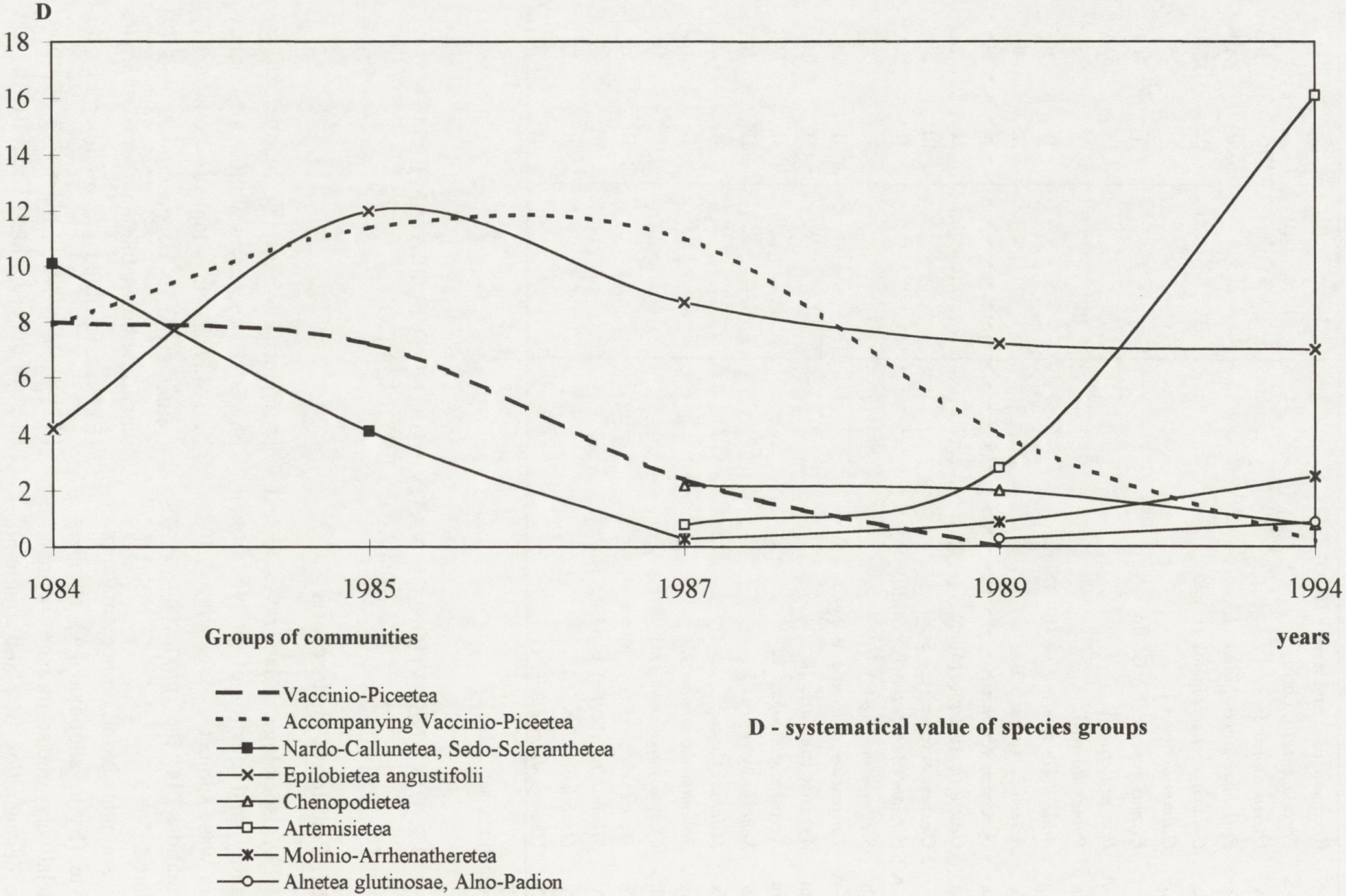


Fig. 2. Directions of vegetation changes in fertilized clearing phytocenosis

after 10-year period of fertilization (Fig. 3).

Nature and intensity of the vegetational changes are an example of phytocenosis response to a degenerative factor, i.e. fertilization. Ground flora species characteristic of the Peucedano-Pinetum association and Dicrano-Pinion alliance disappeared at the initial stages of transformations (first 2–3 years of fertilization). According to Faliński's (1966) concept of degenerative phase system, the forest community examined at this stage of transformations represented II phase of degeneration. After next 4–5 years of fertilization, pinewood community was found to be in III and IV phase of degeneration (elimination of species characteristic of the Vaccinio-Piceetalia order and the Vaccinio-Piceetea class). Species of native ground flora were hardly recorded in the tenth year of observations. Both composition and structure of vegetation were completely altered – V and VI degenerative phases (Fig. 4).

Qualitative changes consisted in invasive appearance of species from the Artemisietea, Alnetea glutinosae, Epilobietea angustifolii, Molino-Arrhenatheretea and Chenopodietea classes (Table 2, Fig. 1). Invasion of these plants brought about a complete transformation of floral composition and structure of ground flora of the fertilized pine forest (see Section 4.1.1).

4.2.2. Clearing phytocenosis

Settlement of foreign species affects degeneration of forest ground flora on areas with removed tree stand. These species find their ecological optimum in new circumstances. If other degenerative factors affect phytocenosis, it can lead to a disturbance or even loss of ecological balance. Quantity of degeneration in the clearing community was less intensive than in the forest phytocenosis; values of the indices amounted from dozen or so – before treatment to several after 10-year fertilization (Fig. 3). It was an effect of degenerative factors which had acted prior to fertilization (clear cutting, tree plantation) and reduced floral richness of the clearing phytocenosis.

Intensity of degeneration process increased under the influence of three subsequent anthropogenic factors: (1) clear cutting – II degeneration phase, (2) introduction of ecologically foreign ecotypes of tree species – III degeneration phase and (3) fertilization with starch sewage rich in organic mater and nutrients – III–V degeneration phases (Fig. 5).

Invasion of synanthropic species principally such as *Senecio sylvaticus, Rubus idaeus, Epilobium angustifolium, Urtica dioica, Galium aparine* was the main reason of qualitative changes in the studied phytocenoses (see Section 4.1.2).

4.3. "VEGETATION-HABITAT" RELATIONSHIPS UNDER CONDITIONS OF SEWAGE FERTILIZATION

Dynamic changes of habitat conditions which occurred as a result of fertilization resulted in a rapid impoverishment of native ground flora and simultaneous increase in number of species characteristic of secondary (anthropogenic) communities. Ten-year fertilization resulted in almost complete diminishment of pinewood ground flora.

"Vegetation-habitat" relations were analyzed on the basis of indicative properties of pinewood species and

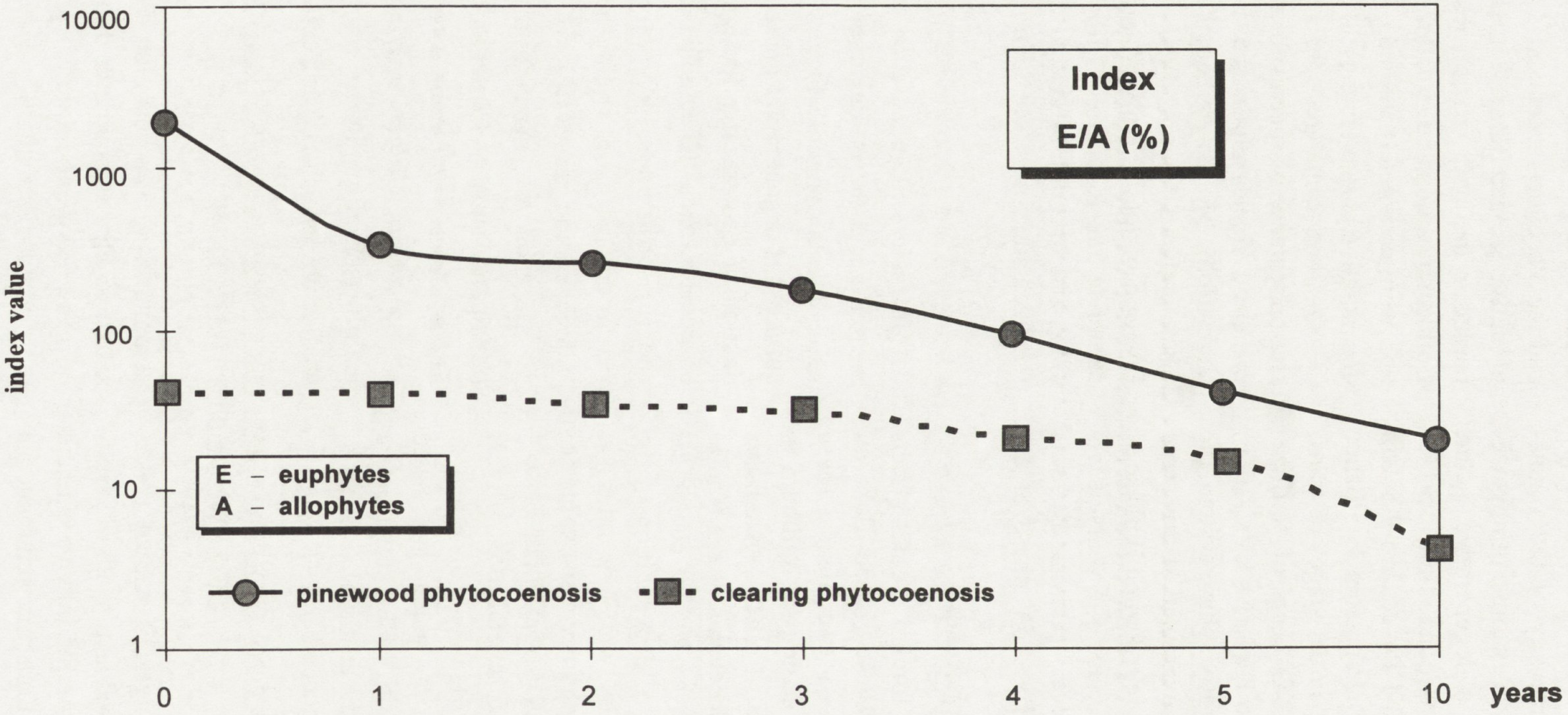


Fig. 3. Quantitative degenerative changes in ground flora

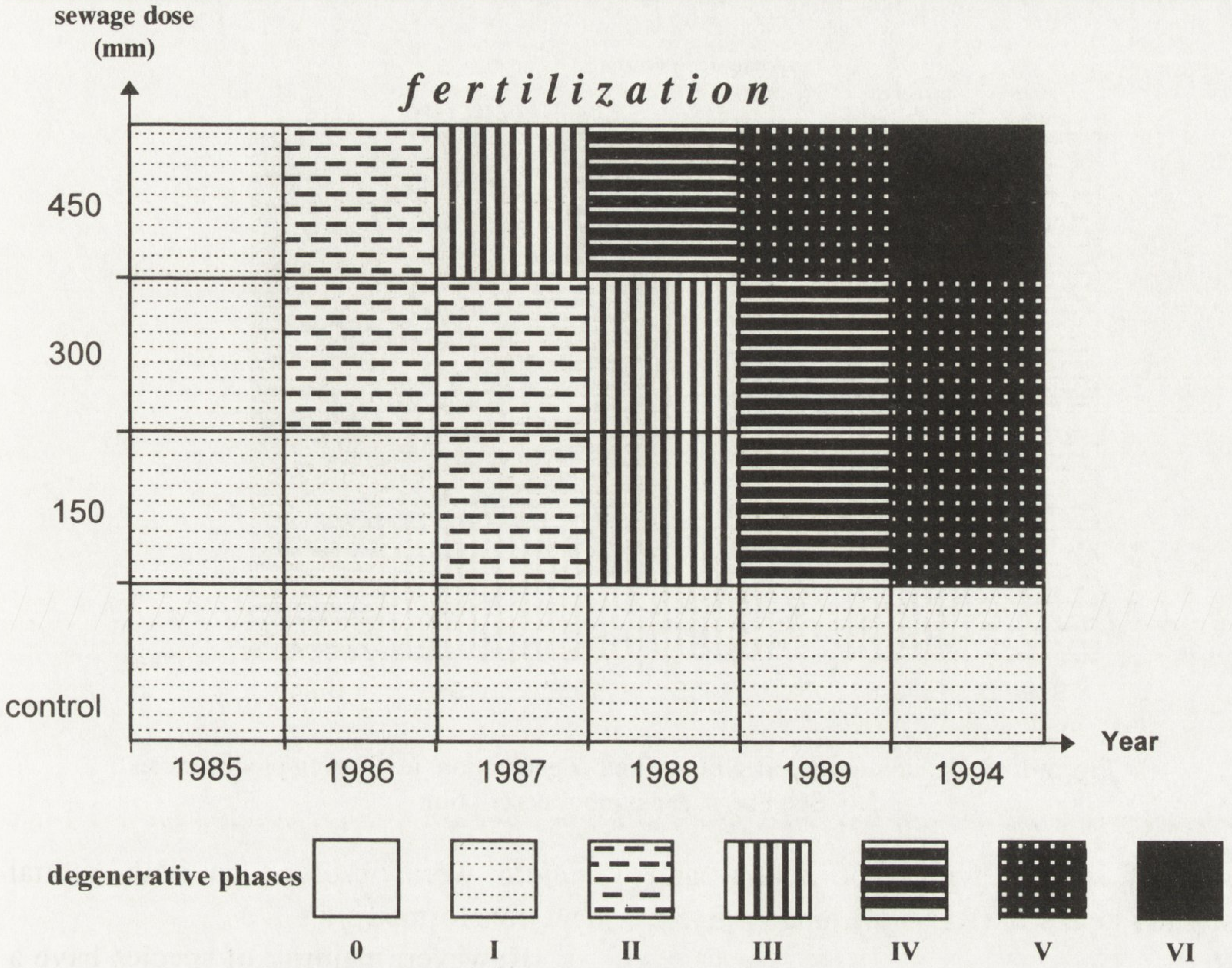


Fig. 4. Increase in intensity of degeneration ground flora in pinewood phytocenosis
0 – natural phytocenosis *Peucedano-Pinetum*, I – reduction of cover coefficient and species number characteristic to the *Peucedano-Pinetum* association and the Dicrano-Pinion alliance, II – disappearance of species characteristic to the *Peucedano-Pinetum* association and the Dicrano-Pinion alliance, and reduction of cover coefficient and species number characteristic to the Vaccinio-Piceetalia order, III – disappearance of species characteristic to the Vaccinio-Piceetalia order, and reduction of cover coefficient and species number characteristic to the Vaccinio-Piceetea class, IV – disappearance of species characteristic to the Vaccinio-Piceetea class, and reduction of cover coefficient and number of accompanying species, V – disappearance of accompanying species, VI – complete degeneration of *Peucedano-Pinetum* association

species of anthropogenic communities (phytoindication method) (Fig. 6).

Moisture conditions (F). Prior to the fertilization, majority of species, e.g. *Vaccinium myrtillus* and *Pleurozium schreberi*, indicated fresh soils (F_3). Species of moist soils (F_4), e.g. *Urtica dioica, Stellaria media, Mysoton aquaticum, Cirsium palustre* and wet soil (F_5), e.g. *Solanum dulcamara, Lycopus europaeus* appeared after ten years of fertilization.

Habitat fertility (N) was estimated on the basis of nutrient, mainly nitrogen requirements of ground flora species. Prior to the fertilization, majority of species (55%), e.g. *Vaccinium myrtillus, Melampyrum pratense, Deschampsia flexuosa*, indicated extremely oligotrophic soils (N_1). After 10 years of sewage influence, 70% of species indicated eutrophic habitats (N_4 and N_5). This group consisted mainly of nitrophilous species such as *Urtica dioica, Rubus idaeus, Solanum dulcamara, Galium aparine, Sambucus nigra*.

Reaction index (R). Majority of species in the non-disturbed pine forest, e.g. *Calluna vulgaris, Polytrichum commune, Deschampsia flexuosa*, were associated with sandy acid or very acid soils (R_{1-3}) of pH range from 3.0 to 4.5. Fertilization resulted in appearance and expan-

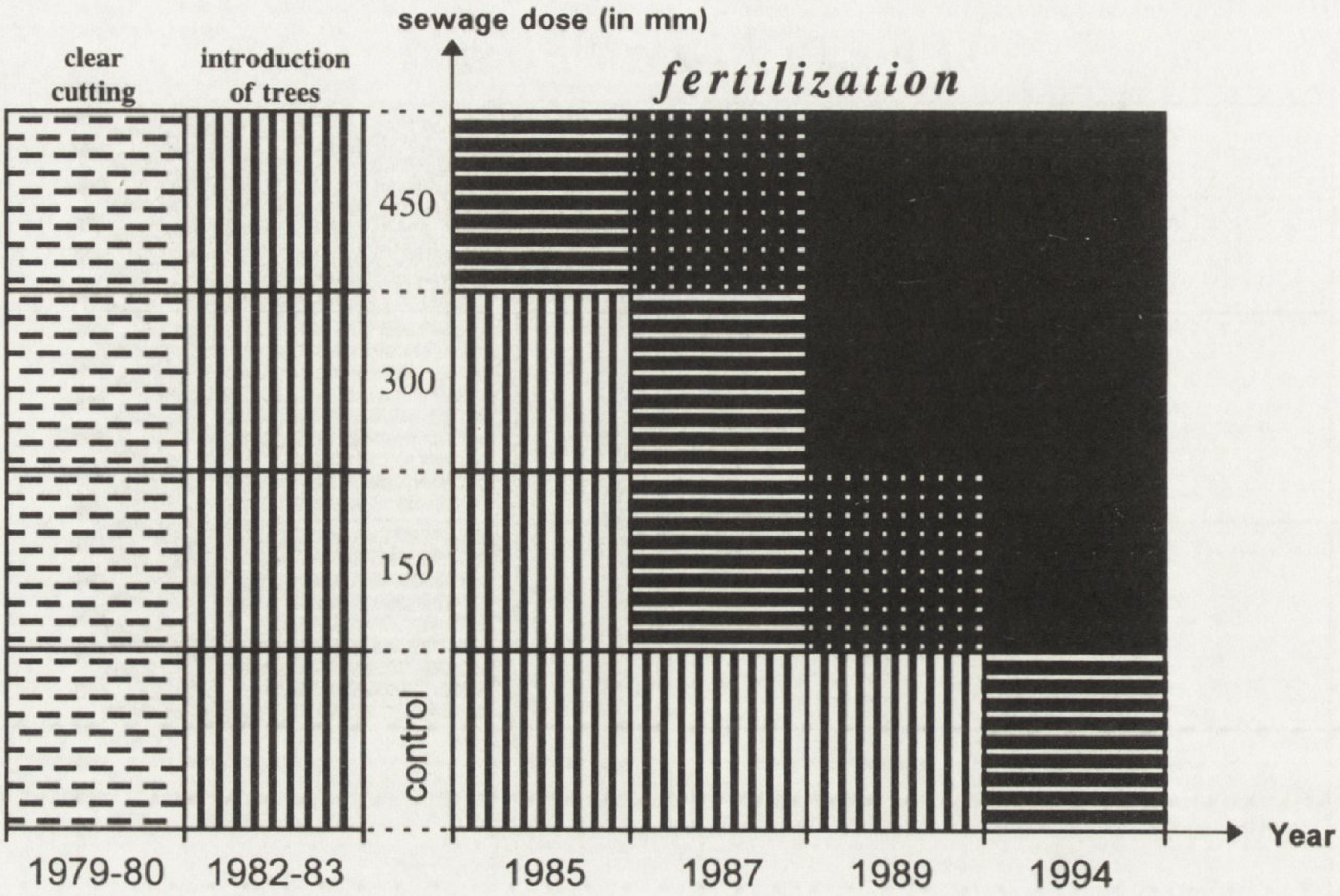


Fig. 5. Increase in intensity of ground flora degeneration in clearing phytocenosis
See Fig. 4. for symbol description

sion of species typical of neutral and slightly acid soil (R_4) – pH range 4.5–5.5 (6.0).

Soil texture index (granulometric composition) (D). Ground flora species which occurred before fertilization were associated with sandy (D_3), loamy or sandy-clayey (D_4) soils. The experiment resulted in appearance of species characteristic of heavy soils (D_{4-5}), e.g. *Solanun dulcamara, Lycopus europaeus, Sambuus nigra, Galium aparine.*

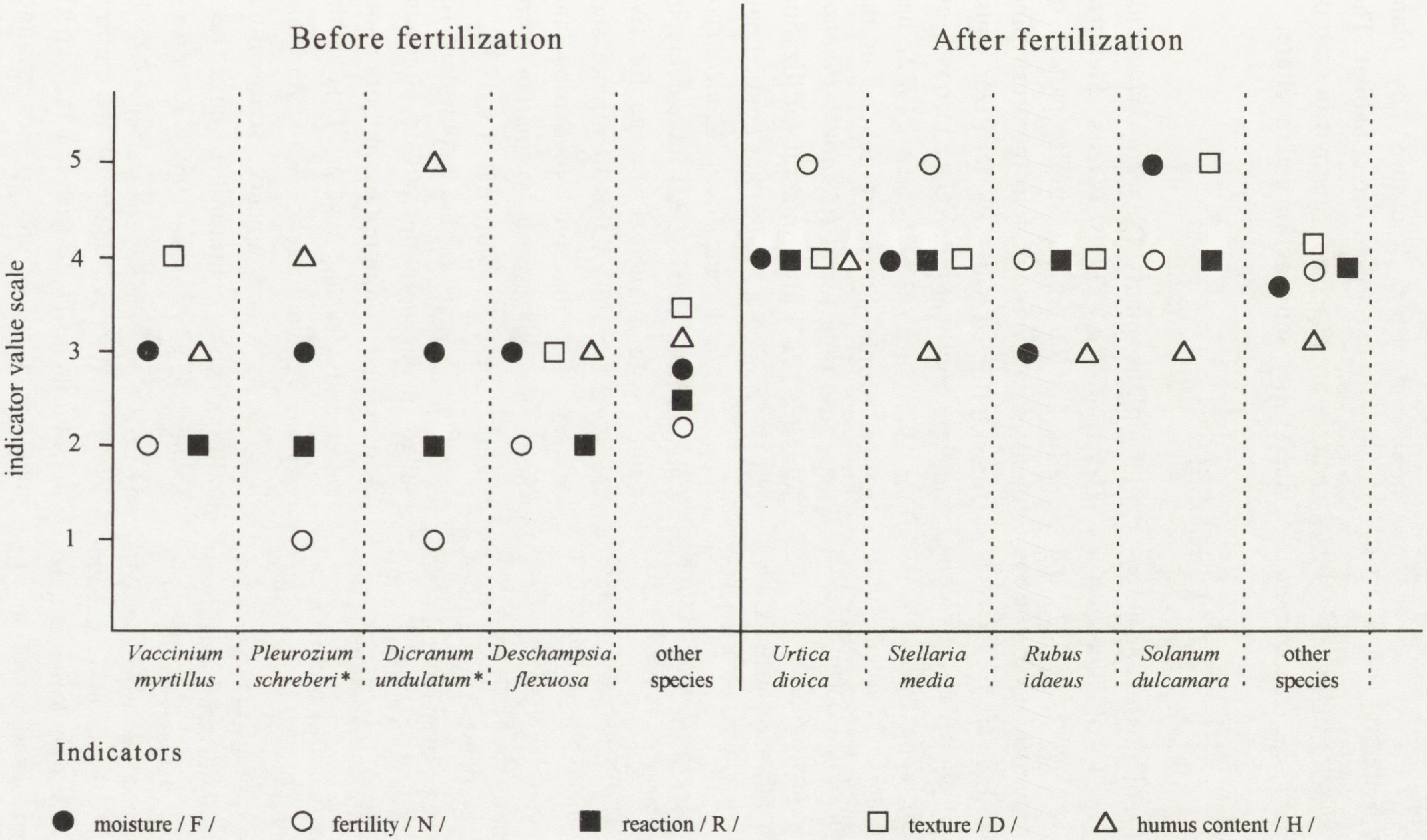
Index of humus and organic matter content (H). Before fertilization, majority of species in the community were indicators of humus-mineral soils (H_3). A shift of index values toward peaty soils with mineral particles (H_4) was observed after 10-year period of sewage fertilization. It was a result of intensive development of *Urtica dioica* and occurrence of *Solanum dulcamara* and *Lycopus europaeus*.

Wide ecological range is characteristic of some species. Such species as *Trientalis europaea, Calamagrostis arundinacea, Anthoxanthum odoratum, Dryopteris carthusiana* and *Convallaria majalis* were observed on both natural and transformed sites.

However, majority of species have a narrow ecological range. Therefore, these species are good indicators of various habitat conditions.

Numerous observations and phytosociological analyses show that plant communities – especially lower syntaxonomic units – are better phytoindicators than particular plant species, since plant communities are characterized by a narrower ecological range than plant populations forming a particular phytocenosis (Braun-Blanquet 1964, Kostrowicki and Wójcik 1972, Wójcik 1983, 1988).

Prior to the fertilization, the Peucedano-Pinetum Mat. 1962 (1973) association was identified on the area studied. Typical combination of species from this association, the Dicrano-Pinion alliance and the Vaccinio-Piceetea class was observed. A relatively high floral richness was characteristic of this community belonging to fresh pine forest type. Ten-year-period of starch sewage treatment resulted in a dis-



* in case of mosses texture was not taken into account

Fig. 6. Changes of site conditions estimated by means of predominant species

turbance of the forest ecosystem characterized by a narrow ecological range. New vegetation system was formed consisting of species belonging to at least five vegetational classes: Epilobietea angustifolii, Chenopodietea, Artemisietea, Molinio-Arrhenatheretea and Alnetea glutinosae.

Fig. 7 shows that fertilization has a significant effect (measured by plant communities) on pine forest habitat. The changes are especially distinct in case of site fertility, soil reaction and moisture.

5. DISCUSSION

High abundance of mosses and herbaceous plants is typical of pine forest ground flora (Matuszkiewicz and Matuszkiewicz 1973, Zaręba 1975). Mosses, alike lichens, are the most specialized group of plants, directly connected with the soil, appeared to be the most sensitive indicator of habitat conditions in those phytocenoses. Herbaceous plants of a narrow ecological range are sensitive phytoindicators, as well (Landolt 1977, Ellenberg 1974, 1988, Ellenberg et al. 1992, Wójcik 1983, 1988, Zarzycki 1984). Response of particular species and vegetational changes are an excellent illustration of habitat alterations, especially in case of industry impact. Using plant species, their ecological groups or plant communities, some habitat properties may be described without expensive soil analyses nor laboratory-analytical methods. Obviously, bioindicative (phytoindication) methods can not replace the analytical ones but phytoindication can be applied on larger scale, e.g. in landscape studies and selectively supplemented with analytical methods. These methods can successfully be used in studies of forest ecosystems protection (recognition of threats, monitoring etc.).

The impact of sewage rich in nutrients (N, P, K, Ca, Mg, and others) degenerated of native ground flora and led to invasion of anthropogenic vegetation in the forest habitat. Pinewood species were successively replaced mainly by the nitrophilous plants (*Senecio sylvaticus, Urtica dioica, Rubus idaeus, Stellaria media* and others). A similar pattern of changes was observed in the fresh pine forest fertilized with NPK fertilizer, caustic lime and bentonite (Guzikowa et. al. 1976). Fałtynowicz (1982) has noticed diminishment of lichens in the cup-moss pine forest (*Cladonio-Pinetum* Juraszek 1927) after mineral fertilization (NPK). Zaręba (1978) has studied patches of a fresh pine forest (*Leucobryo-Pinetum* Mat. 1962 1973) intensively irrigated with municipal sewage for five years. As a result of this treatment, succession of herbaceous vegetation and shrubs tended towards a riparian community (*Salici-Populetum* R. Tx. 1931).

First 3 years of the experiment resulted in degeneration and development of truncated communities in both pinewood and clearing system. This is the way the vegetation reacts on severe man impact. As a consequence, semi-natural anthropogenic communities have been formed (Faliński 1969, Kornaś 1977, 1982, Mirek 1981, Olaczek 1982). Further influence of the anthropogenic factor (4–10 years of the experiment) resulted in new species arrangement. Faliński (1969) has included similar phytocenoses into ksenospontanous type of communities. Olaczek (1982) has called such communities spontaneous anthropogenic phytocenoses.

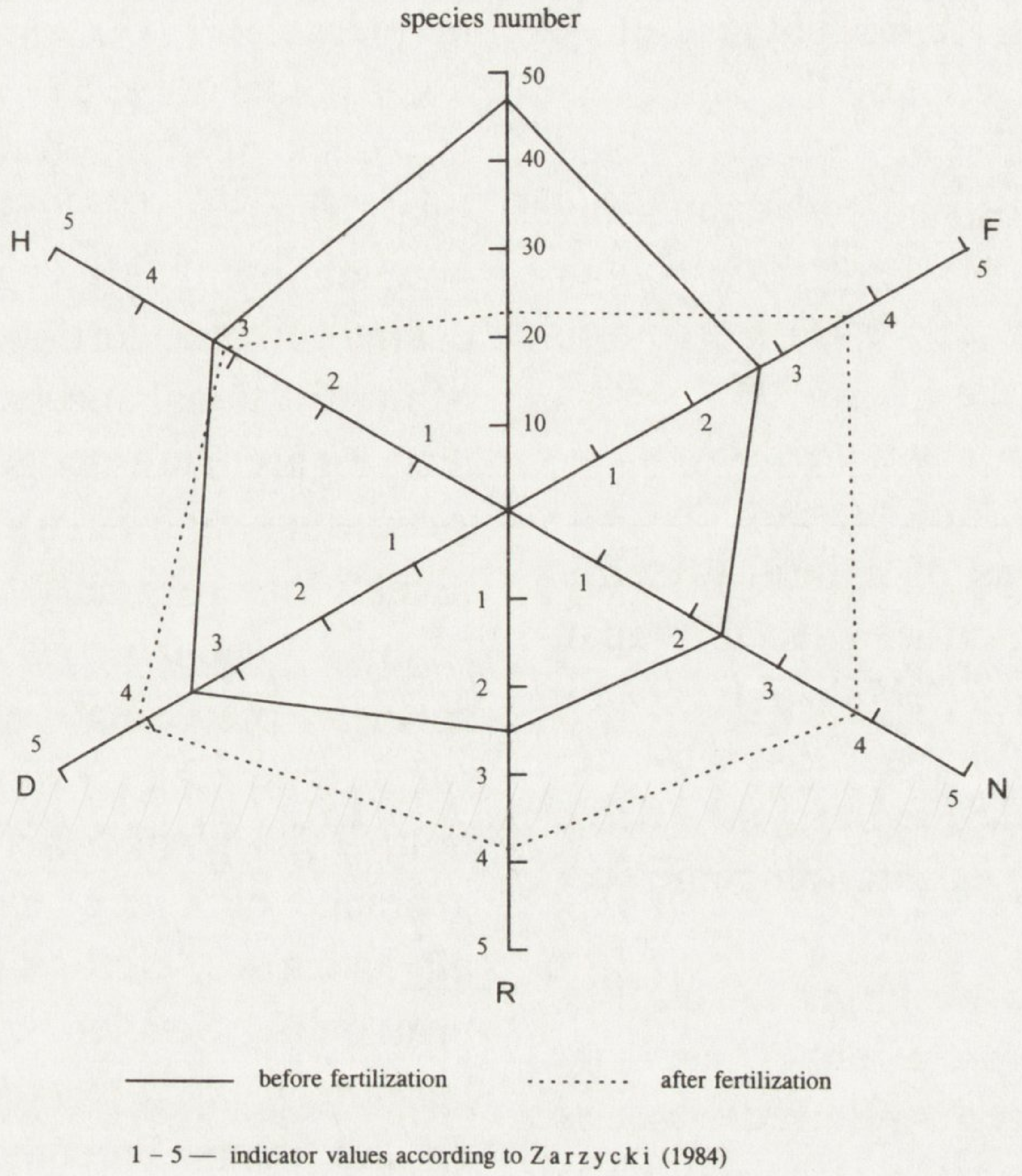


Fig. 7. Changes of site conditions estimated by means of plant communities
1–5 – indicator values according to Zarzycki (1984)
Symbols explanations – see Fig. 6

In this study, quantitative degeneration changes were indicated according to Olaczek (1972) by ratio of species typical of pine forests (euphytes) to extraneous species (allophytes). Faliński's (1966) concept of six degeneration phases is complementary to this method. The method is based on successive elimination of species and decline in subsequent syntaxonomic groups of species. Mirek (1974) has stressed the limitations of the degenerative phase system. According to his opinion, it is results from the relative position and rank of species in the phytosociological system, and discrepancy between taxonomic and ecological units. Mirek's (1974) analysis of the degenerative phase system does not question the idea of the system but shows objective problems which can occur in practice. The degenerative phase system was applied in the study unconditionally. It seems that this method can by useful in studying spontaneous degeneration of natural plant communities, especially when degeneration consists in invasion of foreign plant species, which is typical of strong anthropopression (fertilization, pollutant emissions, etc.).

In phytosociological literature there are only few examples of phytocenoses degenerated by fertilization. Forest phytocenoses degenerated by other anthropogenic factors were described by Tüxen (1950), Mikyška (1964, 1968), Faliński (1966, 1969), Olaczek (1974) and others.

Intensification of man activity leads to weakening, disturbance and even collapse of ecosystem homeostasis. Ecosystems loose indigenous self-protection features and, as a consequence, the communities are exposed to invasion of extraneous species – immigrant, i.e. anthropophytes (neophytes, epecophytes etc.). These phenomena, commonly called synanthropization, can be measured and evaluated by degrees (indices) expressing synanthropization of vegetation cover (Faliński 1966, 1969, Krawiecowa 1968, Olaczek 1972, 1982, Rabotnow 1985, Dyguś 1996a).

In literature, various terms have described deformations of natural or seminatural plant communities caused by man activity. Sukopp (1978) and Olaczek (1972, 1974) have called these deformations as "anthropopression", while Moravec (1969) as anthropogenic succession.

Similar changes resulting in simplification of plant system under man influence have been referred to as retrogression (Moravec 1969, Whittaker and Woodwell 1973, Sukopp 1978). Anthropogenic changes in plant communities were also called allogenic (Danserau 1974, Kershaw 1978, Odum 1982) or biogenic succession (Danserau 1974) whereas changes caused by industrial pollution – industriogenic succession (Wolak 1969, 1970). Last stages of anthropogenic succession have been named anthropogenic subclimax (dysclimax) (Odum 1982).

Common features of these successive processes are directional vegetation transformations with time under the influence of external factors (indirectly related to vegetation).

Many species (populations), so-called "explerents", appeared in the degenerated phytocenoses. Those species formed first stages of habitat regeneration, appearing in place of diminished components of phytocenosis (Rabotnow 1985). In this study, the term "explerents" was replaced by "initial species (populations)" commonly used in Polish literature (Symonides 1979, Gruszczyńska and Symonides 1989).

Lack of competition favoured rapid establishment of initial vegetation. Most populations of this vegetation group appeared at the fertilized clearing area. Multidirectional succession was found in this highly anthropogenic environment. According to Falińska (1989a, b) it reveals heterogeneity of habitat, which enables spontaneous appearance of species preceding succession. Those species (promoters) stimulate transformation of the phytocenosis and initiate appearance of a new one. In the studied phytocenoses, following species were promoters: *Senecio sylvaticus, Lolium perenne, Conyza canadensis, Urtica dioica* and others. Perennial aggregations of species limiting species replacement occurred on the clearing area, e.g. *Calamagrostis epigeios, Elymus repens.*

Severe anthropopression initiated euhemeroby phenomenon (kind of hemeroby). Euhemoroby consisted in a decrease in soil acidity and development of synanthropic communities, mainly ruderal and segetal ones (Sukopp 1973, 1978).

Species of weed communities of root crops from the Polygono-Chenopodietalia order appeared on both fertilized areas: forest and clearing. These species were spread by their diaspores contained in the starch sewage. This type of diaspore propagation is called anthropo-hydrochory (Holub and Jirásek 1971) or rypochory (Lhotská 1973, Kopecky 1978).

One should emphasize that fertilization of oligotrophic forest sites with sewage rich in mineral and organic matter may adversely influence productivity of native stand, water conditions and biochemical processes in forest ecosystems.

6. CONCLUSIONS

1. Long-term organic sewage fertilization applied to oligotrophic pinewood habitats may initiate invasion of synanthropic (Chenopodietea, Polygono-Chenopodietalia), clearing (Epilobietea angustifolii, Epilobion angustifolii, Sambuco-Salicion), meadow (Molinio-Arrhentheratea), and ruderal (Artemisieta), riparian (Alno-Padion) and alder carr (Alnetea glutinosae) species.

2. Such anthropogenic factors as clear-cut, tree planting or fertilization are reasons of many modifications in forest habitats. Degeneration of forest vegetation is one of symptoms of these modifications.

3. Ellenberg's method of phytoindication may be successfully applied to evaluation of habitat changes in ecosystems under severe anthropopression and used in study on ecosystem protection.

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7. SUMMARY

In this paper, results of studies on effects of starch sewage fertilization on composition and structure of ground flora of pinewood and clearing phytocenoses are presented. The study area, so-called soil-vegetation sewage treatment works, was situated in a fresh pine forest. Sewage was mainly contaminated with organic (carbohydrates and protein) and mineral compounds rich in potassium, nitrogen, phosphorus, calcium and other elements (Table 1).

Fertilization of the forest ecosystem with sewage rich in organic and mineral compounds disturbed previously balanced system – fresh pine forest (*Peucedano-Pinetum*). Ruderal (Artemisietea), riparian and alder carr (Alnetea glutinosae, Alno-Padion, *Circeo-Alnetum)* vegetation determined directions of ground flora transformations after 10 years of sewage fertilization (Fig. 1, Table 2). At the same time, the similarly fertilized clearing phytocenosis tended towards ruderal (Artemisietea) and clearing (Epilobietea angustifolii) communities with high abundance of meadow species (Molinio-Arrhenatheretea) (Fig. 2, Table 3).

The native ground flora underwent complete degeneration under influence of the anthropogenic factor (fertilization). This process was gradually intensified with time gradient and doses applied (Fig. 3, Fig. 4). In the clearing phytocenosis, ground flora degeneration occurred as influenced by three successive factors: (1) clear cutting, (2) tree planting and – similarly as in pine forest phytocenosis – (3) fertilization (Fig. 3 and 5).

Habitat changes induced by starch sewage were shown on the basis of indicative properties of species, and grops of pinewood and anthropogenic plant species. Vegetation responded to biological and physico-chemical changes in the soil (fertility, moisture, reaction, texture and humus and organic matter content). A significant increase in fertility, pH, and moisture of the habitat was revealed (Fig. 6, Fig. 7).

8. POLISH SUMMARY

W pracy przedstawiono wyniki badań dotyczących wpływu nawożenia ściekami krochmalniczymi na skład i strukturę runa w fitocenozie borowej i porębowej. Obiektem badań była tzw. glebowo-roślinna oczyszczalnia ścieków krochmalniczych, zlokalizowana na powierzchni sosnowego boru świeżego. Głównymi zanieczyszczeniami ścieków są związki organiczne, tj. węglowodany i białka oraz duża zawartość potasu, azotu, fosforu, wapnia i innych związków mineralnych (tab. 1).

Nawożenie ekosystemu leśnego bogatymi w związki organiczne i mineralne ściekami zachwiało zrównoważony dotąd układ leśny – świeży bór sosnowy (*Peucedano-Pinetum*). Kierunek rozwoju runa w fitocenozie borowej – po 10 latach nawożenia ściekami – wytyczyła grupa roślinności ruderalnej (Artemisietea) i łęgowo-olesowej (Alnetea-glutinosae, Alno-Padion, *Circaeo-Alnetum*), (rys. 1, tab. 2). Natomiast – w tym samym czasie i podobnych warunkach nawożenia – przemiany roślinności w fitocenozie porębowej obrały kierunek rozwoju ku zbiorowiskom ruderalnym (Artemisietea) i porębowym (Epilobietea angustifolii) ze znacznym udziałem gatunków łąkowych (Molinio-Arrhenatheretea), (rys. 2, tab. 3).

Pod wpływem czynnika antropogenicznego (nawożenie) rodzime runo w fitocenozie borowej uległo całkowitej degeneracji. Proces ten nasilał się stopniowo zgodnie z gradientem czasu i wielkości stosowanych dawek ścieków (rys. 3 i 4). Degeneracja runa w fitocenozie porębowej nastąpiła pod wpływem trzech następujących po sobie czynników antropogenicznych: (1) zrębu zupełnego, (2) introdukcji drzew i – podobnie jak w fitocenozie borowej – (3) nawożenia (rys. 3 i 5).

Zmiany siedliskowe wywołane oddziaływaniem ściekami krochmalniczymi wykazano w oparciu o wskaźnikowe właściwości gatunków i grup gatunków roślin borowych i antropogenicznych. Roślinność zareagowała na zmiany biologiczne i fizykochemiczne gleb (trofizm, wilgotność, odczyn, dyspersja, zawartość materii organicznej i humusu). Wykazano m.in. wyraźny wzrost trofii, pH i wilgotności siedliska (rys. 6 i 7).

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