VEGETATION CHANGE FOLLOWING DYKE BREACHING ON THE ENGLISHMAN RIVER ESTUARY VANCOUVER ISLAND, BRITISH COLUMBIA A MULTIVARIATE ANALYSIS

Neil K. Dawe
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Abstract

In 1969, a dyke was constructed on the Englishman River estuary that isolated the western portion of the estuarine marsh from tidal influence. Over the next 10 years, the former marsh vegetation slowly changed to upland vegetation with species such as *Holcus lanatus*, *Epilobium angustifolium*, and *Alnus rubra* growing on the site. Some remnant estuarine species, such as *Carex lyngbyei* and *Distichlis spicata* remained.

In 1979, a 10 m breach was made in the dyke allowing salt water to inundate the site. As an adjunct to breaching the dyke, a study was quickly designed to monitor the changes in vegetation. The purpose of the study was to describe the changes in vegetation species composition and community structure over time and to determine how long it would take the restored estuarine marsh to approach a natural marsh in species composition and community structure.

Vegetation data were gathered from relevés placed along semi-permanent transects. The Braun-Blanquet cover abundance scale was used to estimate species cover. Environmental data were gathered from each relevé in 1986 to try to determine factors influencing the direction of the vegetation changes. Multivariate analyses were used to summarize the vegetation changes both within each year and over time.

Fifty-seven vascular plant species were recorded over the study period and their changes during the course of the study are discussed. Changes in communities and community structure are also given along with species and community relationships to environmental factors.

Eighteen species were eliminated from the study area, 12 of which did not survive the year of the breaching. Seven species colonized the area, the most dramatic of which were *Salicornia europaea* and *Spergularia canadensis*. Twenty-nine residual species occurred on the study area and are grouped according to whether they increased, decreased or remained relatively stable in frequency of occurrence and cover over the study period.

Community structure showed signs of stability by the eighth year of the study, with the marsh approaching vegetation composition and structure similar to other salt marshes in the area.

There is little doubt that the breaching of a dyke is an effective mechanism to restore former intertidal marshes into a functioning estuarine wetlands. The importance of proper planning and long-term monitoring studies associated with such restorations is emphasized.

Résumé

En 1969, une digue fut jetée sur l'estuaire de la rivière Englishman de manière à couper la partie ouest du marais estuarien de l'influence des marées. Au cours des dix années qui s'ensuivirent, la végétation de l'ancien marais s'est lentement transformée et est passée à une végétation de plateaux, avec la présence d'espèces telles que *Holcus lanatus*, *Epilobium angustifolium*, et *Alnus rubra*. Quelques espèces estuariennes ont survécu, comme *Carex lyngbyei* et *Distichlis spicata*.

En 1979, une brèche de 10 m a été pratiquée dans la digue; cela a permis à l'eau salée d'envahir le terrain protégé. Conjointement à cette mesure, on a rapidement entrepris une étude pour suivre les chagements dans la végétation. L'objectif de l'étude était la description des changements dans la composition des espèces végétales ainsi que dans la structure de la communauté en fonction du temps, et la détermination du temps qu'il faudrait pour qu'un marais estuarien rétabli présente à peu près la structure de la communauté et la composition spécifique d'un marais naturel.

Les données sur la végétation ont été prélevées à des stations placées à 5 m d'intervalle le long de transects semi-permanents. On a appliqué l'échelle de la densité de la couverture végétale Braun-Blanquet pour estimer l'importance de la couverture végétale. Des données sur le milieu ont été prélevées à chaque station, en 1986, afin de tenter de déterminer les facteurs qui agissent sur l'évolution de la végétation. On a appliqué des analyses multivariées pour faire un résumé des changements de la végétation chauqe année et sur plusieurs années.

Cinquante-sept espèces de plantes vasculaires ont été dénombrées au cours de la période d'étude; les transformations à ce niveau au cours de la période d'étude sont analysées. Les changements et la structure des communautés sont également indiqués, avec les espèces et les rapports des communautés avec des facteurs du milieu.

Dix-huit espèces sont disparues de la zone d'étude; douze ont disparu au cours de l'année qui a suivi l'overture de la brèche. Sept espèces ont colonisé le secteur. Les progrès les plus spectaculaires ont été obtenus par *Salicornia europaea* et *Spergularia canadensis*. Vingt-neuf espèces résiduelles ont été trouvées dans la région d'étude; elles sont regroupées selon qu'elles aient progressé, qu'elles aient perdu du terrain ou qu'elles soient restées relativement stables, compte tenu de leur fréquence d'apparition et de leur couverture au cours de la période d'étude.

Des signes de stabilité dans la structure de la communauté sont apparus à la huitième année de l'étude; à cette date, le marais avait commencé à prendre la composition et la structure végétales caractéristiques des autres marais salés de la région.

Il y a peu de doute que le fait de pratiquer une ouverture dans une digue constitue un mécanisme efficace de rétablissement d'anciens marais intertidaux à des marais estuariens fonctionnels. Il est fait mention de l'importance de bien planifier les opérations et de procéder à des études de surveillance à long terme lorsqu'on procède à de tels rétablissements.

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Introduction

Estuaries are well known for their high productivity and value as habitat for a variety of animals. In British Columbia, estuaries are particularly important to the survival of Pacific salmon and large populations of waterbirds. Waterfowl and shorebirds depend on those habitats during their spring and fall migrations. During the winter months, severe weather occasionally makes inland ponds and marshes as well as farmlands unavailable and estuaries then become critical habitat for thousands of birds that winter along the British Columbia coast. Estuarine habitat, however, is in short supply--only 2.3% of British Columbia's 27,000 km coastline is estuarine in nature (R. Hunter and L. Jones 1982. Coastal waterfowl and habitat inventory program: summary report. Unpubl. report. British Columbia Ministry of Environment and Ducks Unlimited Canada, Victoria, B.C.)

In the past, estuaries in British Columbia have been dyked or filled for agricultural or industrial purposes, and today many estuarine areas are still under threat. There is some evidence, however, that such threats are diminishing (Prentice and Boyd 1988). A number of marsh creation and dyke removal projects have been undertaken in an attempt to replace or recover habitat lost to industrial, agricultural, or urbanization activities. However, little published information is available that describes the effects of dyke breaching on the vegetation of marshes along the Pacific coast.

In British Columbia, Dawe and Jones (1986) briefly discuss changes in vegetation following a natural breaching of a dyke on the Cowichan River estuary, and Prentice (A.C. 1987. Vegetation change after dyke breaching at the Blackley Farm, Cowichan River estuary. Unpubl. report. British Columbia Ministry of Environment, Wildlife Branch, Nanaimo, B.C.) also describes vegetation changes following a planned dyke breaching on the same estuary. Campbell and Bradfield (1988) discuss changes in vegetation after dyke breaching at the Kokish marsh on northeastern Vancouver Island. Elsewhere along the west coast of North America, Josselyn and Perez (1981) describe vegetation changes following dyke removal at former salt evaporation ponds in San Francisco Bay, and Mitchell (1982) and Frenkel and Morlan (1990, 1991) provide similar information following dyke breaching on the Salmon River estuary in Oregon. All those studies report on short-term vegetation changes; only one continued beyond 4 years following the breaching of the dyke (see Frenkel and Morlan 1990, 1991).

Because of the importance of estuarine habitat to migratory birds, the Canadian Wildlife Service has been monitoring marsh creation and restoration projects on Vancouver Island since 1979 (see also Brownlee et al. 1984, Campbell and Bradfield 1988, Dawe et al. 1987). This paper reports the changes in vegetation that occurred over an eight-year period following the breaching of a dyke on the west marshes of the Englishman River estuary on the east coast of Vancouver Island. The objectives of our study were to describe the changes in vegetation species composition and community structure over time and to determine how long it would take the restored

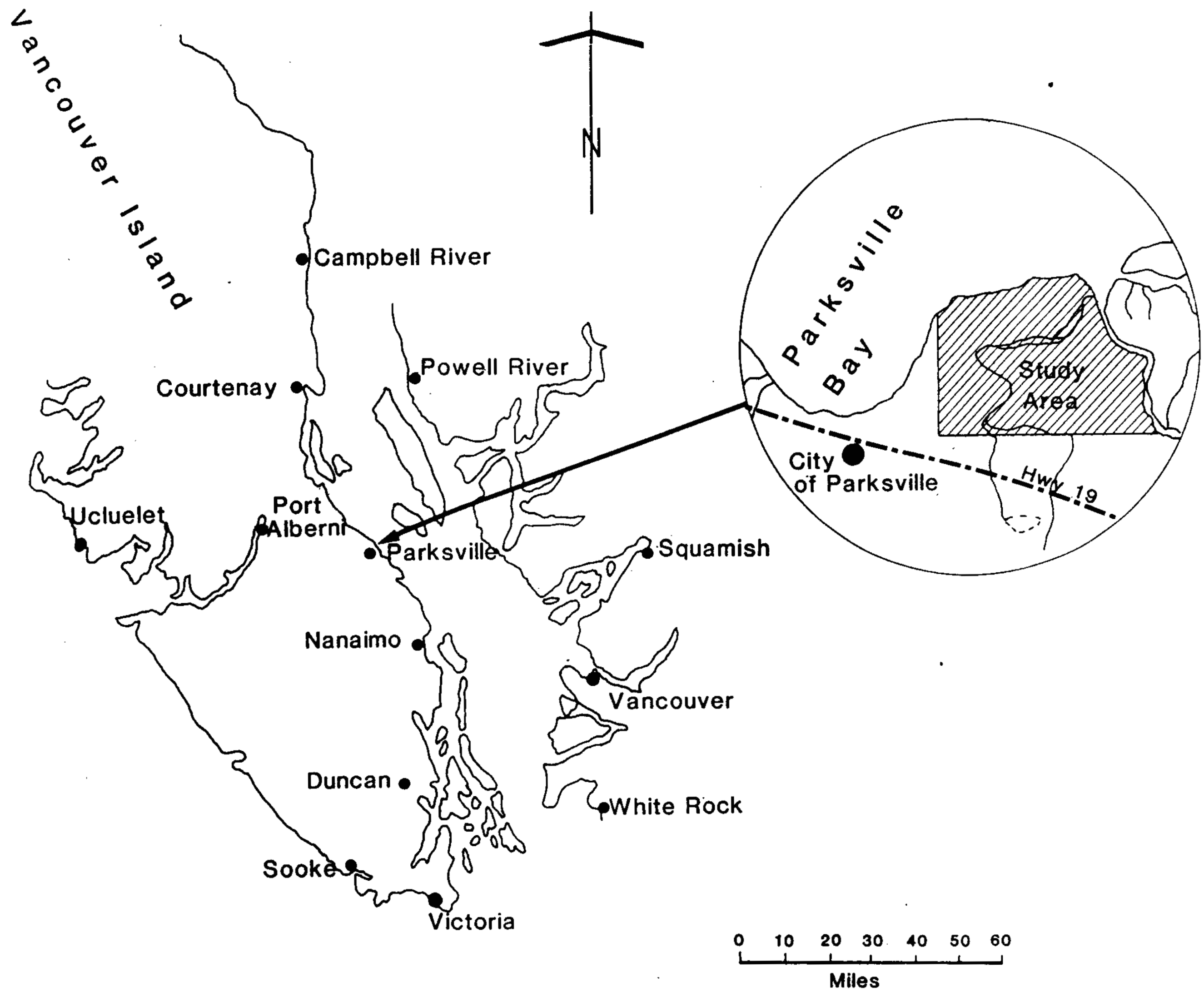

Figure 1. Englishman River estuary, showing the location of the study area.

estuarine marsh to approach a natural marsh in species composition and community structure. Environmental data were gathered in the final year of the study (1986) in an attempt to learn what factors were influencing the direction of the vegetation changes. We used multivariate analyses to help describe the vegetation changes over time. The results will be of value to anyone planning similar restoration projects; the species information will also be of use to those planning marsh creation projects along the south coast of British Columbia. A preliminary report of this study was presented in Dawe and McIntosh (1987).

Study area

The Englishman River estuary (49°20' N, 124°17' W) is situated on the east coast of Vancouver Island near Parksville, 32 km N of Nanaimo, British Columbia (Fig. 1). Mean temperatures (at Nanaimo, B.C.) vary between 3.3°C in January and 18.3°C in July and August. The area has a mean annual precipitation of 929.6 mm (Anonymous 1977). The mean annual discharge of the Englishman River is 14.8 m^3s^{-1}; peak flows occur in December (39.4 m^3s^{-1}), and low flows are during the growing season with the lowest flows in August (1.14 m^3s^{-1}). The river drains an area of 324 km^2 (Anonymous 1983). Channel and floodplain deposits consist largely of sand and gravel although they may be surfaced by silt, clay, or peat (Fyles 1963). The estuarine marsh covers an area of about 60 ha; the area of our study site on the western side of the river exceeds 35 ha.

In 1969, a dyke was constructed that effectively isolated the western portion of the marsh from tidal influence. A 30 cm culvert with a one-way flapgate was placed in the dyke which allowed freshwater runoff from the City of Parksville to flow through the former tidal channel and escape. By 1979 the flapgate was in disrepair; however, the culvert had been colonized by scores of blue mussels (*Mytilus edulis*) which effectively prevented all but a small amount of salt water access behind the dyke.

On 27 March 1979 the dyke was breached; a 10 m section was excavated in the dyke which connected the former tidal channel with one arm of the river. That allowed tidal inundation to once again take place on the western portion of the estuary (Tutty et al. 1983).

Kennedy (1982) carried out some preliminary vegetation work on the estuary in 1975 and 1976. Using aerial photography and field truthing, she recognized 19 vegetation communities on the east side of the estuary, and noted that the vegetation was dominated by species indicative of brackish, saline, and physiologically dry conditions. She did not include the west delta of the estuary in her survey, likely because it had been dyked and was no longer functioning as an estuarine wetland. Recently, Hutchinson (1988) included the Englishman River estuary in his classification of 17 deltas in the Puget Trough lowlands. The Englishman grouped with his Type C deltas which feature large areas of *Salicornia-Distichlis* communities with *Carex-Triglochin* and *Juncus-Potentilla* associations.

Methods

In June 1979, following the breaching of the dyke, 9 semipermanent transects were established across the study area. The end points of each transect were marked with cedar stakes and compass bearings were taken from each stake to prominent landmarks to enable transect location in future years. The transects were placed perpendicular to the main dendritic channel and ran from the highest point on one side of the channel to the highest point on the other. The transects were placed to traverse the variety of elevations on the study site.

Each year about the end of June, from 1979 through 1983 and in 1986, vegetation data were gathered at 5 m intervals along the transects. All vascular plant species within a 1 m^2 relevé were identified and recorded (see Dawe and White 1982, 1986). In 1979, all dead vegetation was carefully scrutinized to determine the species composition of vascular plants that grew there the preceding year. The relative cover of each species within the relevé was determined visually and its Braun-Blanquet cover/abundance value was noted (Mueller-Dombois and Ellenberg 1974). Species were grouped according to their status after the dyke was breached (modified from Mitchell 1982): upland species (species, including freshwater emergents, that were growing on the site in 1978 but were eliminated from the site by 1983), colonizing species (species that were not found on the study area in 1979 but were found in later years), ephemeral species (species that appeared and disappeared with irregularity), and residual species (species that were found on the site throughout the study). Our residual species were also grouped according to those that increased, decreased, or remained relatively stable in frequency and cover. We considered the residual species had either increased or decreased if they showed a change of at least 10 percent in frequency for at least two of the five years after their 1979 values. Increases or decreases in frequency and cover were also tested with simple linear regression. But that method would not indicate a significant change where a species (e.g. *Potentilla pacifica*) dropped in frequency from 1979 to 1980 and then stabilized thereafter or where a species (e.g. *Atriplex patula*) took advantage of the disturbance caused by the breach, colonizing rapidly after the first year (1979) but then dropping in frequency to gradually increase. Our "colonizing species" definition differed from Mitchell's (1982); she included residual species that increased in frequency and cover after dyke breaching in addition to those species that were new to the study site. Vascular plant nomenclature follows Hitchcock and Cronquist (1973).

The salinity of the inundating water and the soil salinity were determined as outlined in Dawe and White (1982).

In 1986, substrate elevation data were determined at the centre of each relevé measured from the nearest geodetic benchmark and subsequently converted to chart datum (see Dawe and White 1986). Also in 1986, soil samples were taken from each relevé and sent to the Ministry of Agriculture Soils Laboratory, Kelowna, British Columbia for determination of soil texture (hydrometer method) and organic content given as percent Carbon (see Chuah and van Lierop 1985). Prior to sending the samples for analysis, they were weighed, dried to constant weight in a ventilated drying oven, and reweighed to determine the percent moisture content of each sample.

The data were analyzed by both average linkage cluster analysis (using cosine separations of quadrat vectors as the similarity measure) and by correspondence analysis (Orloci 1978). Relevés that clustered at the 0.7 level were considered as communities in the community analysis. Only those species (considered dominant species) with combinations of a mean frequency > 10% or a mean cover value > 10% in at least 3 of the 6 study years were included in the analyses (Table 1). Although *Ruppia maritima* met the criteria it was subsequently removed from the analysis as it tended to act as an outlier.

Table 1. Dominant vegetation, species numbers, and abbreviations used in the ordination analyses for this study.

Species	Species Number	Abbreviation
Distichlis spicata	1	Dist spic
Salicornia europaea	2	Sali euro
Atriplex patula	3	Atri patu
Plantago maritima	4	Plan mari
Salicornia virginica	5	Sali virg
Spergularia canadensis	6	Sper cana
Hordeum brachyantherum	7	Hord brac
Grindelia integrifolia	8	Grin inte
Agrostis alba	9	Agro alba
Carex lyngbyei	10	Carx lyng
Poa pratensis	11	Poa prat
Achillea millefolium	12	Achi mill
Triglochin maritimum	13	Trig mari
Puccinellia nutkaensis	14	Pucc nutk
Festuca rubra	15	Fest rubr
Agropyron repens	16	Agro repn
Elymus mollis	17	Elym moll
Juncus balticus	18	Junc balt
Sonchus arvensis	19	Sonc arve
Polygonum aviculare	20	Poly avic
Bromus mollis	21	Brom moll
Hypochaeris radicata	22	Hypo radi
Aira praecox	23	Aira prae
Rumex acetosella	24	Rumx acet

A summary of the changes in vegetation composition over the study period was prepared by conducting a correspondence analysis of the frequency of occurrence data of the dominant species (see Table 2). The resulting scatter diagrams of both the species scores and year scores were superimposed to show the trend in vegetation changes over the years (see Figure 3). Product moment correlations of environmental variables with component scores from the first two axes were calculated, and the correlation coefficients of each axis were plotted as vectors to show trends in environmental variables on the study site in 1986. We correlated component scores from each year with those of the following year assuming that as the vegetation approached some stability the correlation coefficient would approach 1. Best estimates of mean cover/abundance for each species were calculated by summing the midpoint of each Braun-Blanquet scale range (i.e. by setting r=.01, +=.5 1=3, 2=15, 3=37.5, 4=67.5, 5=87.5) and dividing by the number of occurrences of the species within the dataset.

Results

Over the 10 years previous to 1979, most of the vegetation behind the dyke had converted to upland grasses, herbs, shrubs, and trees (e.g. *Holcus lanatus, Epilobium angustifolium, Pyrus fusca, Alnus rubra).* Because freshwater runoff from Parksville continued to flow through the former main channel of that portion of the estuarine marsh, freshwater species composed most of the channel edge vegetation (e.g. *Typha latifolia, Scirpus validus, Phalaris arundinacea*). Some remnant estuarine species (e.g. *Carex lyngbyei, Triglochin maritimum, Distichlis spicata*) were also present. Following the breaching of the dyke, saltwater in the order of 25 ‰ began inundating the site. Most of the upland vegetation was killed within the first year, as were the freshwater emergents *Typha* and *Scirpus*. In the second year, large areas of bare soil were exposed, interspersed with clusters of salt tolerant species such as *Distichlis spicata, Salicornia virginica,* and *Atriplex patula,* as well as colonizing species not recorded in the first year such as *Salicornia europaea, Spergularia canadensis,* and *Plantago maritima.* By the third year, colonizers had covered large portions of the bare soil and by the fourth year, perennial halophytes such as *Distichlis spicata* and *Salicornia virginica,* had begun to dominate the vegetation. Increases in perennial vegetation frequency and cover continued through 1986. See Appendix 1 for a photographic summary of the changes.

Species changes

From a total of 200 relevés, 57 vascular plant species were recorded over the study period. They, along with their mean covers and frequencies, are presented in Table 2, grouped according to their change over time following the breaching of the dyke.

Eighteen species were eliminated from the study area, 12 of which did not survive the year of the breaching. All were either species typically upland in habit or species intolerant of saline waters.

Table 2. Vascular plant species of the Englishman River estuary showing changes in percent frequency of occurrence (F) and mean percent cover (C) following breaching of a dyke which allowed salt water inundation to a former upland site. Species have been grouped according to their status after the dyke was breached: upland species, colonizing species, ephemeral species, and residual species.

	1979		1980		1981		1982		1983		1986	
	F	C	F	C	F	C	F	C	F	C	F	C
Upland species eliminated in 1979:												
Alnus rubra												
Pyrus fusca												
Rubus discolor												
Epilobium angustifolium												
Sambucus racemosa												
Aster subspicatus												
Juncus effusus												
Scirpus americanus												
Scirpus validus												
Dactylus glomerata												
Deschampsia cespitosa												
Phalaris arundinacea												
Upland species eliminated after 1979:												
Montia perfoliata	+1	1										
Stellaria media	+	3										
Cirsium arvense	17	28	4	7	1	2	1	+				
Taraxacum officinale	3	6	+	+	1	2	+	+				
Eleocharis palustris	1	1										
Typha latifolia	+	3										
Colonizing species:												
Salicornia europaea			10	1	29	7	42	7	43	13	36	5
Spergularia canadensis			20	2	32	14	35	5	31	4	27	2
Glaux maritima			3	+	4	1	9	1	9	4	9	2
Cuscuta salina			1	+	5	1	5	1	6	5	10	1
Plantago maritima			6	+	19	3	21	4	32	10	28	20
Cotula coronopifolia					2	1	3	+	3	1	3	2
Puccinellia nutkaensis			3	3	18	3	19	3	15	5	14	16
Ephemeral Species:												
Stellaria humifusa									1	+		
Hordeum jubatum					1	7			1	2		
Holcus lanatus	+	1	1	+							1	1

Table 2 (Continued)

	1979		1980		1981		1982		1983		1986	
	F	C	F	C	F	C	F	C	F	C	F	C
Residual species which increased in frequency:												
Polygonum aviculare	3	+	7	3	18	3	10	+	7	1	17	3
Atriplex patula	19	5	45	6	34	6	41	2	44	6	48	4
Salicornia virginica	+	+	10	2	17	7	18	14	25	19	35	16
Grindelia integrifolia	9	4	7	2	17	6	14	6	21	12	36	19
Distichlis spicata	19	3	28	16	34	24	41	27	48	36	51	43
Festuca rubra	15	4	16	5	16	12	21	10	15	12	28	15
Residual species which decreased in frequency:												
Potentilla pacifica	14	6	4	3	4	4	5	6	4	9	2	1
Cirsium vulgare	14	2	7	1	6	2	3	1			+	15
Sonchus arvensis	38	8	26	9	14	11	13	4	10	12	5	8
Agrostis alba	35	10	28	10	32	26	26	13	25	14	13	7
Hordeum brachyantherum	32	7	29	11	32	15	29	11	28	7	13	2
Poa pratensis	42	35	35	36	37	33	32	18	19	23	20	6
Stable residual species:												
Rumex acetosella	16	9	12	9	9	4	10	3	4	3	13	4
Cerastium arvense	6	3	6	4	5	5	5	4	3	6	7	6
Rosa nutkana	3	7	2	8	3	10	3	7	1	5	2	26
Lotus micranthus	+	1	+	38	1	30	1	1	1	9	4	6
Daucus carota	3	2	3	4	6	5	1	2	3	+	2	+
Plantago lanceolata	10	4	7	5	13	4	6	2	9	2	4	5
Achillea millefolium	23	10	25	11	25	11	20	5	16	4	20	5
Hypochaeris radicata	4	5	10	2	12	4	7	4	3	13	7	7
Triglochin maritimum	7	14	8	12	7	18	8	13	9	14	7	22
Ruppia maritima	+	+	+	+	1	3	1	18	4	46	2	13
Juncus balticus	14	28	12	37	10	39	13	24	12	33	12	30
Carex lyngbyei	14	21	10	20	10	26	10	26	12	37	6	19
Agropyron repens	9	6	12	4	18	6	16	1	17	4	14	1
Aira praecox	+	+	4	2	4	15	7	14	3	21	7	8
Bromus mollis	15	15	7	6	7	6	10	7	7	2	6	11
Danthonia californica	+	1	+	3	+	3			1	8		
Elymus mollis	8	19	10	15	10	9	12	5	10	14	8	6

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1 <1%

Seven species, all of which would be considered either halophytic or at least tolerant of high salinities, colonized the study area. The most dramatic colonizers were the annuals *Salicornia europaea* and *Spergularia canadensis*. Neither species was found on the transects in 1979, but by 1980 they occurred with frequencies of 10% and 20% respectively, and in 1982 and 1983 they were found in over 40% and 30% of the relevés respectively. They both eventually exceeded a mean cover of 10%, *Spergularia* in 1981 and *Salicornia europaea* in 1983. *Plantago maritima* and *Puccinellia nutkaensis* also increased substantially in both cover and frequency.

Twenty-nine residual species occurred on the study site. Of those residuals, six increased in frequency or cover, six decreased, and 17 remained relatively stable.

Species scores from the correspondence analysis are plotted on scatter diagrams to show their relationships with one another over time (Figure 2). The main feature of the species changes from 1979 to 1980 was the appearance of *Salicornia europaea*, *Spergularia canadensis*, *Puccinellia nutkaensis* and *Plantago maritima*. There were some minor shifts in species growing at higher elevations. In 1981, the major change was the joining of most of the halophytic vegetation into one species group, a trend which continued into 1982 with the addition of *Distichlis spicata*. There was little change in species associations in 1983, which suggested that some stability was occurring on the marsh. By 1986, both of the annuals, *Spergularia canadensis* and *Salicornia europaea* had drifted away from the main halophyte species group and species near the mid-/high marsh interface had increased in frequency (e.g. *Plantago maritima*).

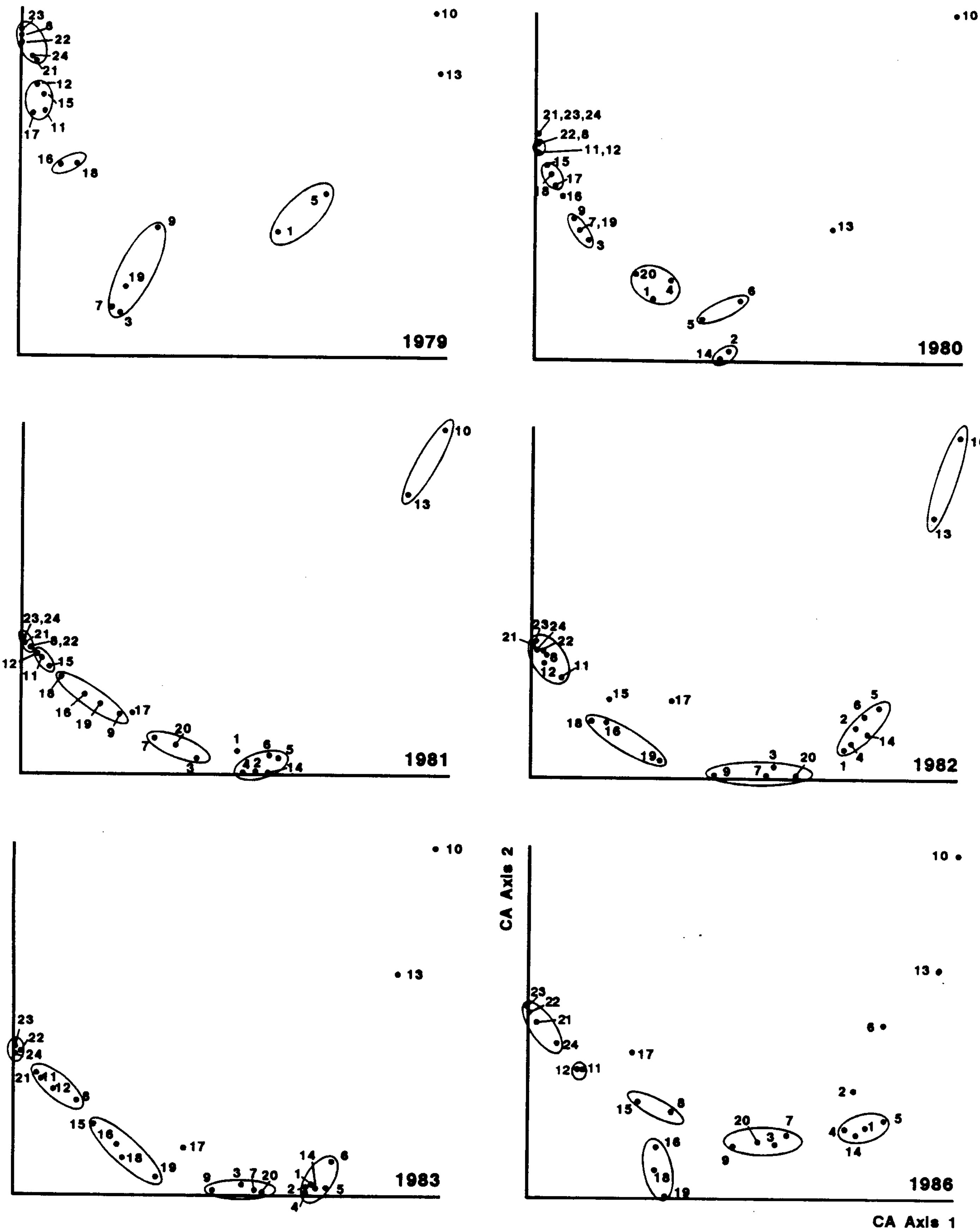
Following are brief discussions of the 24 species used in the correspondence analysis ordinations (refer to Table 2; Figure 2). They are discussed in order of increasing mean elevation based on our 1986 data.

Carex lyngbyei, a stable residual, perennial species, displayed a significant increase in cover from 1979 through 1983 ($p < .05$), but that trend was lost in 1986 when there was an obvious decrease in both the frequency and cover of *Carex* on the study site. Areas that had 100 % cover in 1983 were devoid of vegetation or held only *Spegularia canadensis* in 1986. *Carex* was obviously under stress in 1986, as most of the stands were infested with aphids (Aphididae). The mean elevation of *Carex* increased on the marsh platform for the period 1979 through 1983 ($p < .05$), moving from 4.00 m above chart datum (ACD) to 4.06 m ACD, but then dropped to a mean elevation of 4.02 m ACD in 1986. Increased soil salinities appear to account for the *Carex* decrease in frequency, cover, and elevation from 1983 to 1986.

Triglochin maritimum a stable residual, perennial species, displayed an increase in mean elevation throughout the study period, moving from 3.89 to 4.10 m ACD ($p < .05$).

Spergularia canadensis, colonized rapidly in 1980 occurring in 20 % of the relevés. It rose to a high of 35 % frequency in 1982 and dropped to a

Figure 2. Plot of species scores for Englishman River estuary on the first two CA axes, 1979 to 1986. Species: 1 - *Distichlis spicata*, 2 - *Salicornia europaea*, 3 - *Atriplex patula*, 4 - *Plantago maritima*, 5 - *Salicornia virginica*, 6 - *Spergularia canadensis*, 7 - *Hordeum brachyantherum*, 8 - *Grindelia integrifolia*, 9 - *Agrostis alba*, 10 - *Carex lyngbyei*, 11 - *Poa pratensis*, 12 - *Achillea millefolium*, 13 - *Triglochin maritimum*, 14 - *Puccinellia nutkaensis*, 15 - *Festuca rubra*, 16 - *Agropyron repens*, 17 - *Elymus mollis*, 18 - *Juncus balticus*, 19 - *Sonchus arvensis*, 20 - *Polygonum aviculare*, 21 - *Bromus mollis*, 22 - *Hypochaeris radicata*, 23 - *Aira praecox*, 24 - *Rumex acetosella*.


1979
1980
1981
1982
1983
1986
CA Axis 2
CA Axis 1

frequency of 27 % in 1986. Its cover was highest in 1981. *S. canadensis* moved from 4.30 m ACD to 4.48 m ACD ($p < .05$) over the study period.

Salicornia virginica, a residual, perennial species increased substantially in both frequency ($p < .01$) and cover ($p < .05$) over the study period. It also increased its mean elevation from 4.15 m ACD to 4.49 m ACD ($p < .002$).

Salicornia europaea together with *Spergularia canadensis*, both annuals, were the most dramatic of the colonizing species. *Salicornia europaea* did not appear in our relevés in 1979, by 1980 it occurred in 10 %, and peaked in 1983 when it was found in 43 % of the relevés. Its cover also peaked that year, but by 1986 both the frequency and cover had decreased as the perennials began to dominate. *Salicornia europaea* changed its mean position on the marsh platform from 4.30 m ACD in 1980 to 4.55 m ACD in 1986 ($p < .05$).

Distichlis spicata, a residual, perennial species, increased in both frequency ($p < .01$) and cover ($p < .01$) over time and by 1982 was the dominant species on the study area. Over the eight years of the study, the mean position of *D. spicata* increased in elevation from 4.36 m (ACD) to 4.57 m ACD ($p < .02$).

Plantago maritima, a colonizing perennial species, increased in both frequency and cover although its frequency appears to have stabilized at about 30 % from 1983 on. However, its cover continued to increase ($p < .001$) and it had an obviously denser growth in 1986 near the upper reaches of the mid-marsh communities. *P. maritima* also increased its mean position on the study site from 4.41 m ACD in 1980 to 4.73 m ACD ($p < .001$).

Puccinellia nutkaensis, a perennial, began colonizing the study area in 1980 occurring in 3 % of the relevés. It increased to a frequency of 18 % in 1981, and remained about that level through to 1986. Its cover increased ($p < .05$) over that period as well. *P. nutkaensis* increased its mean elevation from 4.11 m ACD to 4.74 m ACD ($p < .01$) over the study.

Atriplex patula, a residual, annual species, increased dramatically in frequency from 1979 to 1980, then dropped in 1981. A consistent increase began again in 1982 and continued through 1986. Its cover remained relatively low and stable. A. patula is able to take advantage of disturbed sites, which likely accounts for its increase in frequency in the first two years. It remained at a fairly constant elevation over the study period (mean - 4.74 m ACD; range - 4.68 to 4.82 m ACD; $p > .05$).

Hordeum brachyantherum, a residual, perennial species, also decreased in frequency, dropping from 32 % to 13 % over the study ($p < .05$). *H.* brachyantherum rose in cover through 1981 to 15 % but then declined rapidly through 1986 to 2 %. It moved up in mean elevation from 4.69 m ACD to 4.87 m ACD ($p < .05$) over the study.

Agrostis alba, a residual, perennial species, decreased in frequency from 35 to 13 % ($p < .01$). Its cover increased dramatically in 1981 from 10 to 26 %; however, in 1982 it dropped back to its pre 1981 level where it remained until 1986. *A. alba* increased its mean elevation over the study from 4.59 m ACD to 4.92 m ACD ($p < .05$).

Polygonum aviculare, an annual, was included as a residual that increased in frequency because of its higher frequencies over the last four years of the study. Its cover remained quite low over the study period. *P. aviculare* increased its mean position on the marsh platform from 4.64 m ACD to 4.92 m ACD over the period 1979 through 1986 ($p < .001$).

Grindelia integrifolia, a residual, perennial species, gradually increased in both frequency ($p < .01$) and cover ($p < .01$). *G. integrifolia* was the only species on the study area that had its mean position decrease in elevation over the study period, going from 5.18 m ACD to 4.95 m ACD ($p < .04$).

Sonchus arvensis, a residual, perennial species, decreased in frequency from 38 % in 1979 to 5 % in 1986. In terms of cover, *S. arvensis* remained relatively constant at around 10 % over the study period. *S. arvensis* increased its mean elevation from 4.64 m ACD to 4.96 m ACD over the study period ($p < .05$).

Juncus balticus, a stable residual, perennial, remained at a fairly constant elevation throughout the study period (mean - 4.95 m ACD; range - 4.87 to 4.97 m ACD; $p > .05$).

Agropyron repens, a stable residual, perennial species, remained at a fairly constant elevation throughout the study period (mean - 4.96 m ACD; range - 4.90 to 5.00 m ACD; $p > .05$).

Festuca rubra, a residual, perennial species, increased in both frequency ($p < .05$) and cover ($p < .05$) over the study period. *F. rubra* remained at a fairly constant elevation throughout the study (mean - 5.04 m ACD; range - 5.00 to 5.07 m ACD; $p > .05$).

Poa pratensis, a residual, perennial species, decreased in both frequency ($p < .05$) and cover ($p < .01$) over the study period. *P. pratensis* also "moved" higher on the marsh platform over the study, shifting from 4.98 m ACD to 5.14 m ACD ($p < .01$).

Elymus mollis, a stable residual, perennial species, tended to have lower cover over the last three years of the study than over the first three years. *E. mollis* remained at a fairly constant elevation throughout the study period (mean - 5.05 m ACD; range - 5.00 to 5.15 m ACD; $p > .05$).

Achillea millefolium, a stable residual, perennial species, occurred in about 20 % of the relevés throughout the study, its cover dropping from about 10 % in the first three years to about 5 % over the last three years. *A. millefolium*, closely associated with *Poa pratensis* throughout the study, also shifted to a higher position on the marsh from 5.08 m ACD to 5.15 m ACD ($p < .05$).

Bromus mollis, a stable residual, annual species, remained at a fairly constant elevation throughout the study period (mean - 5.11 m ACD; range - 5.01 to 5.16 m ACD; $p > .05$).

Rumex acetosella, a stable residual, perennial species showed a slight decrease in cover over the study. It remained at a fairly constant mean elevation over the study period (mean - 5.22 m ACD; range - 5.13 to 5.27 m ACD; $p > .05$).

Hypochaeris radicata, a stable residual, perennial species, remained at a fairly constant elevation throughout the study period (mean - 5.31 m ACD; range - 5.18 to 5.45 m ACD; $p > .05$).

Aira praecox, a stable residual, annual species, increased in cover dramatically in 1981 remaining relatively high over the following three years. *A. praecox* remained at a fairly constant elevation throughout the study period (mean - 5.34 m ACD; range - 5.16 to 5.39 m ACD; $p > .05$).

Figure 3 summarizes the vegetation composition over the study period based on a correspondence analysis of mean frequency data of the dominant species. The dominant vegetation moved from upland and brackish marsh species such as *Soncus arvensis*, *Poa pratensis*, and *Carex lyngbyei* in 1979 and 1980 toward colonizing species (e.g. *Salicornia europaea* and *Spergularia canadensis*) in 1981 and 1982, and finally toward halophytic dominants (e.g. *Distichlis spicata*, *Salicornia virginica*) in 1983 and 1986. The species were separated along the first correspondence analysis axis into two main groups: one group consists of residual species that dropped in frequency or remained relatively constant and the other consists of colonizing species and residual species that increased in frequency.

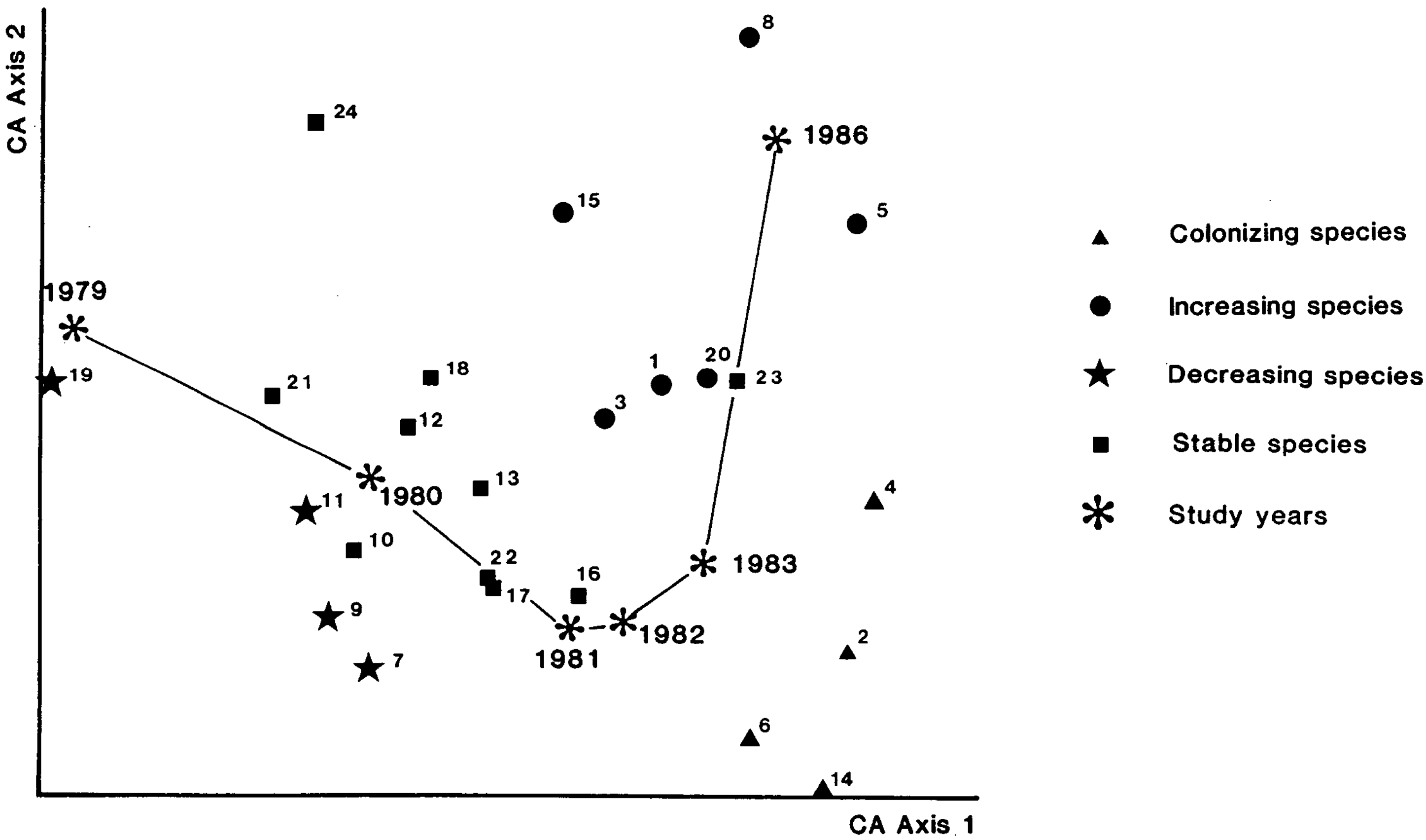
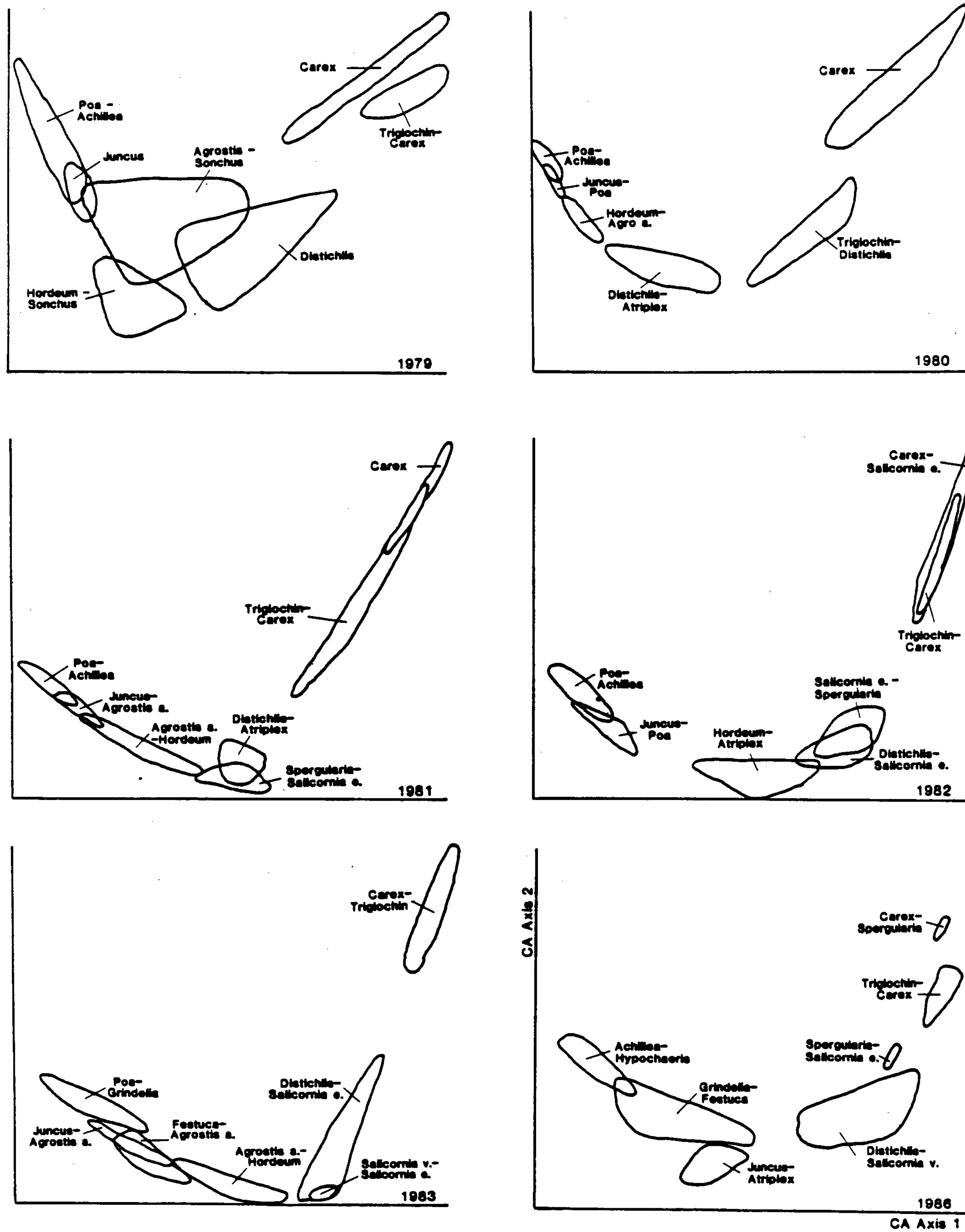


Figure 3. Summary of changes in vegetation composition of the Englishman River estuary over the study period based on species scores of the dominant species' mean frequency values from the first two CA axes, 1979 to 1986 (see text for methods). Superimposed is a plot of CA scores for the six study years which shows the shift in vegetation on the marsh platform from residual species that subsequently decreased or remained relatively stable to colonizing species and finally to residual species that increased significantly in frequency.

Figure 4. Plot of relevé scores for Englishman River estuary on the first two CA axes, 1979 to 1986. Community boundaries (0.7 clusters from the average linkage clustering) connecting the outermost relevés were drawn by eye.


Carex
Poa -
Achillea
Triglochin-
Carex
Juncus
Agrostis -
Sonchus
Distichlis
Hordeum -
Sonchus
1979
Carex
Poa-
Achillea
Juncus-
Poa
Hordeum-
Agro a.
Triglochin-
Distichlis
Distichlis-
Atriplex
1980
Carex
Triglochin-
Carex
Poa-
Achillea
Juncus-
Agrostis a.
Agrostis a.
-Hordeum
Distichlis-
Atriplex
Spergularia-
Salicornia e.
1981
Carex-
Salicornia e.
Triglochin-
Carex
Poa-
Achillea
Salicornia e. -
Spergularia
Juncus-
Poa
Hordeum-
Atriplex
Distichlis-
Salicornia e.
1982
Carex-
Triglochin
Poa-
Grindelia
Distichlis-
Salicornia e.
Juncus-
Agrostis a.
Festuca-
Agrostis a.
Agrostis a.-
Hordeum
Salicornia v.-
Salicornia e.
1983
CA Axis 2
Carex-
Spergularia
Triglochin-
Carex
Achillea-
Hypochaeris
Spergularia-
Salicornia e.
Grindelia-
Festuca
Distichlis-
Salicornia v.
Juncus-
Atriplex
1986
CA Axis 1

Community changes

The 0.7 clusters from the average linkage clustering are mapped onto the component score plots in Figure 4, and show the community changes over the study period. Canonical correlations for the first two sets of species and relevé scores are high (Table 3) suggesting that the reliability of the scores as ordering criteria is also high (Orloci 1978). The first two canonical variates accounted for about 30% of the total Chi-square over all the years (Table 3), which is low but not surprising considering the impacts and ongoing changes on the study area.

Table 3. Canonical correlations for the sets of CA species scores and relevé scores and total Chi-square accounted for by canonical variates for the Englishman River estuary data, 1979 to 1986.

	1979	1980	1981	1982	1983	1986
Canonical correlations						
Axis 1	.904	.946	.934	.936	.923	.902
Axis 2	.787	.871	.871	.830	.850	.770
Chi-square (%)						
Axis 1	16	15	17	17	16	19
Axis 2	13	12	15	14	14	14
Cumulative	29	27	32	31	30	33

Changes in community composition over time are given in Table 4. In 1979, the marsh was dominated by the *Poa-Achillea* and *Hordeum-Sonchus* communities which included over 56% of all the relevés. Those communities were composed primarily of upland species; halophytic species formed only a small component of the structure of the marsh. There was also considerable overlap between communities. That overlap continued (see Figure 4) through 1983 but by 1986 it was much reduced with only the *Achillea-Hypochaeris* and *Grindelia-Festuca* communities overlapping. By 1986, the marsh was dominated by the *Distichlis-Salicornia virginica* community which included over 52% of all the relevés; halophytic vegetation was now dominant.

Table 4. Floristic tables of vegetation communities and differential species on the Englishman River estuary, showing changes in community structure over the period 1979 to 1986. Percent frequency of occurrence (F) and mean percent cover (C) are given for each species within the communities.

(a) 1 9 7 9

	Trig Carx		Carx		Agro a. Sonc		Dist		Hord Sonc		Junc Sonc		Poa Achi	
Mean Elevation	3.76		4.10		4.39		4.40		4.62		4.93		5.04	
Inundation (%)														
Total day	36.9		24.1		13.4		12.6		5.1		.9		.5	
Daylight	20.8		13.6		7.4		6.9		3.0		.5		.3	
(n)	(7)		(14)		(19)		(12)		(38)		(8)		(41)	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Rupp mari							8	+[1]						
Trig mari	100	23			10	1	16	2	2	3				
Carx lyng	85	9	100	33	15	1			2	3				
Sali virg									2	1				
Dist spic	71	3	7	1	21	1	100	6	23	2			2	3
Poly avic							8	1	10	1			2	1
Agro alba	14	1	50	14	100	17	25	1	42	6	50	1	12	4
Sonc arve	14	1			78	9			68	10	87	8	14	7
Atri patu			7	1	15	2			55	6	37	1	2	3
Hord brac					36	3	33	1	78	10	37	2	14	4
Junc balt	28	1	7	1	5	15			2	15	100	49	24	24
Agro repn					5	1					50	5	14	1
Poa prat					21	21	8	1	21	1	75	9	100	54
Fest rubr					15	6	8	1	2	3			39	2
Achi mill					10	2			2	1	50	2	58	11
Elym moll													17	6
Brom moll					21	5			2	3	12	3	36	17
Rumx acet							8	1	5	2	12	3	39	7
Hypo radi													17	5
Grin inte													26	3
Aira prae													2	1

1 < 1%.

Table 4 (Continued)

(b) 1 9 8 0

	Trig Dist		Carx		Dist Atri		Hord Agro a.		Junc Poa		Poa Achi	
Mean Elevation	3.95		4.03		4.53		4.77		4.98		5.13	
Inundation (%)												
Total day	29.9		26.6		8.2		2.5		.7		.2	
Daylight	16.9		15.0		4.6		1.4		.4		.1	
(n)	(10)		(11)		(24)		(25)		(17)		(28)	
	F	C	F	C	F	C	F	C	F	C	F	C
Carx lyng	40	2	100	31	8	1						
Trig mari	100	16	18	2	4	1	3	+[1]				
Sali euro	10	1			12	+	11	+				
Pucc nutk					+	+						
Sper cana	60	2	18	2	33	1	3	+				
Sali virg	20	8	9	+	12	1	3	1				
Plan mari	10	+			12	+						
Dist spic	60	4	18	3	100	29	19	2	5	+	3	3
Poly avic					29	5					3	3
Atri patu					83	3	80	14	64	2	14	1
Hord brac					33	3	100	17	5	1	14	5
Sonc arve					29	2	3	3	76	6	10	2
Agro alba					16	4	84	15	58	5	10	11
Agro repn					4	1	15	5	52	3	3	1
Elym moll							3	1			28	4
Junc balt							38	4	100	44	3	1
Fest rubr							15	2	47	6	32	1
Poa prat							34	6	94	30	100	53
Achi mill							7	+	70	4	78	13
Grin inte							3	3			28	1
Hypo radi									35	+	35	2
Brom moll									5	1	32	5
Rumx acet									5	3	53	7
Aira prae											14	1

[1] < 1%.

Table 4 (Continued)

(c) 1 9 8 1

	Trig Carx		Carx		Sper Sali e.		Dist Atri		Agro a. Hord		Junc Agro a.		Poa Achi	
Mean Elevation	3.92		4.02		4.39		4.52		4.78		4.96		5.13	
Inundation (%)														
Total day	30.8		27.3		13.4		8.2		2.5		.8		.2	
Daylight	17.4		15.5		7.4		4.6		1.4		.5		.1	
(n)	(7)		(8)		(36)		(13)		(28)		(11)		(33)	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Rupp mari							7	3						
Carx lyng	57	5	100	51	11	8	7	3						
Trig mari	100	28	25	9	2	+[1]	15	2						
Sali virg	14	15			58	6	38	5						
Pucc nutk					75	3	15	3						
Sper cana	28	8	25	2	100	20	38	2	21	4				
Sali euro	14	1			94	9	38	1	21	1				
Plan mari					66	4	30	2	10	2				
Dist spic	42	10	12	3	52	11	100	76	57	8	9	+	6	3
Atri patu					47	9	61	3	82	2	27	1		
Poly avic					16	1	30	2	57	4	9	3	3	1
Hord brac					41	6	30	2	96	23	9	15	3	3
Elym moll					11	6							24	3
Agro alba	14	1			8	11	30	4	100	36	90	26	12	3
Sonc arve					5	1	7	1	35	12	63	12	6	2
Agro repn									46	7	72	4	15	7
Junc balt									3	15	100	47	15	26
Fest rubr					2	1			10	11			48	5
Poa prat									50	7	72	16	100	51
Achi mill									3	1	72	6	81	12
Grin inte					5	+	7	+	7	2	27	1	54	8
Hypo radi											18	1	48	4
Brom moll											9	3	24	8
Rumx acet													39	5
Aira prae													12	3

[1] < 1%.

Table 4 (Continued)

(d) 1 9 8 2

	Rupp		Trig Carx		Carx Sali e.		Sali e. Sper		Dist Sali e.		Hord Atri		Junc Poa		Poa Achi	
Mean Elevation	3.74		3.84		4.07		4.38		4.46		4.80		5.00		5.16	
Inundation (%)																
Total day			34.2		24.9		13.4		10.4		2.2		.6		.1	
Daylight			29.3		14.1		7.4		5.6		1.3		.4		.1	
(n)	(3)		(4)		(11)		(23)		(28)		(25)		(16)		(25)	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Rupp mari	100	18														
Carx lyng			75	3	100	39	4	+[1]	7	2						
Trig mari			100	26	27	10	13	1	14	10						
Sali virg			25	3	27	14	82	19	25	4	4	1				
Pucc nutk					9	1	86	5	32	1	4	1				
Sper cana	33	1	50	1	72	1	100	10	60	2	24	4				
Sali euro	33	1	50	+	81	1	100	14	78	5	32	3				
Plan mari							73	7	46	2	16	2				
Dist spic			25	1	27	3	69	7	100	56	60	8	6	1	4	15
Poly avic							4	+	7	1	40	+				
Hord brac							39	1	21	1	100	19	12	2		
Atri patu							43	1	53	1	100	2	18	+	16	+
Agro alba							4	1	17	2	92	18	50	1	8	9
Elym moll							13	2	3	1	4	3			32	4
Sonc arve							4	3			32	3	62	4	4	+
Agro repn											20	3	81	1	20	1
Junc balt									3	3	4	1	100	31	4	1
Fest rubr							13	2	7	3	4	1	62	3	52	11
Poa prat							4	1			28	2	87	9	100	31
Grin inte									3	3			12	1	60	5
Achi mill													50	3	84	6
Hypo radi															40	5
Rumx acet													12	1	52	3
Brom moll													25	1	44	8
Aira prae															40	11

1 < 1%.

Table 4 (Continued)

(e) 1 9 8 3

	Rupp		Carx Trig		Sali v. Sali e.		Dist Sali e.		Agro a. Hord		Fest Agro a.		Junc Agro a.		Poa Grin	
Mean Elevation	3.79		4.03		4.29		4.50		4.85		4.93		4.98		5.12	
Inundation (%)																
Total day			26.5		16.4		8.8		1.5		.9		.7		.2	
Daylight			15.0		9.2		4.9		.8		.5		.4		.1	
(n)	(7)		(13)		(15)		(42)		(19)		(7)		(14)		(23)	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Rupp mari	100	52	7	+[1]												
Carx lyng	28	3	100	56			11	7								
Trig mari			53	16	13	3	11	17								
Sper cana			46	3	100	8	52	2	21	1						
Sali virg			7	3	100	37	52	9					7	3		
Pucc nutk					60	4	30	6							4	1
Dist spic			23	1	73	9	100	62	78	9	14	1			13	2
Sali euro			38	1	100	12	64	18	89	2						
Plan mari					80	12	54	14	52	3	14	1				
Poly avic					6	1	7	1	31	2			7	1		
Hord brac					40	3	28	4	100	12	57	1	14	1		
Atri patu					13	2	54	3	94	13	85	1	64	2	34	1
Agro alba					13	2	9	2	100	21	85	15	71	6		
Elym moll							7	3							21	7
Sonc arve									42	5			64	19		
Junc balt							2	3			42	7	100	43		
Agro repn									15	6	85	3	78	1	26	1
Fest rubr									5	3	100	28	28	1	47	5
Grin inte							7	1	21	14	42	6	21	1	86	17
Achi mill											42	2	35	4	78	5
Poa prat									5	3			35	7	100	30
Brom moll													7	1	47	2
Hypo radi															17	11
Rumx acet															26	3
Aira prae															17	23

1 < 1%.

Table 4 (Continued)

(f) 1 9 8 6

	Rupp		Trig Carx		Sper Sali e.		Carx Sper		Dist Sali v.		Junc Atri		Grin Fest		Achi Hypo	
Mean Elevation	3.82		3.87		4.11		4.19		4.54		4.97		5.03		5.42	
Inundation (%)																
Total day			33.3		23.3		20.3		7.5		.6		.5		0	
Daylight			18.8		13.1		11.4		4.2		.4		.3		0	
(n)	(3)		(6)		(6)		(4)		(75)		(11)		(30)		(10)	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Rupp mari	100	18	16	1												
Carx lyng			83	5			100	38	1	15						
Trig mari			100	48					14	15						
Sper cana			83	1	100	5	100	8	36	1						
Sali euro			83	1	100	1	100	1	53	7	18	2	3	1		
Sali virg									77	16						
Dist spic			33	8					97	50	18	2	16	7	10	1
Pucc nutk									32	16						
Plan mari									54	21	9	38	3	1		
Hord brac									18	1	18	2	6	1		
Atri patu			16	1					68	3	81	12	46	5		
Poly avic									17	4	27	7	36	1		
Agro alba									12	3	45	3	16	3		
Sonc arve											63	10	6	2		
Junc balt									1	1	90	38	33	25		
Agro repn									1	1	63	1	46	1	10	1
Grin inte									26	8	18	2	100	31	30	3
Fest rubr									2	9	36	1	90	15	80	13
Elym moll									6	5			3	15	80	6
Poa prat											18	15	73	3	90	10
Achi mill											27	3	70	5	100	9
Rumx acet													43	3	90	5
Brom moll													23	2	40	26
Hypo radi													6	1	100	8
Aira prae													10	1	90	11

The change in mean vegetation cover over the study period is shown in Table 5. The mid and low marsh show a gradual increase in mean cover from 29% following the breaching of the dyke to 80% in 1986. The high marsh showed a gradual increase for the first three years and then a sudden drop in 1982 and a slow increase over the last three years. The drop in 1982 was due primarily to a decrease of *Agrostis alba*, *Juncus balticus*, and *Poa pratensis*, all down in cover at least 15% from the previous year.

Table 5. Change in mean vegetation cover following dyke breaching on the Englishman River estuary (1979 to 1986).

	1979	1980	1981	1982	1983	1986
Mid and low marsh[1]	29	32	58	57	86	80
High Marsh	54	67	83	52	62	65

[1] Includes marsh elevations inundated more than 5% of each year (see Table 4).

Summary data of environmental factors for the 1986 communities on the Englishman River estuary are given in Table 6. Product moment correlation coefficients of environmental data with the 1986 component scores for Axis I and II have been plotted as vectors in Figure 5, and can be related directly to Figures 2 and 4. The main continuum (Axis I) reflects the elevational gradient from the higher, drier, less saline, and sandier soils, with their attendant species such as *Aira praecox* and *Hypochaeris radicata* through to the lower, wetter, more saline silts and clays and species such as *Distichlis spicata*, *Salicornia virginica*, and *Carex lyngbyei*.

Figure 5. Environmental factors associated with Englishman River estuary relevés in 1986; the product moment correlation coefficients of the first two CA axes with original environmental data are plotted as vectors to show the trends of the environmental factors. They can be related to the species groups (Figure 2) and vegetation communities (Figure 3) and their distribution on the marsh platform for 1986. The marsh platform is represented by the first CA axis in those figures.

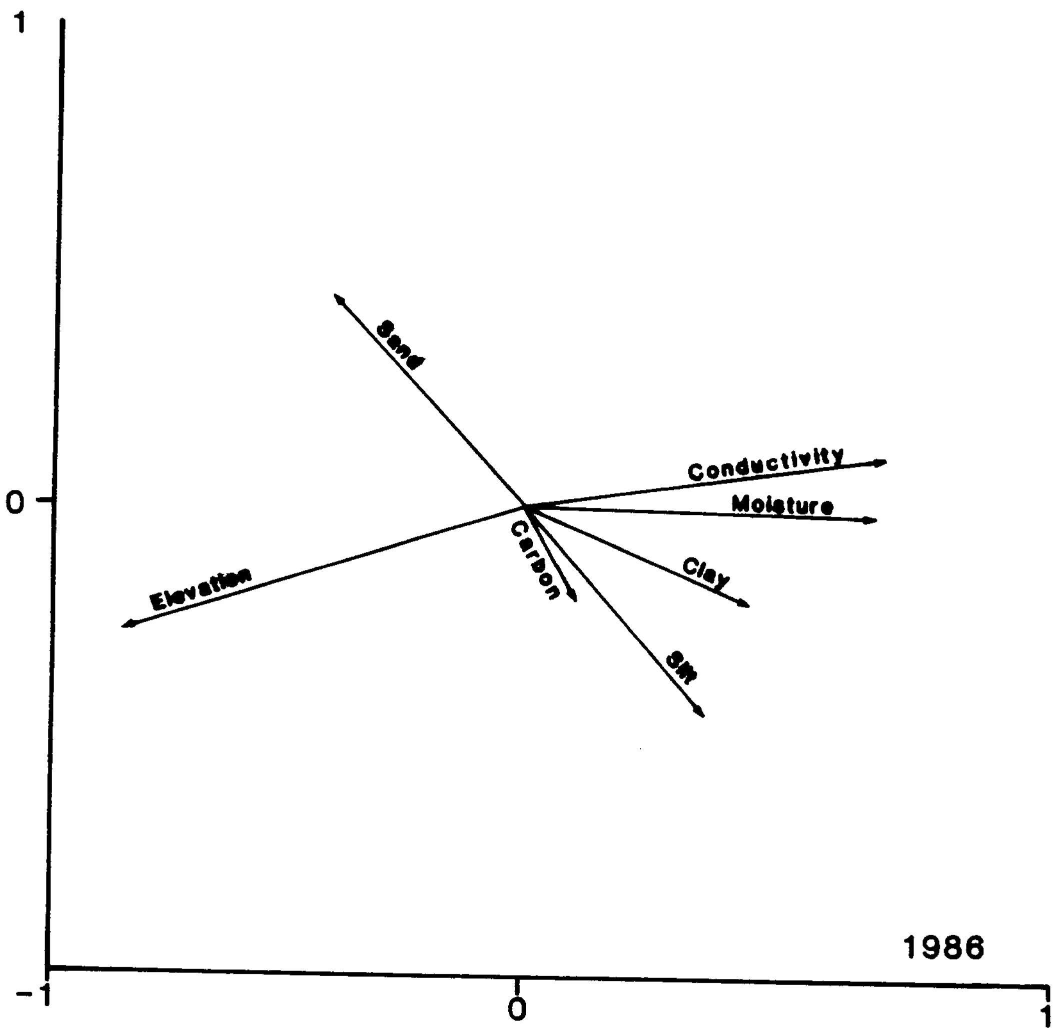

1
0
-1
0
1
Sand
Conductivity
Moisture
Carbon
Clay
Elevation
Silt
1986

Table 6. Environmental summary data for the vegetation communities on the Englishman River estuary, 1986 (mean ± standard deviation) Environmental factor values with the same letter are not different at the P = .05 level.

(n)	Trig/Carx 6	Sper/Sali e. 6	Carx/Sper 2	Dist/Sali v 74	Junc/Atri 11	Grin/Fest 28	Achi/Hypo 8
Elevation (m ACD)	3.87^{a} ± .13	4.11^{a} ± .09	4.19	4.54^{b} ± .30	4.97^{c} ± .09	5.03^{c} ± .07	5.42^{d} ± .11
Cond (mmhos/cm)	16.7^{ac} ± 6.3	29.0^{a} ± 7.2	28.0	18.6^{a} ± 9.2	8.0^{bc} ± 4.9	3.8^{b} ± 4.1	0.2^{b} ± 0.1
Moisture (%)	38.8^{ad} ± 8.1	66.9^{a} ± 11.4	64.3	46.0^{a} ± 12.7	33.5^{ac} ± 8.2	25.7^{bcd} ± 7.0	12.6^{b} ± 6.9
Carbon (%)	2.8^{bcd} ± 1.4	9.4^{a} ± 2.2	9.3	8.0^{a} ± 3.5	7.4^{ad} ± 2.7	7.5^{ab} ± 1.7	5.2^{ac} ± 1.3
Clay (%)	7.4^{dfg} ± 3.2	18.1^{b} ± 3.4	17.3	13.9^{ab} ± 3.5	10.4^{aceg} ± 3.6	10.3^{cd} ± 2.6	5.5^{ef} ± 2.4
Silt (%)	26.0^{e} ±14.7	57.7^{bdf} ± 7.8	61.5	59.1^{ab} ± 10.2	48.4^{acf} ± 16.4	49.4^{cd} ± 11.5	18.4^{e} ± 7.5
Sand (%)	66.6^{e} ±17.8	24.2^{bdf} ± 10.6	21.3	26.9^{ab} ± 12.5	41.3^{acf} ± 18.1	40.3^{cd} ± 13.0	76.1^{e} ± 9.8

The first axis of the correspondence analysis component scores were correlated between years (Table 7) as an indication of whether or not the vegetation structure of the marsh was approaching some stability. The correlation coefficients moved toward 1 over the period 1979 through 1983 ($p = .005$) which suggests the marsh was moving toward a more stable condition each year. Between 1983 and 1986, that trend was lost. Normal variation in vegetation structure between years due to climatic factors alone, however, would suggest that such a correlation would never equal 1 nor even remain constant, although it would remain high.

Table 7. Product moment correlation coefficients of Englishman River estuary CA component scores for the first axes correlated between years.

1979 with 1980	.85
1980 with 1981	.87
1981 with 1982	.93
1982 with 1983	.97
1983 with 1986	.93

Discussion

Species changes

In this study, the general sequence of the loss of upland species followed by the influx of colonizers and culminating in the dominance of perennial vegetation is similar to the results reported by Mitchell (1982), Prentice (A.C. 1987. op. cit.), and Frenkel and Morlan (1990, 1991).

Dominant species occurring both on the Englishman study site and the Salmon River estuary in Oregon such as *Agrostis alba, Juncus balticus, Salicornia virginica, Potentilla pacifica,* and *Distichlis spictata* (Frenkel and Morlan 1990, 1991) showed similar trends on the marsh platform following the breaching of the dykes. Three species, however, had different trends. On the Salmon River estuary, both *Atriplex patula* and *Hordeum brachyantherum* peaked in the second year of the study and then declined thereafter whereas in this study *A. patula* increased in frequency while *H. brachyantherum* decreased in both frequency and cover over the eight years following the dyke breach. *Carex lyngbyei* was the "overwhelmingly dominant" plant in the 1988 restored marsh on the Salmon River estuary (Frenkel and Morlan 1990, 1991). In this study, *Carex* played a minor role in comparison; however, its changes over time are noteworthy. *Carex* was relatively stable for the first five years. By 1986, however, it had decreased in both cover and frequency. In 1989, we reran a portion of one transect where, in 1983, *Carex* had a mean cover of 73% and a frequency of 100% and in 1986 its mean cover and frequency had dropped to 53% and 33% respectively. We found no *Carex* at all in 1989; most of the area along the transect was bare mud. Interstitial salinities taken along the transect with a refractometer ranged between 50 ‰ and 70 ‰. Frenkel and Morlan (1990, 1991) note that the higher salinities on their study site (>33 ‰) favoured the halophytes while areas of lower salinities (<32 ‰) were characterized by *Carex lyngbyei*. Other areas on the Englishman estuary that, in 1986, supported monospecific stands of Carex had been replaced by stands of vegetation where *Distichlis spicata* was dominant. Undoubtedly, the high interstitial salinities played a role in reducing the Carex frequency and cover on the site. A more important point, however, is the fact that had our study ended after five years as we had planned, the decline of Carex would not have been noted--it apparently took that long for the interstitial salinities to concentrate to the point where Carex could no longer tolerate those high salinities. The importance of long-term studies cannot be overemphasized.

Frenkel and Morlan (1990, 1991) noted that 3 colonizers (*Cotula coronopifolia, Puccinellia pumila, Spergularia marina*) on their Oregon study area were ephemeral and that by the eleventh year of monitoring they were no longer a part of the vegetation on the Salmon River estuary. All our colonizers were still present at relatively constant levels in the eighth year, although the cover of the annuals *Salicornia europaea* and *Spergularia canadensis* was declining. We would expect that eventually those two species, at least, would drop in both frequency and cover as perennial vegetation cover increased.

All the dominant species in our study but one, tended to "move" higher on the marsh platform over the study period. Presumably the increase in mean elevation of those species was due to the increasing salinities coupled with the inundation periods to which the vegetation was subjected. Only *Grindelia integrifolia* had its mean position on the marsh platform decrease in elevation.

Community changes

The changes in composition and dominance of the developing communities on the Englishman River estuary followed patterns similar to the communities on the Salmon River estuary (Frenkel and Morlan 1990, 1991). Considerable overlap in the areal extent of various communities within each year was evident throughout the first five years; by the eighth year sharper zonation between communities was evident. Some community stability appeared to have been reached between the fifth and eighth years. The plant communities that resulted eight years after the breaching of the dyke on our study area resembled the composition of communities described in other studies where the salinity and elevation regimes were similar (e.g. Dawe and White 1986, Burg et al. 1980, Frenkel and Morlan 1990 and 1991, Jefferson 1975, Seliskar and Gallagher 1983).

The main axis of the correspondence analysis for the Englishman study area reflects an elevational and moisture gradient. Elevation appeared to be the main factor determining the distribution of vegetation as it plays a major role in determining inundation periods and the resultant moisture regime. Similar results were found by Dawe and White (1982, 1986) and Frenkel and Morlan (1990, 1991). Haeck et al. (1985) using reciprocal averaging to study Dutch coastal plant communities found that the distribution of plant communities along their first axis reflected a moisture gradient. They discuss three other studies, two of which also found soil moisture to be the most important factor. Some authors have noted subsidence of the land following years of dyking (Taylor 1983, Mitchell 1982). That subsidence is generally attributed to the settling of sediments due to a loss of the buoyant effect of water (Stephens and Spier 1970 cited in Mitchell 1982). While we did not determine if subsidence took place on our study site, we believe that, at least at the lower elevations, any subsidence would have been minimal due to the stormwater runoff from the City of Parksville being routed through the main dendritic channel of the study area, thus maintaining the buoyancy of the soils in that area.

Another important factor in determining the distribution of vegetation on the Englishman marsh platform was soil texture which was reflected to some degree in the second axis of the correspondence analysis.

Conclusions

Because of the urgency to have the dyke removed on the Englishman estuary, little planning was done in terms of determining the size of the opening or the design of monitoring programs to follow floral and faunal changes after the breaching of the dyke. The present study was, by necessity, quickly designed and executed. Thus, only the skeleton of a complete study was instigated and important factors such as productivity, diversity, and changes in morphology of tidal creeks were not addressed.

Frenkel amd Morlan (1990, 1991) found that over the 11 years of their study, tidal creeks deepened and channel widths narrowed. Their experience with two creeks in particular suggest the importance of completely removing the dyke for a successful restoration because the presence of the dyke segment inhibited tidal exchange. We, however, lost the opportunity to confirm or otherwise comment on their findings.

Bird data were gathered for one year following the breaching of the dyke (Dawe, unpublished data) and fish use was monitored for a few months (see Tutty et al. 1983). However, invertebrate, reptile, and mammal use was ignored.

This lack of planning and monitoring is a common complaint when such projects are undertaken. For example, Campbell and Bradfield (1988) noted only small changes in the cover and frequency of most plant species 15 months following the breaching of a dyke; the anticipated results were not met. They state that greater changes in the vegetation would likely only result with greater habitat changes (i.e. creating a larger opening in the dyke). Their results underline the need for adequate planning even in restoration projects where something as seemingly simple as removing a portion of a dyke is expected to cause certain changes in the vegetation.

Blomberg (1987) and Kentula (1986) both stress the need to bring more rigorous environmental science to bear on mitigation actions. They note that monitoring is rare and when it occurs it is often observational and not quantitative. Kentula and Mitchell (1986), as well, found that the most important need in new creation and restoration projects is improved follow-up monitoring. The importance of long-term monitoring was demonstrated in this study, based on the changes in frequency and cover of *Carex lyngbyei* over the study period. Long-term monitoring, for at least 10 years, was also emphasized by Frenkel and Morlan (1991).

There is little doubt that reintroducing seawater and tidal action through dyke breaching is one successful way of "restoring" estuarine wetlands at least to a form that resembles a natural marsh. Even areas having severe impacts such as those that were formally used as salt evaporation ponds have been colonized within a year by species such as *Spergularia marina*, *Salicornia virginica*, *Salicornia europaea*, and *Cotula coronopifolia* (Niesen and Perez 1981).

However, because we usually lack the baseline data, we cannot know for sure that we have restored the wetland. As Zedler (1984, p.7) notes, replacing what's been lost usually means making "our more disturbed salt marshes resemble our less disturbed marshes as they have been described in recent years." We don't see that as a problem, however, when simply given the choice between having or not having the wetland.

Boulé and Bierly (1987) note that it is a generally acceptable, cost-effective mechanism for mitigating the potential development in wetland habitat. We, however, would recommend the exercise of caution in restoring coastal wetlands as mitigation for allowing development in wetland habitat. It makes little sense to destroy a healthy, functioning, natural wetland in the hopes that a restored wetland will compensate for the loss.

Based on the results reported here and those of Frenkel and Morlan (1990, 1991), these restored wetlands seem to resemble and function as do other natural salt marshes--at least in the short term. On the Englishman estuary, heavy migratory bird use of the restored wetland occurred the first winter following the breach of the dyke. That heavy use has continued through to the present (Dawe, unpublished data). Fish use of the newly restored wetland, as well, occurred almost immediately (Tutty et al. 1983), and field observations of macroinvertebrate, reptile, and mammal use are consistent with those from other natural coastal wetlands in the area (Dawe, personal observation). We regard the restoration of the west marsh of the Englishman estuary as successful and have no reason to believe that this marsh won't continue to function other than as a healthy and productive wetland similar to other natural salt marshes in the area.

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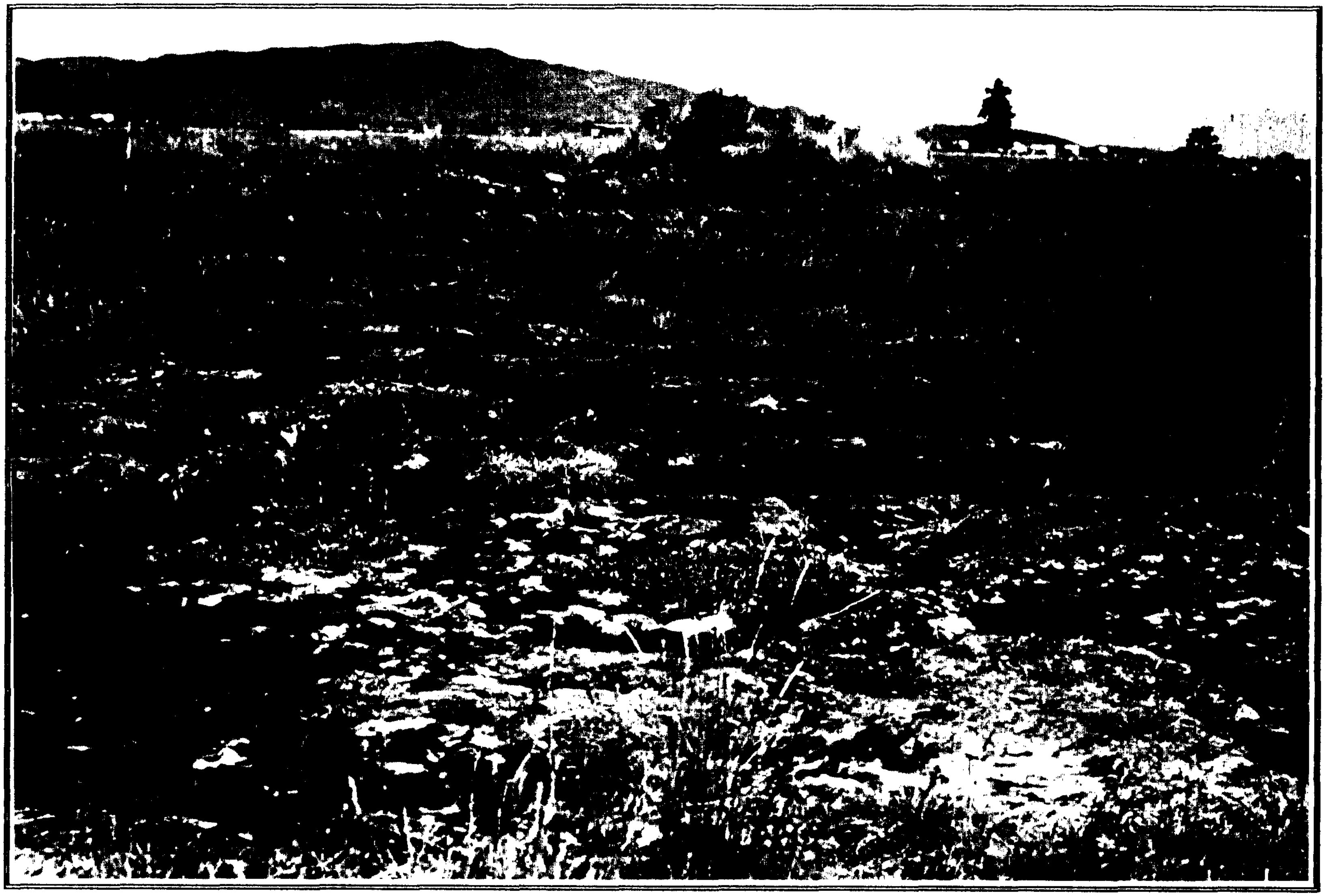
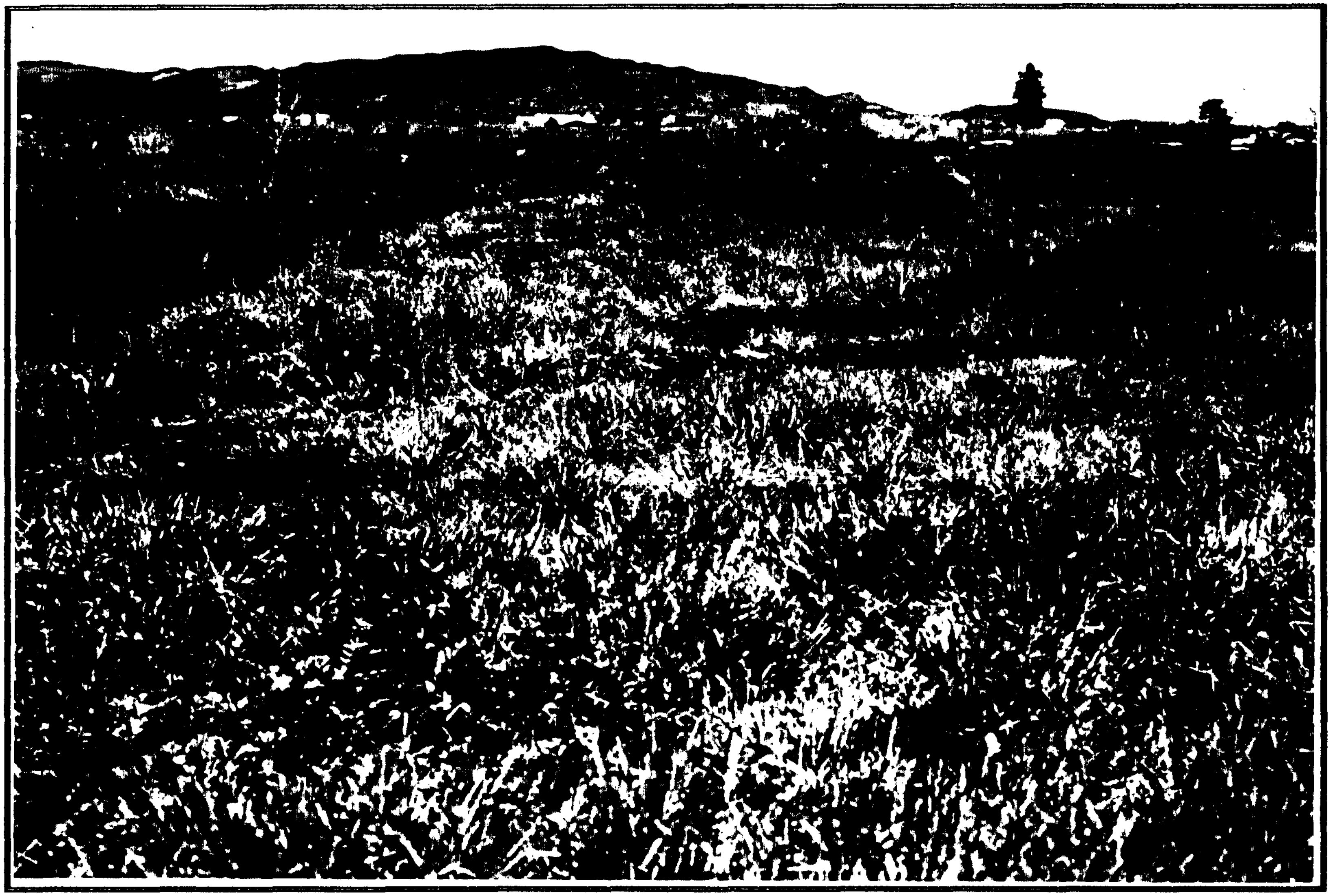
Appendix I. Photographic summary of the vegetation changes following the breaching of a dyke on the Englishman River estuary, 1979 - 1986.

30 July 1979. Four months after the breaching of the dyke. The main channel is in the upper left of the photograph and contains a stand of dying *Typha latifolia*. Upland grasses in the centre and foreground have been killed as have forbs such as *Achillea millefolium* and *Epilobium angustifolium* (left foreground). Trees, such as *Pyrus fusca* (centre) and *Alnus rubra* (upper left) have also been killed. Some remnant species that make up the *Hordeum-Sonchus* community (centre and surrounds) include *Potentilla pacifica*, *Atriplex patula*, and grasses such as *Distichlis spicata*, *Agrostis alba* and *Hordeum brachyantherum* particularly at the higher elevations of the marsh platform away from the channel (upper right of the photograph).

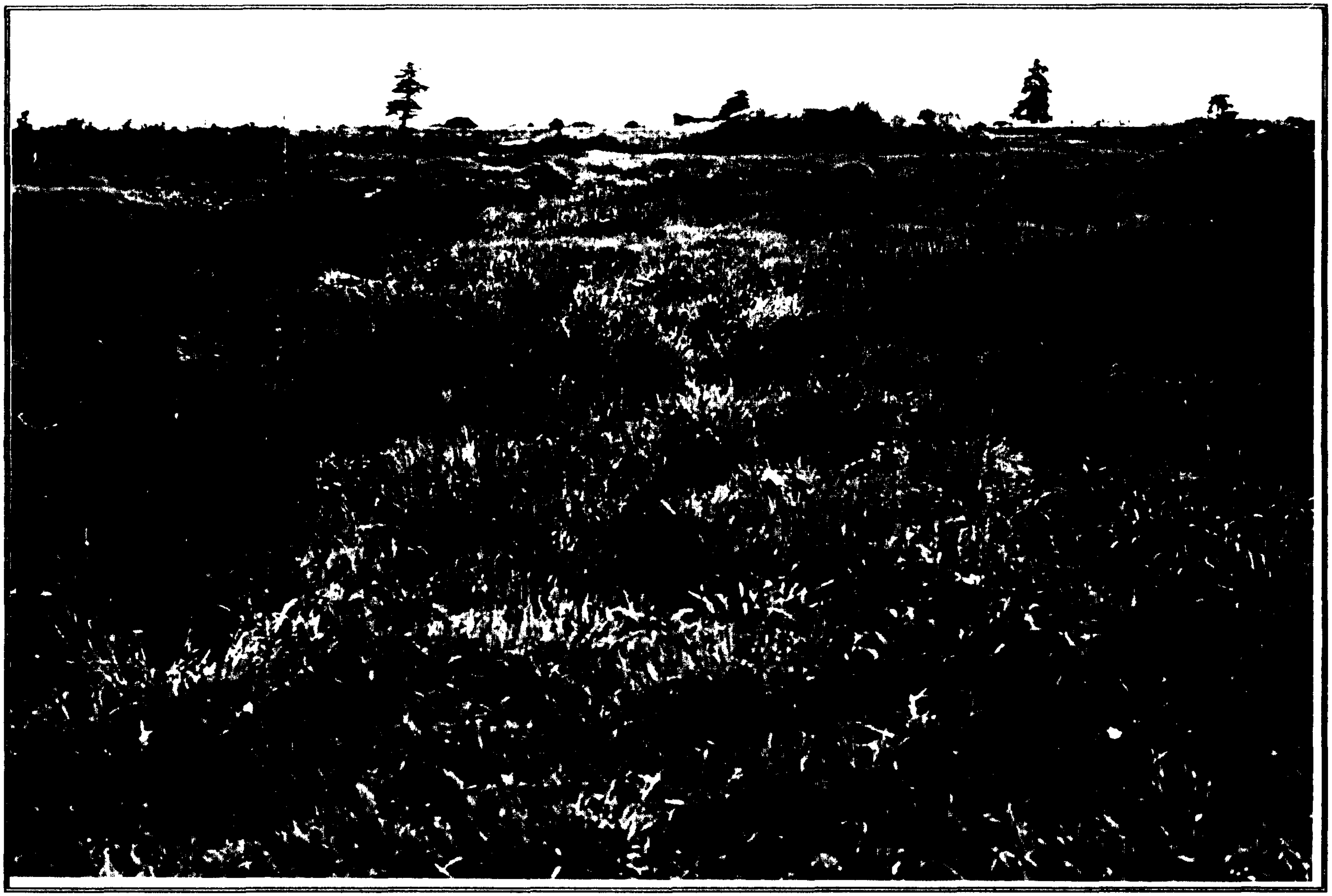


12 June 1980. One year and four months following the breaching of the dyke, large areas of the marsh were bare soil, interspersed with clusters of remnant salt tolerant species such as *Distichlis spicata*, *Salicornia virginica*, and *Atriplex patula*. Colonizing species, particularly *Spergularia canadensis* and *Salicornia europaea*, have now appeared. *Carex lyngbyei* has begun to expand its growth adjacent to the channel edge.

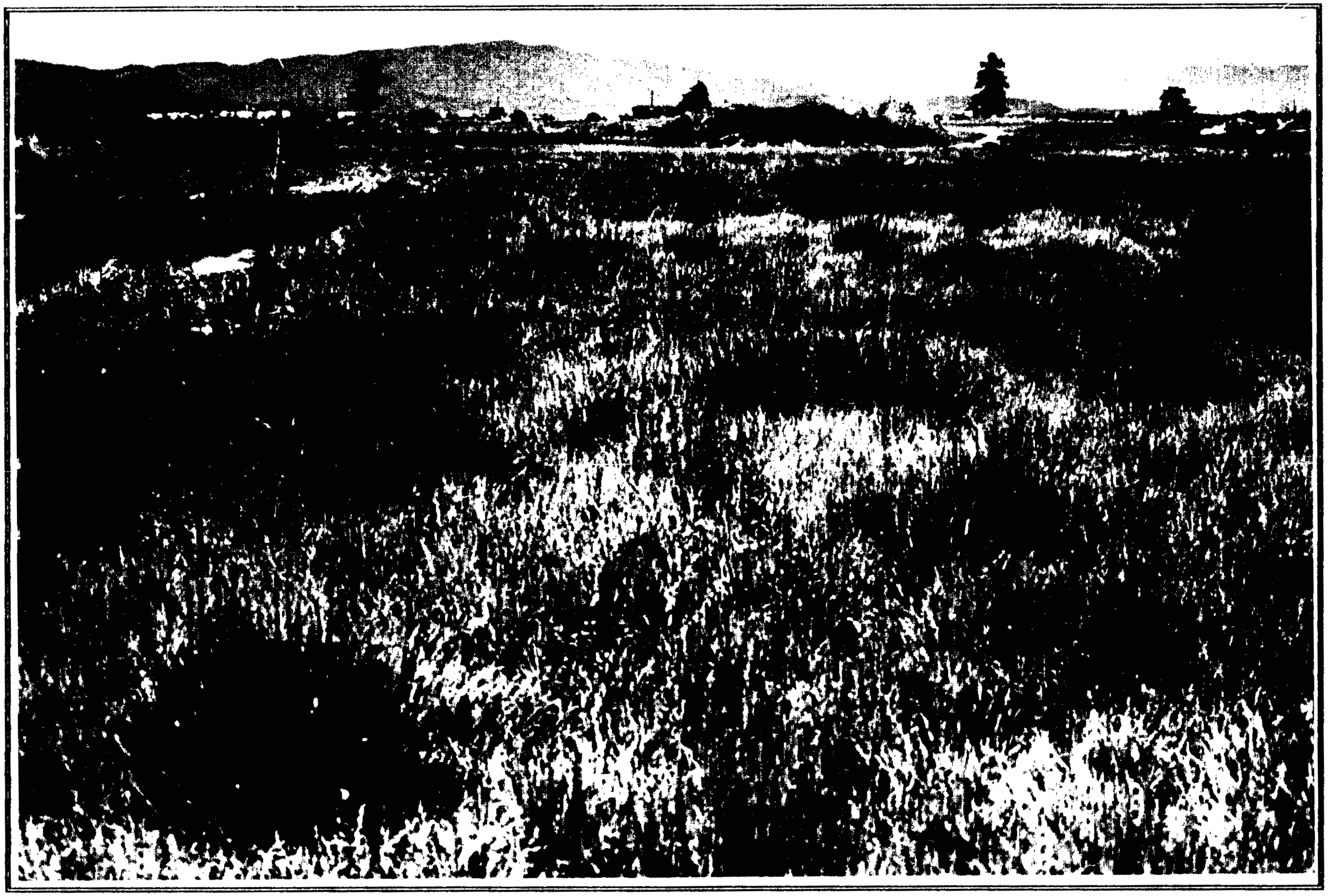
15 June 1981. Over two years after the breaching of the dyke, colonizing species have covered the areas that were bare soil the previous year. The centre and surrounds of the photograph include the *Spergularia-Salicornia europaea* community. Note the *Carex lyngbyei* growth adjacent to the channel edge.



15 June 1982. By the fourth summer following the breaching of the dyke, perennial vegetation begins to dominate. Species are continuing their shifts on the marsh platform, most of them "moving" higher in relation to their positions in 1979.



14 June 1983. Now, perennial vegetation, with species such as *Distichlis spicata* (lighter vegetation, centre), *Triglochin maritimum* (taller, dark clumps), and *Potentilla pacifica* (foreground), dominates the photograph. Note the *Carex lyngbyei* growth along the channel edge (upper left in photograph).



27 June 1986. In the eighth summer, the *Distichlis-Salicornia virginica* community now dominates the area. Clumps of *Triglochin maritimum* are obvious interspersed throughout the *Distichlis spicata*, *Salicornia virginica*, and *Plantago maritima*. Note the decline of *Carex lyngbyei* as a channel edge species (upper left in photograph below water in channel).