J. Aquat. Plant Manage. 31: 148-154

The Impact of Mechanical Harvesting Regimes on the Species Composition of Dutch Ditch Vegetation: A Quantitative Approach

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ABSTRACT

It was demonstrated that management regime can influence the species composition of ditch vegetation. This effect, however, is very small compared to the effects of other factors such as the within-site spatial variation and soil and water quality. Cutting late in November had the largest effect.

The vegetation was composed of 139 plant species. The semi-aquatic and aquatic species were less numerous than the terrestrial ones (52 compared with 87). The total number per vegetation type and site ranged from 2 to 49, that of persistent plant species from 1 to 22. Only 20% of the species were influenced significantly by management regime.

Significant effects inherent to within the year repeated management regimes on plant species were ascribed to (1) freeing sites for colonization of new species, (2) improving the light climate for seedlings, which had already colonized, and (3) exhaustion of carbohydrate reserves of solitary species. Management once a year had the reverse effect and caused suffocation due to its undecomposed autumn harvest.

The highest species richness was attained for the semi-aquatic and aquatic vegetation: (1) on sand and clay by cutting three times per year, (2) on peat by cutting once a year (late in November); and for the shore vegetation: (1) on sand and clay once a year (in spring) or two times per year (in spring and summer), and (2) on peat, once a year (in spring or late autumn).

Key words: wetland vegetation, ditches, species-environment relations, conservation, The Netherlands.

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INTRODUCTION

The largely cultivated landscape of The Netherlands, rich in embankments, grassland and arable land, is frequently dissected by ditches which form an intricate interconnecting network. Particularly in the low-lying parts of the country the ditch length can be considerable, varying from >225 m/ha in parts of the provinces of Utrecht and Zuid-Holland to 26 to 75 m/ha in the peat-grasslands of the provinces of Noord-Holland, Zuid-Holland and Friesland (Bruinsma 1982).

The management of ditches usually falls under the jurisdiction of water management services like Water Boards and Provincial Services, cooperating with the national service, "Rijkswaterstaat." Ditch management practice was aimed in the past at securing the transport of water from areas with a surplus, involving the complete removal of vegetation mass by mechanical harvesting. Public awareness that ditches can be valuable landscape elements and may function as refugia for plant species is growing, as is the willingness of water management agencies to modify their ditch-cleaning practice to better suit nature conservation purposes. These modifications would involve not the complete but the partial removal of the vegetation mass and changes in timing and frequency of mechanical harvesting. It remains to be seen, however, if, and which, changes in ditch-cleaning practice will be sufficient to conserve or enhance natural values.

Recently attention has been given in The Netherlands to the various effects of mechanical harvesting practices (frequency, timing and equipment; Melman 1991, Van Strien *et al.* 1991, Ter Stege and Pot 1991) and to the effects of several environmental factors (Van Strien *et al.* 1989) on the vegetation of ditch banks. These studies had a more observational than experimental nature. Information on the quantitative effects of well-described management regimes on species composition of aquatic and shore vegetation of ditches versus the effects of environmental factors is lacking.

This study was carried out to investigate whether species composition and species richness of aquatic and shore vegetation can be influenced by mechanical harvesting regime, the issue being that if influence could be demonstrated then mechanical harvesting regime could be a useful tool for nature conservation. An experimental approach was chosen in which management regime was the factor to be tested and in which the duration of the experiment was secured. This was done, because in all other studies uncertainties regarding the exact nature and performance of management regime were obvious, and often the number of years during which the vegetation was treated varied, obscuring the evaluation of the results.

The present study is aimed at quantifying the impact of mechanical harvesting regime on species composition of ditch vegetation. Three underlying questions can be distinguished in regard to this: (1) Is it possible to demonstrate an impact of mechanical harvesting on the species composition of ditch vegetation? (2) Which environmental factor (including mechanical harvesting) affects the species composition of ditch vegetation the most? and (3) Which species are sensitive to mechanical harvesting regime and which are tolerant?

METHODS

Site characteristics. Six ditches were chosen, which at the beginning of the experiment were judged representative for ditches in low-lying agricultural areas. The total of six ditches was composed of two groups of three ditches of which one group was supposed to have eutrophic fresh water and one group eutrophic brackish (Cl-concentration>300 mg/l) water. Division into the fresh and brackish group was based on the water quality data of the preceding 5 yrs. Both ditch groups encompassed one sand, one peat and one clay bottom (soil quality according to the national soil survey map (De Bakker and Locher 1991). All ditches were similar in history (dredged longer than 1 yr ago), land use (both sides in use for agriculture), morphometry (4 to 6 m wide, 0.3 to 0.5 m deep) and exposure to irradiation (north-south orientation). The last characteristic entailed that most ditches were situated in the southwest of The Netherlands.

In the course of the experiment, however, it became clear that the actual characteristics deviated from those originally ascribed to the sites chosen. New water quality data indicated that two sites, which were expected to have brackish water (Callantsoog and Tempelpolder) in reality had fresh water most of the time. Three sites, which were supposed to have a thick monotypic topsoil, turned out to have a two-layered topsoil (Hazerswoude-Rijndijk, Callantsoog and Zonnemaire). Thus, the experiment encompassed five freshwater sites and one brackish site, and the soil for aquatic and shore vegetation differed at Callantsoog, Hazerswoude-Rijndijk and Zonnemaire (Table 1).

Cutting regimes, cutting method and experimental design. The effects of four management regimes on the species composition of ditch vegetation were investigated. The criteria for the choices of these regimes were that they are (a) currently in use in The Netherlands and (b) satisfy legal requirements to maintain the primary ditch function. On the basis of these criteria the following three regimes were chosen: (1) 1 x p.y. (May), (2) 2 x p.y. (May, July), (3) 3 x p.y. (May, July, September), abbreviated as M5; M5, 7 and M5, 7, 9. The fourth management regime chosen was carried out late in November (M11), which is later than usual (August-September). This regime was thought least detrimental for the vegetation but was required to maintain the ditches' open water zone. The regimes were imposed during three successive years (1989-1991). Ditches in The Netherlands are usually dredged once every five years, and therefore the duration of this experiment is representative for the normal "lifetime" of Dutch ditches.

One cutting method, a mowing basket, was utilized. The harvested plant material was deposited on the ditch sides; consequently, nutrients in the plant mass were removed from the water and added to the ditch banks. This method is the one most widely utilized in The Netherlands.

At each ditch a randomized block design was used to investigate the effects of management regimes. A stretch of

TABLE 1. SIGNIFICANCE TEST OF MECHANICAL HARVESTING ON SPECIES COMPOSITION. DATA ALL SITES TESTED PER YEAR (test of significance of trace static; RDA, CANOCO).

Vegetation	1989			1990			1991		
	P-value	F-ratio	Trace	P-value	F-ratio	Trace	P-value	F-ratio	Trace
Aquatic	0.01	1.52	0.01	0.01	1.62	0.01	0.01	1.40	0.01
Shore	0.01	5.84	0.08	0.01	1.96	0.02	0.08	1.27	0.01

100 m was used for the experiment. Each stretch was divided into five sequential, 20-m-long blocks in the south-north direction. Each block was composed of a western shore portion, a ditch portion and an eastern shore portion. The four management regimes were randomized within the blocks.

Vegetation. Aquatic and shore vegetation were described separately. Aquatic vegetation grew in the permanently inundated part of the ditch, shore vegetation on the lower bank parts as far as the influence of the water on vegetation was visible.

Plant species were recorded annually (mid-July) in five plots of 5 by 4 to 6 m (aquatic vegetation) and 5 by 0.30 m (shore vegetation). Each year relevés were made of the aquatic vegetation (one per location per block per treatment) and the shore vegetation (two, one on each side of the ditch, per location per block per treatment). The actual percentage cover per species was estimated. Rare species received a cover percentage of 0.1. Nomenclature of vascular plant species follows Van der Meijden *et al.* (1990). Filamentous algae were considered as one group. Mosses were excluded.

The plant species (139) of the full dataset were classified into eight ecological groups, notably: three terrestrial groups (grasses, sedges and herbs) and five semiaquatic plus aquatic groups (pseudohydrophytes, helophytes, pleustohelophytes, reptohelophytes and hydrophytes; according to Den Hartog and Van der Velde, 1988). The terrestrial groups were subdivided into two life forms, notably annuals and perennials. The classes of the semiaquatic and aquatic plants are distinguished largely using life form as criterion. Both the terrestrial and the semiaquatic and aquatic groups were ranked according to flowering period to investigate the relationship between the timing of management regime and the cover of the species.

Species which tolerated the same management regime for three successive years at a site were termed persistent. Species absent at the beginning but present at the end of the experiment at the same management regime at a site were termed as species increase. Species present at the beginning and absent at the end of the experiment were termed as species decrease.

Sampling and analysis of soil and water. Representative soil samples were taken at the beginning of the experiment: of the ditch bottom, one sample per location per block; of the bank, two samples, one on each side of the ditch (15-cm sampling depth, core volume 295 cm^3; roots removed by hand before processing). Soil and water samples were transported to the laboratory and kept deep-frozen until analysis. The average values of five replicates were used in the statistical analyses.

Representative water samples were taken monthly at each site (1989-1991; surface water). Water temperature and transparency (Secchi disk) were recorded *in situ.* The average summer values (April-September) for each year were used in the statistical analyses.

The soil samples were analyzed for granular composition, and the contents of organic matter, $CaCO_3$, total-N and total-P. The contents were expressed on dry weight basis.

The water samples were analyzed for pH, and the concentrations of HCO_3^-, nitrogenous compounds (total N, NH_4^+ and NO_3^-), phosphorus compounds (total and $H_2PO_4^-$) and Cl^-. Determinations were according to Dutch standard methods (Best, in press).

Statistics. Aquatic vegetation and shore vegetation were analyzed separately.

Two statistical approaches were used: redundancy analysis and analysis of variance.

Redundancy analysis (RDA) was applied to analyses of relevés and both measured and nominal environmental data. Version 3.1 of the program CANOCO (Ter Braak and Prentice 1988, Jongman *et al.* 1987) was used. RDA is a technique which relates a set of multivariate data (vegetation relevés) to explanatory variables (environmental variables). The latter consisted in the analysis of soil parameters (four grain size classes, and the organic matter contents, $CaCO_3$, total-N and total-P), water parameters (temperature, pH, and the contents of HCO_3^-, NO_3^-, NH_4^+, $H_2PO_4^-$ and Cl^-), and the nominal variables management regime (1-4), site (1-6) and block (1-5).

It was tested whether the species composition of the vegetation was affected by management regime after elimination of the site and block effects (CANOCO; overall significance tested by Monte Carlo permutation test at the 1% level). All samples per vegetation type and all environmental variables were included in this ordination. The percentage cover data were transformed to the natural logarithms, after addition of 1 to accommodate zero values. The management treatments were used as environmental variables and sites and blocks as covariables.

Analysis of variance (ANOVA; Genstat V.1 Package) was used to assess the sensitivity of plant species to management regime. Only those species were tested which (1) occurred in >15% of all relevés per vegetation type (aquatic or shore) and (2) were present for three successive years at any particular site (1 of 6). Effects of sites and blocks were eliminated. Effects at confidence levels below 10% were noted as significant. This analysis unfortunately provides only information on the frequently occurring species with often high cover. So far it proved technically unjustified to analyze data of infrequent species with often low cover, usually comprising the rather rare species in The Netherlands. Therefore, analysis of this group still remains "handwork."

RESULTS AND DISCUSSION

The impact of management regimes on the species composition of ditch vegetation. Management regime influenced the species composition of the aquatic and shore vegetation only to small extent. The management effect was continuously significant on the aquatic vegetation, and only during the first and second experimental year on the shore vegetation (Table 1, $P < 0.01$). The fraction variation in the vegetation response explained, however, was very small (trace < 0.08).

From an RDA test per site (data not shown) it became clear that the variance explained by the blocks usually exceeded the variance explained by the management regimes indicating that most variation in species composition at any location was caused by block-related factors. It was, therefore, wise to carry out the experiment in blocks. Various soil and water quality parameters usually also explained a larger fraction of variance than mechanical harvesting did (Best, in press). M11 had the largest impact. M5,7 sometimes significantly affected the aquatic vegetation, and M5 and M5,7,9 the shore vegetation.

Characteristics of ditch vegetation: species composition, species richness, tolerance and sensitivity to management regime. The vegetation of the ditches investigated was composed of 139 plant species (Table 2). The semiaquatic and aquatic species were less numerous than the terrestrial ones (52 compared with 87). Most semiaquatic and aquatic species were classified as helophytes (18 species) and hydrophytes (14 species); most terrestrial species as dicotyledonous herbs (61 species). One species, *Rorippa nasturtium-aquaticum*, has been listed as potentially endangered in The Netherlands (Van der Meijden *et al.* 1990).

Only 25 species (about 20% of total) were influenced significantly by management regime (Table 2). The effects of a particular management regime on a sensitive plant species could be significant on one soil type, but not on another pointing to the importance of nutritional status of the plant at the time of cutting. M11 proved the management regime causing most extremes in plant cover: under this regime the majority of the minima but also of the maxima in plant cover occurred.

The total and the persistent number of plant species varied strongly with location (Figure 1). The total number per vegetation type and site ranged from 2 to 49; that of persistent plant species from 1 to 22. The total number was highest for Reeuwijk (peat), somewhat lower for Callantsoog (sand/clay), intermediate for Hazerwoude Dorp and Hazerswoude Rijndijk (sand/sand and clay/sand), and lowest for Zonnemaire (sand/clay, brackish).

It was attempted to relate the significant effects of management regime to plant-inherent factors such as life form and cycle. Few distinct patterns emerged, which are discussed in more detail by Best (in press). Management several times a year, on one hand, opened up the vegetation, not only freeing sites for colonization of new species but also improving the light climate for seedlings, which had already colonized; on the other hand, it also exhausted carbohydrate reserves of solitary species. Management once a year had the reverse effect and caused suffocation due to its undecomposed autumn harvest. The latter has been pointed out already by Westhoff (1971) and more recently for ditch bank vegetation in particular by Melman (1991). Van Strien (1991), however, hypothesizes that infrequent mechanical harvesting (less than once a year) yields longer succession series and, therefore, more differentiation in plant species composition. Van Striens' hypothesis is supported by Ter Stege and Pot (1991).

Management geared at enhancing species richness. In this study the behavior of ditch vegetation for certain constant management regimes has been observed and expressed in terms of species composition, species richness and sensitivity and persistence to management regime. However, it may still be difficult for water management agencies to decide which regime might be a useful tool to conserve the natural value of ditch vegetation. Reasons for this are that (1) natural value can be expressed in different ways, mostly as species richness and the number of rare species (on a regional, national or international scale), (2) species richness is not constant over time, and (3) rare species can belong to ecologically different groups and, therefore, a certain management regime can be favorable for one desired species but not for another. It has been demonstrated, however, that species richness and the natural value of ditch bank vegetation are positively correlated (Van Strien *et al.* 1991), and, therefore, a high species richness can be used synonymously with natural value. From this it can be inferred that a suitable criterion for the most favorable management regime can be to aim at the highest "net" number of species possible for a particular location, *i.e.* the number of persistent species augmented by the newly colonized ones. Using this criterion, it becomes clear that there is not one most favorable management regime for ditch vegetation, but several favorable management regimes of which the degree of success is related to vegetation type (semiaquatic and aquatic versus shore) and soil class (Table 3). Management three times per year yields most species for the semiaquatic and aquatic vegetation on sand and clay, but management once a year (late in November) on peat. Management once (in spring) or two times per year (in spring and summer) allows most species for shore vegetation on sand and clay, and once a year (in spring or late autumn) on peat.

TABLE 2. PLANT SPECIES, ARRANGED ACCORDING TO ECOLOGICAL GROUP, HEIGHT (short <50 cm; tall >50 cm), LIFE FORM (LF: A, annual; P, perennial) AND FLOWERING TIME. S, SIGNIFICANCE (ANOVA; *, P <0.1).

Ecological group of species	LF	S	Ecological group of species	LF	S	Ecological group of species	LF	S
			TERRESTRIAL					
1. Grasses, short			**3. Herbs, short (Con't)**			**3. Herbs,tall (Con't)**		
Poa annua	A		*Spergularia arvensis*	A		*Polygonum persicaria*	A	
Alopecurus geniculatus	A	*	*Stellaria uliginosa*	A		*Solanum nigrum*	A	
Festuca rubra	P	*	*Geranium molle*	A		*Bidens tripartita*	A	
Agrostis stolonifera	P	*	*Matricaria recutita*	A		*Chenopodium album*	A	
Grasses, tall			*Polygonum aviculare*	A		*Polygonum hydropiper*	A	
Bromus hordeaceus	A	*	*Scutellaria galericulata*	A		*Bidens cernua*	A	
Alopecurus pratensis	P		*Juncus bufonius*	A		*Equisetum arvense*	P	
Anthoxanthum odoratum	P		*Matricaria discoidea*	A		*Ranunculus acris*	P	
Poa pratensis	P		*Scirpus setaceus*	A		*Anthriscus sylvestris*	P	
Poa trivialis	P	*	*Cerastium fontanum*	P		*Glechoma hederacea*	P	*
Holcus mollis	P		*Sonchus arvensis*	P		*Rumex acetosa*	P	
Dactylis glomerata	P		*Taraxacum officinale*	P	*	*Juncus conglomeratus*	P	
Holcus lanatus	P	*	*Cardamine pratensis*	P	*	*Lychnis floscuculi*	P	*
Catabrosa aquatica	P		*Bellis perennis*	P		*Stellaria palustris*	P	
Cynosurus cristatus	P		*Ranunculus repens*	P	*	*Rumex crispus*	P	*
Festuca arundinacea	P		*Potentilla anserrina*	P		*Cirsium palustre*	P	
Phleum pratense	P		*Sagina procumbens*	P		*Hypochaeris radicata*	P	
Elymus repens	P	*	*Plantago lanceolata*	P		*Juncus effusus*	P	
Festuca pratensis	P		*Prunella vulgaris*	P		*Lathyrus pratensis*	P	
Deschampsia cespitosa	P		*Trifolium pratense*	P		*Cirsium vulgare*	P	
Lolium perenne	P	*	*Trifolium repens*	P	*	*Cirsium arvense*	P	
2. Sedges			*Plantago major*	P		*Epilobium hirsutum*	P	
Carex nigra	P		*Rorippa sylvestris*	P		*Urtica dioica*	P	
Carex hirta	P		*Lotus corniculatus*	P		*Rumex obtusifolius*	P	
Carex cuprina	P		*Archillea millefolium*	P		*Senecio jacobea*	P	
Carex distans	P		*Leontodon autumnalis*	P		*Achillea ptarmica*	P	
Carex oederi	P		**Herbs, tall**			*Angelica sylvestris*	P	
Carex spec.	P		*Capsella bursa-pastoris*	A		*Rubus idaeus*	P	
3. Herbs, short			*Ranunculus sceleratus*	A		*Epilobium spec.*	P	
Senecio vulgaris	A		*Galium aparine*	A		*Rumex spec.*	P	*
Stellaria media	A							
			SEMIAQUATIC AND AQUATIC					
1. Pseudohydrophytes, short			**2. Helophytes (Con't)**			**4. Reptohelophytes**		
Myosotis palustris		*	*Eleocharis palustre*			*Rorippa amphibia*		
Galium palustre			*Glyceria fluitans*		*	*Rorippa nasturtium-aquat.*		
Triglochin palustris			*Phalaris arundinacea*			*Berula erecta*		
Pseudohydrophytes, tall			*Scirpus maritimus*			**5. Hydrophytes**		
Veronica catenata			*Lycopus europaeus*			*Elodea nuttallii*		*
Equisetum palustre			*Sparganium erectum*			*Potamogeton crispus*		
Oenanthe fistulosa			*Butomus umbellatus*			*Stratiotes aloides*		
Oenanthe aquatica			*Juncus articulatus*			*Potamogeton pectinatus*		*
Lysimachia nummularia			*Alisma plantago aquatica*			*Zannichellia palustris*		
Lotus uliginosus			*Polygonum amphibium*			*Ceratophyllum demersum*		
Sagittaria sagittifolia		*	*Glyceria maxima*		*	*Potamogen trichoides*		*
Ranunculus flammula			*Rumex hydrolapathum*			*Hydrocharis morsus-ranae*		
Mentha aquatica			*Phragmites australis*			*Potamogeton acutifolius*		
2. Helophytes			**3. Pleustohelophytes**			*Potamogeton pusillus*		
Carex disticha			*Wolffia arrhiza*			*Ranunculus circinatus*		
Carex acutiformis			*Lemna spec.*		*	*Potamogeton natans*		
Carex paniculata			*Lemna trisulca*			*Myriophyllum spicatum*		
Equisetum fluviatile			*Spirodela polyrhiza*		*	*Callitriche spec.*		
Iris pseudacorus			*Azolla filiculoides*					

TABLE 3. MANAGEMENT REGIMES ALLOWING THE HIGHEST "NET" SPECIES RICHNESS. BETWEEN PARENTHESES: THE NET INCREASE AND DECREASE IN SPECIES NUMBER RELATIVE TO THE NUMBER OF PERSISTENT SPECIES. Man., management.

Location name	Water type	Aquatic vegetation		Shore vegetation	
		Soil type	Man. regime	Soil type	Man. regime
Hazerswoude Dorp	fresh, eutr.	sand	M5,7,9 (+100%)	sand	M5 (-22%)
Callantsoog	fresh, eutr.	sand	M5,7,9 (+2%)	clay	M5,7 (+39%)
Reeuwijk	fresh, eutr.	peat	M11 (-7%)	peat	M5 (+2%)
Tempelpolder	fresh, eutr.	peat	M11 (+17%)	peat	M11 (-5%)
Hazerswoude Rijndijk	fresh, eutr.	clay	M5,7,9 (+28%)	sand	M5,7 (-46%)
Zonnemaire	brackish, eutr.	sand	M5,7,9 (+400%)	clay	M5,7 (+150%)

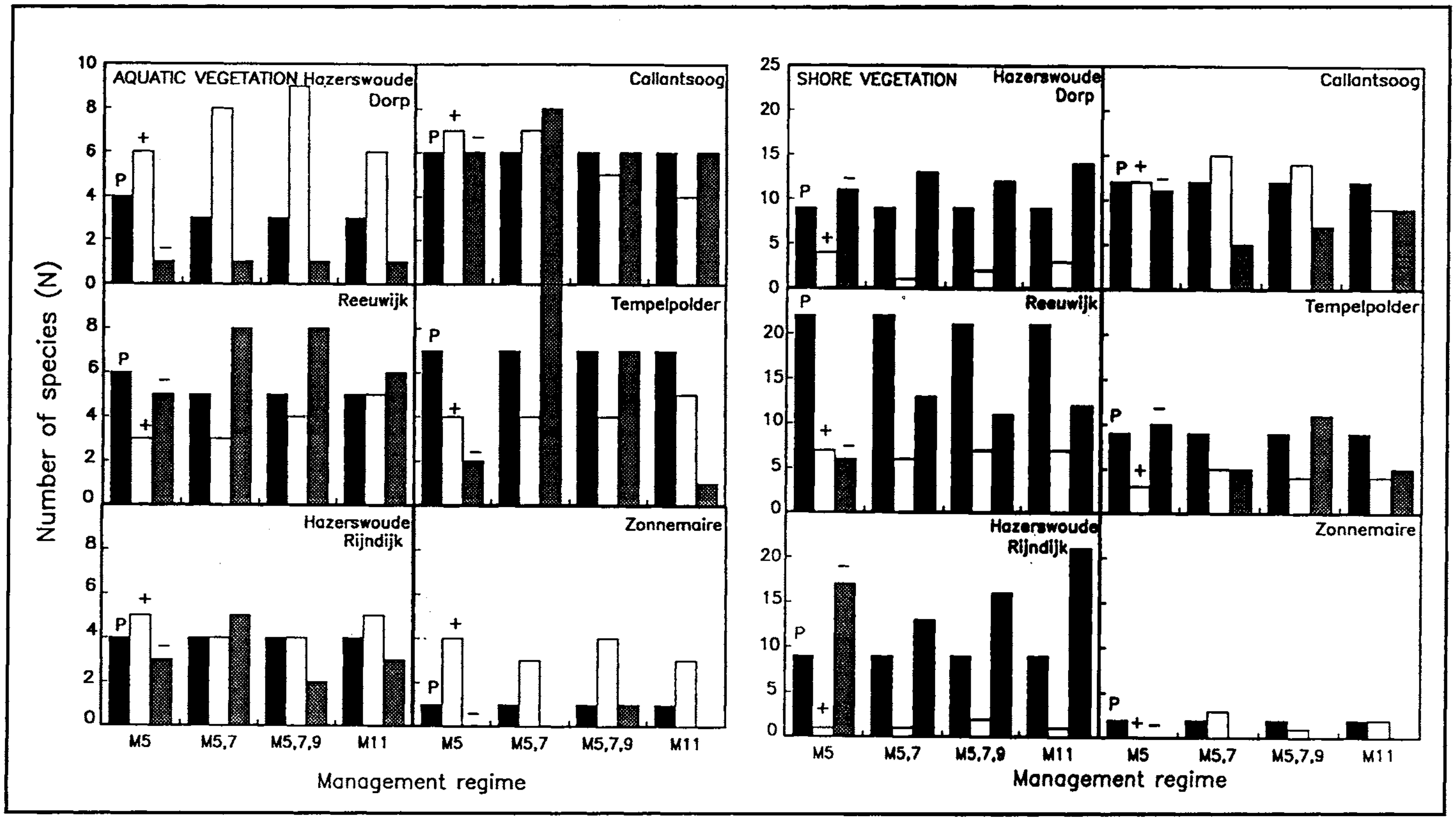

Figure 1. Numbers of plant species of the aquatic (left) and shore (right) vegetation which are persistent (P), increasing (+) or decreasing (-) due to the management regimes applied.

ACKNOWLEDGMENTS

I am very grateful for the support of several Dutch Water Boards (Hoogheemraadschap Rijnland, Leiden; Hoogheemraadschap Uitwaterende Sluizen, Edam; Waterschap Aangedijkte Landen en Wieringen, Anna Paulowna; Waterschap Schouwen Duiveland, Zierikzee) and the State Forest Service (Dept.Gouda) to this project. W.van der Zweerde and T.Kraak (CABO-DLO) made most of the relevés. C.J.F.ter Braak (Agricult.Mathematics Group, Wageningen) is greatly acknowledged for valuable discussions on the potential of CANOCO and for assistance in its use. J.Withagen (CABO-DLO) supported the performance of ANOVA using Genstat. F.H.H.Jacobs (CABO-DLO) assisted in the data analysis.

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