Upper Thurne grazing marsh ditches: An analysis of data on aquatic flora and fauna, 1973 to 2009

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Summary

The project followed the response of the aquatic plants and invertebrates at ditches in a block of grazing marsh that underwent conversion to arable then restoration to pasture, and compared this with an adjacent ‘control’ site that remained as pasture. The site, in the upper Thurne catchment, is close to the coast on sandy, slightly acidic soil and is naturally brackish.

Samples were collected by Rob Driscoll in 1973, 1981, 1982, 1997 and 2009, on dates between early August and mid October. Of 134 ditches sampled in the first year, 54-59 were later re-sampled and form the basis of this report. Five metrics were used for both plants and invertebrates: species richness, species conservation status, habitat quality (using a different index for plants and invertebrates), naturalness measured as the complement of non-native species, and brackishness.

Owing to the naturally brackish nature of the site and the acidic soil, the total and mean numbers of aquatic plant and invertebrate taxa were low. When compared with a national dataset of grazing marshes of high quality, the number of plant species was close to that found in brackish ditches but the number of invertebrates was exceedingly low.

At the start of the project, the environmental features of the sites were similar in most respects but the ‘control’ site HW2 was more brackish. After conversion to arable, site HW1 lost most of its ditch-side pasture, mean water depth halved, water width narrowed as levels dropped lower in the channel, and the proportion of frequently cleaned ditches and those with iron oxide deposits rose. No comparable changes were seen at the ‘control’ site. Electrical conductivity rose gradually over the study at the reversion site to eventually reach those at the ‘control’ site which showed only non-significant fluctuations with time. By 2009, conditions at the reversion site returned to those in 1973, although water levels were still marginally lower, there were almost no cattle-damaged edges owing to extensive fencing along ditches, and the 15km of ditches in-filled during the arable phase remained lost.

The flora clearly deteriorated following conversion to arable, shown by a marked drop in average species richness, total species and quality indicators between the first survey and the 1980s, but recovered once pasture was re-instated. Species-richness and Species Conservation Status Score of plants converged on those at the ‘control’ site but still had not reached the same value by 2009.

The invertebrates also showed a decline and recovery at the arable site. Species-richness and Species Conservation Status Score at the two sites diverged markedly after arable conversion and converged again to similar values by 2009, and at both sites they were higher in 2009 than in 1973.

Ordination (DECORANA) was used to identify changes in the plant and invertebrate assemblages through time. Plants showed a response in which the pasture ‘control’ site samples clustered in one part of ordination space while those at the arable conversion site moved away from this starting point before returning again by 2009. Thus land-use clearly influenced the flora at the reversion site. The invertebrate assemblages of the two sites were not clearly differentiated in the ordination. Samples moved their position in ordination space through time, drifting away from where they started in 1973 then returned toward the part of the ordination by 2009. The invertebrate assemblage therefore changed with time but not with a simple one-way trend, and both sites behaved similarly, so that the effect of conversion to arable farming did not show up. Several environmental variables correlated with the axis scores,

and of these electrical conductivity (brackishness) was the most important; aspects of land-use were less strongly correlated.

It was concluded that land management practices associated with arable farming had a strongly detrimental effect on both plants and animals. Re-introducing benign pasture management reversed the declines, although complete restoration of the plants had not occurred by 2009, at least a decade after re-version to pasture had begun.

1. Introduction

Long-term monitoring of plants and invertebrates is unusual. Waning enthusiasm and increasing costs usually lead to the demise of all but a few well thought-out studies, for example Rothamsted's Park Fields and moth trapping, the Butterfly Monitoring Scheme, and the Environment Agency water quality monitoring using invertebrates identified to family level. Examples from grazing marshes cover relatively few years, for example Gwent Wetland Reserve SSSI undertaken by CCW. Buglife has examined how grazing marshes have changed over the four decades since their conservation value was first recognised by comparing surveys of single sites over this period, but none of those included in that study were undertaken consistently (Drake *et al*., 2010). Here we report the results obtained by Rob Driscoll using the same method at a set of ditches taken at approximately decade intervals from 1973 to 2009.

The site was in the Upper Thurne catchment in the northwest of Norfolk's Broadland. The original survey in 1973 was undertaken to explore the relationship between land management and water quality in the catchment area of the upper Thurne (Hornby, 1973). The results were later incorporated into a wider investigation into the conservation interest of ditches in Broadland (Driscoll, 1976; Driscoll & Lees, 1974). A large part of one surveyed area, which fell within one Internal Drainage Broad (IDB) sub-district, was later converted to arable land between 1979 and 1980, thus providing an opportunity to investigate how the ditch flora and fauna were affected. The soil here was saline and acidic so the agricultural improvement was not as successful as hoped, and part of the land was converted back to pasture in the 1990s. This provided a second opportunity to investigate the effect of land-use change and to see whether the flora and fauna would respond to more benign conditions. An adjacent but hydrologically separate IDB sub-district remained as pasture and was surveyed for comparison. Further conversion back to pasture continued after 1997 so that, by 2009, the pattern of land-use had returned to that seen in the early 1970s. Details of the changes in agricultural practice are given in several publications that describe changes in the flora, fauna and land-use between the initial surveys in the 1970s and those in the 1980s (Driscoll 1983, 1984a, 1985, 1986a, b). There are also unpublished maps of animal and plant distribution (e.g. Driscoll 1981, 1984b).

Data were collected on aquatic invertebrates, aquatic plants and a number of environmental variables. This report examines changes in the plants and animals, and how these relate to changing conditions in the ditches.

An interim report was produced before the 2009 survey (Drake, 2009). While the present report is based upon it, changes in the methods of calculating some metrics and the taxa included make the 2009 report obsolete.

2. Methods

2.1. Sites

The marshes lie at the upper end of the Thurne catchment in north-east Norfolk, close to the coast. Most sampled ditches now lie within the Broads Authority boundary (Figure 1). They fall into hydrologically separate sub-districts of the Happisburgh-Winterton IDB. The two sub-districts are abbreviated to HW1 and HW2 in this report:

- **HW1 (reversion site)** is within the parishes of Somerton and Winterton, where much of the marshes was converted to arable between 1978 and 1981 and then back to pasture before the 1997 survey.
- **HW2 ('control' site)** is in the parish of Horsey, where land-use remained unchanged pasture, and this provided a comparison.

In the original survey of 1973, 134 ditches were sampled across this area. A subset of these was sampled for the later comparison of the area converted to arable with the 'control' area (Table 1). Nearly all ditches in this subset were re-sampled on each occasion but a few could not be sampled, for instance because they had been filled-in or were dry.

Table 1. Number of ditches sampled for plants and invertebrates in each year, with the dates of visits.

Year	HW1	HW2	Span of visits
1973	32	26	3 September – 17 October
1981	33	26	22 August – 31 August
1982	33	21	27 August – 5 September
1997	32	26	24 August – 3 September
2009	30	26	5 August – 18 August

2.2. *Field methods*

Emergent, marginal and floating plants were recorded from the banks, and submerged plants were sampled using a pond net and weed grapple. Aquatic animals were collected by pond-netting and by hand from aquatic plants, and sampling continued until at least three net sweeps had been taken without catching any new species. Estimates were made of the abundance of each species. Adult Odonata were also recorded but have not been included in the analyses as they may have originated from elsewhere.

Several environmental variables were measured (Table 2). Most of these are self-explanatory.

The measures of brackishness were chlorinity and conductivity, and these were taken the year after the survey on 21 February (HW1) and 7 March (HW2) in 1974, and on 6 March 1984. Measurements in 1997 and 2009 were taken while surveying for plants and animals. Only one or other was used except in 1984 when both were measured. The relationship between them in 1984 (using the linear regression y=2.8516 + 1121.4, with $R^2 = 0.975$) was used to convert chlorinity measured in 1974 to conductivity, so that brackishness could be compared using the same units across the entire period of the project. These measurements were not taken at all ditches, and a smaller proportion was sampled in 1974 and 1984 than in the later years (in 1974-84: 11-12 at HW1, 8 at HW2; in 1997-2009: 28-29 at HW1, 25 at HW2).

Abundance of aquatic plants and animals was estimated visually using a four-point scale: R (rare), O (occasional), F (frequent), A (abundant). L (locally) was used with F and A. More than one code was used if the abundance of a species varied along the length of a dyke (e.g. O-F). + indicates that the species was present but its abundance was not recorded.

The surveys took place in late summer each year (Table 1).

Plants and animals were identified by Rob Driscoll except for the following: Clive Jermy, Derek Wells and Jenny Moore helped with plant identification; water beetles were identified by Dr Tony Warne (1973) and Dr Garth Foster (1981, 1982) and caddis larvae by Ian Wallace (1981, 1982). A small number of molluscs were confirmed by Derek Howlett, and some beetles and caddis from 2009 samples were identified by Martin Drake.

An error in identification was pointed out by Rob Driscoll in the draft report, resulting from the long-standing confusion in the use of the names for the two species of *Noterus*. Only *Noterus clavicornis* (the common species) was present, and not *N. crassicornis* (nationally scarce and with some fidelity to grazing marsh ditches.) This has not been corrected in the analyses (only in lists) since it would entail re-working of much of the invertebrate results and presentation. Median values of SCS Score and Habitat Fidelity Score are therefore higher than they should be for 1973, 1981 and 1982 (but not for later samples).

Table 2. Environmental variables recorded.

Variable	Measurement and notes
Width	of the water surface to nearest 0.1m
Depth	of the water to nearest 0.1m
Length	of ditch between joining ditches, in m
Turbidity	of water, estimated on a four-point scale from clear (1) to very cloudy (4)
pH (1)	measured with Johnsons Test Papers to nearest 0.1 units
pH (2)	measured using a meter at a small proportion of ditches
Chloride concentration	in mg l^{-1}, which approximates to ppm, at a small proportion of ditches in 1974 (the year following the main survey)
Electrical conductivity	in $\mu S\ cm^{-1}$ in 1984 (the year following survey), 1997 and 2009.
Ferruginous	a record of iron staining resulting from oxidation of iron sulphide following exposure to air when the soil was deep-drained
Recently cleaned	cleaned out since the previous summer
Ditch edges damaged by cattle	recorded as 1 for damage by cattle trampling to one side and 2 for both sides
Land use	recorded on both sides, using the categories arable, grass, woodland, natural and semi-natural vegetation, track and road, and up to three combination of these (although mostly just one per side)
Water colour	description; not used in this analysis
Flow	not used in this analysis as it was nearly always recorded as 'negligible'
Nature of the bottom	description; not used in this analysis

2.3. *Analysis*

Data were input to an Excel spreadsheet from copies of the transcribed field sheets. Rob Driscoll retains the original datasheets.

2.3.1. Species Metrics

The scoring system in the ditch survey manual by Palmer *et al*. (2010) was used to assess the conservation value of the plant and invertebrate assemblages. Four of the five scores contain elements of the 'Nature Conservation Review' evaluation criteria of diversity, rarity, representativeness and naturalness (Ratcliffe, 1977). The scores are for:

Native Species Richness (number of native taxa)

Species Conservation Status Score (SCS) (the mean of rarity scores: the Species Quality Score (SQS))

Habitat Quality (for plants, the number of good water quality indicators; for invertebrates, the % of species closely associated with grazing marsh – Habitat Fidelity)

Naturalness (impact of introduced species, as indicated by a negative 'threat score')

Brackishness

The scores were applied as outlined in the manual by Palmer *et al*. (2010) and, for the invertebrate Brackishness Score, Drake *et al*. (2010). The manual includes check lists of invertebrates and plants recorded in grazing marsh ditches. In this report, only plant taxa included in these check lists were considered, along with higher taxa (e.g. genus) of these species. This accounts for the apparent absence of marginal plants such as *Mentha aquatica* and *Oenanthe lachenalii*. A few more invertebrate taxa than listed in the checklist were included since triclads and a few dipteran taxa had been recorded systematically, and the numbers of all taxa were so low that including these extra taxa marginally improved the analysis.

2.3.2. Statistical tests

Parametric methods of statistical analysis were considered justified since, although samples were not taken randomly, they included a large proportion of the available ditches and the same set were sampled on successive occasions. Normality in the metrics was checked visually using QQ plots (normal plots) and frequency histograms, and tested for skewness and goodness-of-fit to normality using a Kolmogorov-Smirnov test.

For the plant metrics the non-significant skewness and the Kolmogorov-Smirnov test suggested that no transformation was needed for HW2 plant data, but for HW1 plant data transformation markedly improved the distribution of the number of species (using square-root) and Habitat Quality Score (using log), even if not eliminating some significant p-values in the tests. However, since one cannot mix transformed and untransformed data in the same tests, no transformation was applied. Some justification for this was found in the almost invariably similar significance levels of parametric and non-parametric test on the untransformed data.

Almost all invertebrate metrics were very strongly skewed and gave significant p-values with a Kolmogorov-Smirnov test. Although QQ plots and examination of histograms of frequency distributions suggested that species-richness of all taxa and several major groups, and the score for brackishness, would be improved by a square-root transformation, only total taxa at HW1 was clearly improved, but no other groups of taxa or total taxa at HW2 could be improved by transformation and were usually made worse. Scores for Species Conservation Status, Habitat Fidelity and Naturalness were far too skewed for any transformation to rectify. All the metrics for invertebrates were therefore tested using non-parametric methods.

The species metrics were calculated for each sample and their mean and median values, and those of environmental variables, calculated for each of the two IDB sub-districts. Differences across years in mean values were tested using 1-way ANOVA and those for medians were tested using a Kruskal-Wallis test. Metrics were compared between the two sub-districts for each year to show the magnitude of the differences that may have been due to the change in land-use at reversion site HW1. A Kolmogorov-Smirnov test for normality of the data for both sub-districts combined for each year showed that, apart from Conservation Status Score, normality may be assumed to hold without the need for transformation (Table 10). Means for species-richness and the scores for habitat quality and brackishness were compared with a t-test, and Conservation Status Score was compared using a Mann-Whitney U test (Table 11).

The metrics may change over time due to environmental influences but there is also residual variation that cannot be simply explained and will be due to such factors as year-to-year differences in the 'season', stochastic fluctuations in populations of each species, and sampling error. This was investigated by Drake *et al*., (2010) who give the minimum change in mean and median values of the species metrics that must be exceeded to be sure that a change is not merely due to these unmeasured effects. These values are expressed as the 95% confidence limits of the means, and are given in Table 3. As two means may be considered significantly different if the 95% confidence limits of one mean do not encompass the other actual mean, then the values in Table 3 can be roughly interpreted as equivalent to the difference between the means expressed as a percentage of the larger mean. This is not strictly accurate but close enough for practical purposes, especially as the values in Table 3 were derived from a limited study of ten Somerset NNR ditches sampled at yearly intervals for only three years, and so may not be universally applicable.

Diagrams of means and medians are from the Analyse-it add-on to Excel, and these are explained in Appendix 3.

2.3.3. Ordination

Ordination was carried out using detrended correspondence analysis (DECORANA) to detect any obvious pattern in the datasets for both plants and animals. This method was selected as it tends to show patterns when samples follow a gradient, of which there are many potential ones in ditch systems, for example, ditch dimensions and salinity (Henderson & Seaby, 2008). A preliminary run was carried out on both plants and invertebrates to check that this method, which is applicable to unimodal data, was justified, rather than Principle Component Analysis, which is more suitable to linearly distributed data.

Canonical (constrained) correspondence ordination could not be undertaken because there were far too many missing values among the environmental variables. Instead, trends in the ordination were investigated by correlating axis scores with the environmental variables using Spearman's rank correlation. For this purpose, land-use was converted to ordinal values for grass, arable and mixed (see below); thus if a ditch had grass on one or other bank, it scored 1 for grass, and a ditch with grass on one side and arable on the other scored 1 in both categories. Cattle damage was left as originally scored in the field (1 for damage to one bank, 2 for both). Where intermediate values had been allocated, they were converted to the nearest whole number, or to the largest depth or width. Values that had been scored as ranges (e.g. width 3-4m) were converting to the nearest proper number.

Land-use categories were simplified and reduced to three from the 17 combinations of categories that had been recognised in the surveys. These were:
'g' – grass on both banks or in combination with natural/semi-natural vegetation or woodland.
'a' – arable on both banks
'm' – mixed, consisting of arable and grass on either bank, or arable in combination with natural/semi-natural vegetation or woodland.
The categories of track and road were ignored (grass or arable taking precedent).

Abundance on the DAFOR scale was converted to numerical values to facilitate analysis (Table 4). They were also simplified by lumping intermediate values, taking the higher abundance value in each case or the 'average' when this seemed a better representation of complex values.

Table 3. Minimum 95% confidence limits of means of each species metric, expressed as a percentage of the mean, that must be exceeded to indicate a real difference between two values.

Metric	Plants	Invertebrates
Native Species Richness	14	22
Species Conservation Status Score	8	11
Habitat Quality Score	8	8

Table 4. DAFOR plant values and their conversion to numerical equivalents.

Field value		**Value used in analysis**
animals	**plants (suggestions only since they were not used in this report)**	
D - not used on field sheets	D - not used on field sheets	
A, LA	A, LA	4
	F-A, F-LA	3.5
F, LF, O-F, O-LF, R-LF	F, LF, O-A, O-F-A, O-F-LA, O-LA, R-F-LA	3
	O-F, O-LF	2.5
O	O, R-LF	2
R, tick (for presence)	R, tick (for presence)	1

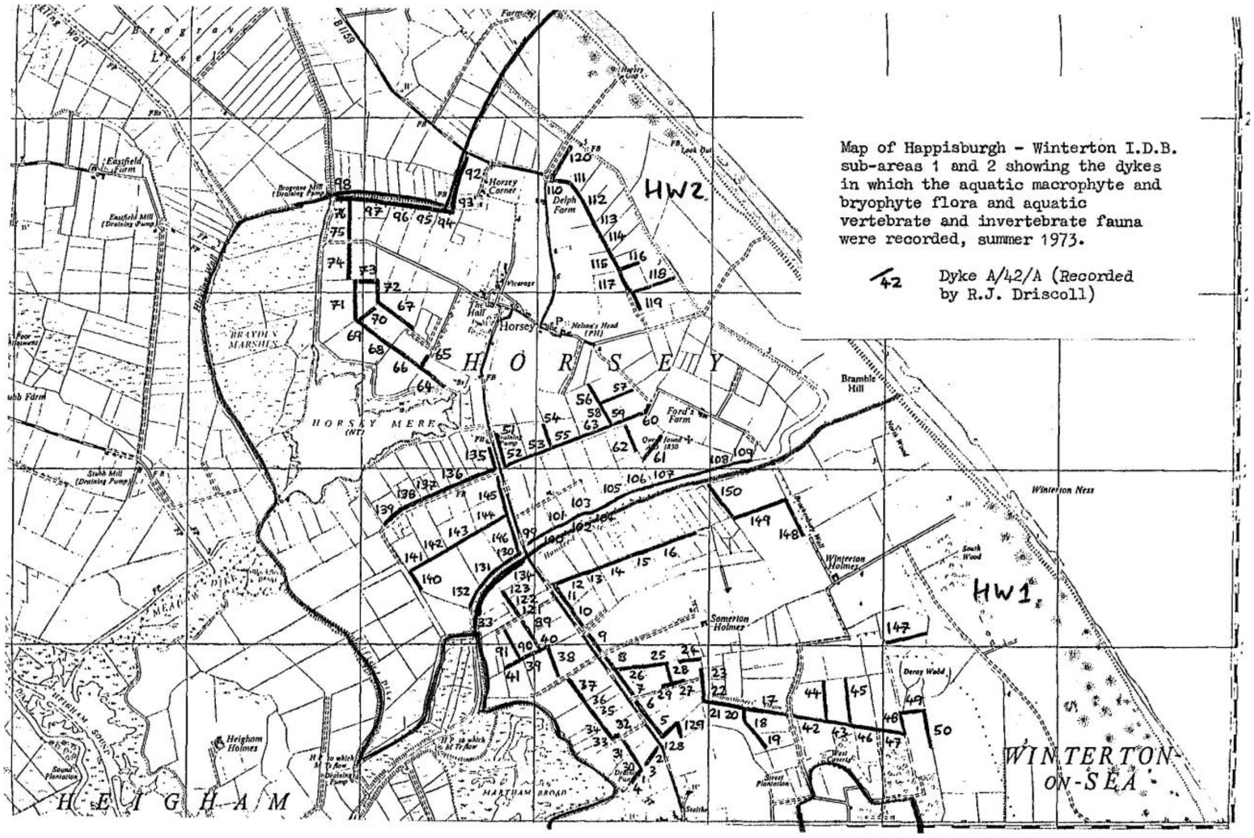


Figure 1. Position of sampling points.

3. Results

3.1. Environmental features

The most important environmental features are shown in Figures 2 to 5. Mean values are shown with 95% confidence limits as Kolmogorov-Smirnov tests indicated no deviation from a normal distribution for these variables.

At the start of the project in 1973, the two IDB sub-districts were similar in most of these measured variables. There were no differences in water depth or width, or in land-use which was almost entirely pasture.

The main environmental difference was that HW2 ('control') was more brackish than HW1 (reversion site) in all years, although only significantly so in 1974 (*sic* - chlorinity was measured the year after the survey). HW1 became increasingly brackish through time (Figure 3), whereas conditions at HW2 remained moderately steady with the mean conductivity fluctuating between 8,780 and 10,050 μS cm^{-1}. In this analysis, one extreme value in 1997 was excluded since it was taken from very shallow water that was drying out, resulting in unusually high salinity. There were no freshwater ditches, defined as having a conductivity lower than 2000 μS cm^{-1}, at HW2 ('control'), and only one to three ditches at HW1 (reversion site) were fresh; this represented 8-11% of the ditches that were sampled for invertebrates and plants (brackishness was not measured at all ditches).

The conversion of HW1 to arable involved in-filling of about 15km of ditches, installing under-drainage in the fields, and lowering the water levels helped by the installation of a second pump. These modifications were reflected in the measured environmental variables. There was a near-loss of ditches completely within pasture. A large and significant drop in mean water level was accompanied by a narrowing of the ditches as water was drawn down to the bottom of the trapezoidal profile, leading to increased oxidation of the substrate and release of iron oxides reflected in a large increase in the proportion of ferruginous ditches. The infilling of many of the subsidiary ditches and installation of under-drainage exacerbated the release of iron. Arable farming required better drainage, so the proportion of recently cleaned ditches rose steeply and, as cattle were no longer important, no cattle-damaged edges were recorded in the 1980s. There was a small increase in the average turbidity.

The restoration to pasture that had begun by 1997 was clearly reflected in these variables returning towards their early values, which were often reached by 2009. However, at HW1 (reversion site) there was still a signal of the arable period in the large number of ferruginous ditches. The failure of water levels to reach those in 1973 is probably due to the combination of better control of water levels now than in the 1970s as a second pump was installed in the 1980s, and fencing of many ditches and the installation of drinking troughs which obviated the need for high water levels as wet fences or to allow stock to reach it for drinking. About 15km of ditches were removed during conversion to arable, and were not replaced.

The ‘control’ site, HW2, remained effectively unchanged between 1973 and 2009. The number of ditches with cattle-damaged margins was higher in the two later surveys than in the earlier ones, and ditch cleaning was infrequent after wide-scale cleaning in 1971-2. Although the land remained under grass, its management has nevertheless changed since the 1970s. The pasture in 2009 was re-seeded ley, water levels were controlled more rigorously, and many ditches were now fenced.

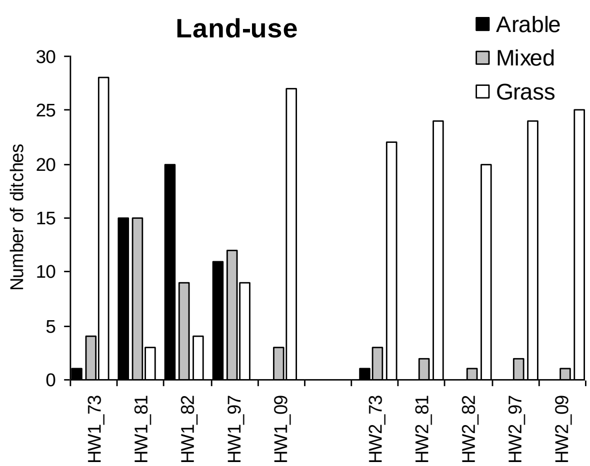


Figure 2. Number of ditches in each land-use class at the two IDB sub-districts in each year of sampling.

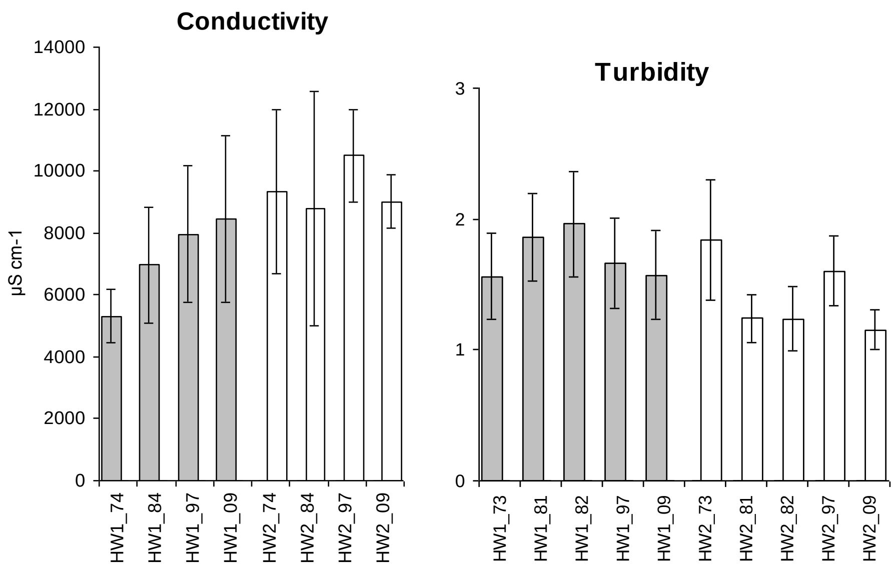


Figure 3. Mean conductivity in 1997 and 2009, and mean turbidity at the two IDB sub-districts (with 95% CL).

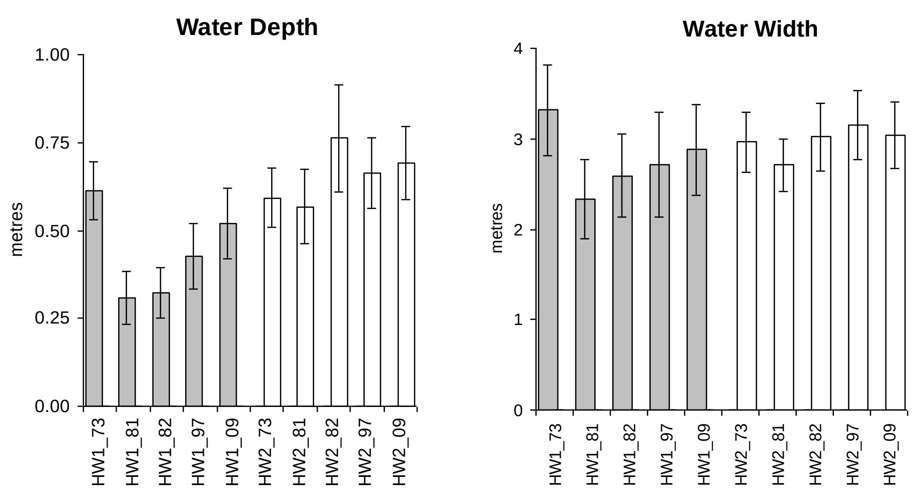


Figure 4. Mean depth and width of water in ditches at the two IDB sub-districts in each year of sampling (with 95% CL).

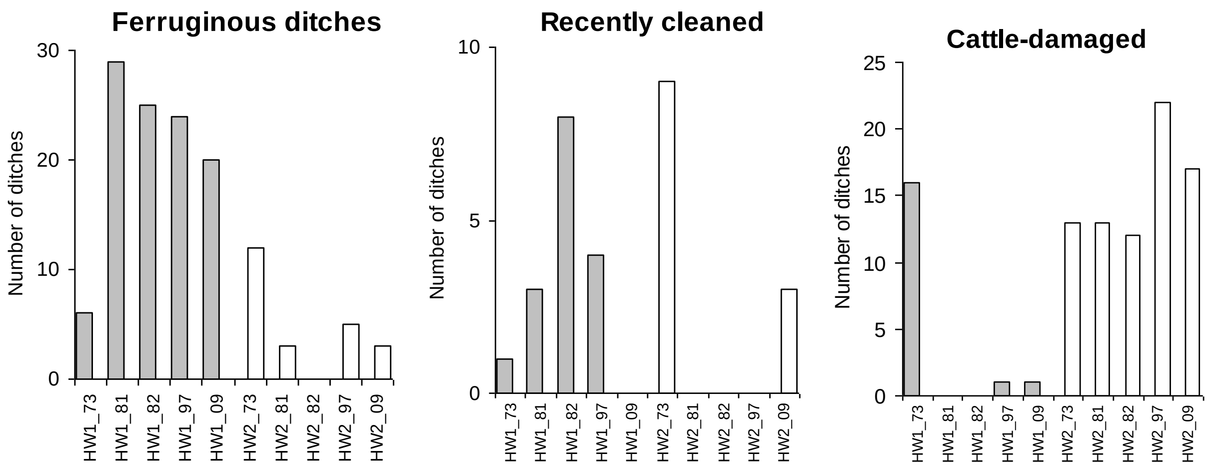


Figure 5. Number of ditches at the two IDB sub-districts in each year of sampling for the variables ferruginous, recently cleaned and cattle-damaged margins.

3.2. Plants

3.2.1. Species variables

Altogether, 56 taxa of fully aquatic plants were recorded, together with another 17 wetland taxa not included in the check list (Table 4, Appendix 1). Two aquatic species, *Myosotis scorpioides* and *Potentilla palustris*, were found only in 1973 samples that were not included in the sub-set sampled in all years. The sub-sample of 59 ditches therefore included nearly all the species recorded in the whole marsh area and characterised the flora well.

Throughout the period of the study, the flora of the two sites maintained separate identities. Despite the detrimental land-use changes at HW1, 53 of the 56 species of aquatic plants recorded in the project were recorded here, compared to only 40 species at HW2 ('control'). The ditches were dominated by *Phragmites*, which occurred in almost every ditch (Table 5). All other frequently occurring plants are common species except for the red-listed *Myriophyllum verticillatum.* Several other widespread plants were about equally frequent in the two sub-districts. These included *Hippuris vulgaris, Potamogeton pectinatus* and *Callitriche* sp but, apart from these, there were large differences between sites in the occurrence of other frequent species. More species were clearly more frequent at HW1 (reversion) than at HW2 ('control'). They included *Potamogeton pusillus*, *P. natans*, *P. crispus*, *Zannichellia palustris, Lemna minor*, *Apium nodiflorum*, *Alisma plantago-aquatica*, *Rorippa nasturtium-aquaticum*, *Elodea canadensis*, *Sparganium erectum*, *Enteromorpha* sp, and *Glyceria maxima*. Plants that were clearly more frequent at HW2 were *Myriophyllum spicatum*, *Schoenoplectus tabernaemontani*, *Lemna trisulca*, *Bolboschoenus maritimus* and *Typha angustifolia*. All these, apart from *Lemna trisulca*, are at least fairly salt-tolerant. Thus there were marked differences between the IDB sub-districts, many of which were apparent in 1973 before marked changes in land-use began.

3.2.2. Patterns of change in the IDB sub-districts

Happisburgh-Winterton 1 (reversion site)

The number of species, and scores for Species Conservation Status and Habitat Quality dropped markedly between 1973 and the early 1980s after the conversion to arable (Figure 6, Table 6). From then on there was very little change in these metrics until 2009 when the number of species and Conservation Status Score rose slightly, although not reaching the 1973 values. Over the entire period, the medians of the number of species and status score showed significant differences (Kruskall-Wallis statistic was significant), and the means for the number of species also differed significantly. It is likely that the low value in 1982 was most responsible for the significant results of these tests.

The Conservation Status Score did not perform particularly well in statistical terms since it was very strongly left-skewed owing to most samples containing no uncommon species, and this behaviour is partly responsible for the lack of significant change in mean and median values over the years (Figure 6). However, there were a few marked changes in uncommon species. *Myriophyllum verticillatum* was frequent in 1973 but declined or disappeared thereafter, and presumably it was strongly adversely affected by the change in land-use (Table 7). In comparison, this species showed no marked change in the 'control' site HW2 apart from a small increase in 2009. Plants that failed to reappear well after arable conversion (in 1997 and 2009) were *Baldellia ranunculoides*, *Chara globularis*, *Oenanthe fistulosa*, *Riccia fluitans* and *Sagittaria sagittifolia*. However, they were represented by so few records (usually only one per year) that it is difficult to distinguish between sampling error and genuine loss, especially since the 'control' site HW2 also lost four species in the same period. The immediate impacts of arable conversion clearly were not responsible for the apparent ultimate loss of *B. ranunculoides* and *C. globularis* since these were recorded after conversion in the 1980s, and populations of some *Chara* and *Riccia* may temporarily benefit from ditch clearance. In the two sampling occasions (1997, 2009) when pasture had been restored to HW1, only two plants, *Carex pseudocyperus* and *Potamogeton coloratus*, were found for the first time. Thus there was a net loss of species and little indication of those remaining becoming more widespread.

There was no significant change in the median or mean of Habitat Quality Score over this period, although it showed an initial fall after 1973 as seen in the other metrics (Figure 7, Table 6). Four of the more demanding species that were widespread in 1973 showed an apparently permanent reduction in their frequency – *Hippuris vulgaris*, *Lemna trisulca*, *Potamogeton natans* and *P. perfoliatus* (Table 8). *Juncus subnodulosus*, showed a small and probably unimportant increase over the study period, and this may merely reflect that it was probably excluded from the survey as part of the dry bank vegetation when water levels were low in the 1980s. In comparison, these plants, with the exception of *P. natans*, showed no equivalent decline at HW2 ('control'), and *L. trisulca* even increased here. Only two species contributing to the HQS, *Baldellia ranuculoides* and *Chara globularis*, failed to maintain population at HW1 well after the arable period.

The score for brackishness fell gradually from the start of the study until 1997 after which it rose again to the level found in the 1980s, but the mean values were not significantly different over the period (Figure 7). Changes in the occurrence of just a few key species were probably responsible for this trend (Table 9). *Myriophyllum spicatum* almost disappeared after the agricultural improvement and reappeared in 2009. *Potamogeton pectinatus*, *Zannichellia palustris* and *Scirpus tabernaemontani* took a little longer to decline and *Z. palustris* failed to recover to its original abundance. These changes may have resulted from a decline in water quality independently of changes in brackishness, since the trend for brackishness was very clearly upwards from the start to the end of the project (Figure 3.). However, a huge increase in *Z. palustris* (and *Potamogeton pusillus*) did correlate well with the increasing salinity levels, and these plants did temporarily benefit from the arable conversion. Similar changes were seen at HW2 ('control') for *P. pectinatus*.

The only non-native species in the whole survey was *Elodea canadensis*, which was moderately widespread and sometimes had DAFOR scores of frequent to abundant at HW1 in 1973 but almost disappeared after this, and was infrequent in 1997 and 2009.

For Native Species Richness, SCS Score and HQS, the change from the smallest to largest values across the study period was far greater than needed to demonstrate a real change that was unlikely to be due merely to unmeasured or chance effects (compare values in Table 6, last column, with the minimum required given in Table 3). This was also true for the next site, HW2.

Happisburgh-Winterton 2 ('control' site)
At the 'control' pasture site, average species richness rose significantly from a low value in 1973 to a high value in subsequent years, when there was no further change (Table 6, Fig. 6). The means and medians were significantly different but this was certainly due to the initial rise in the numbers of species.

The Species Conservation Status Scores followed a similar pattern to that of total species, showing an apparent gradual increase over the years, but this was not significant when medians were compared. The poor performance of this metric has already been mentioned, and inspection of the uncommon species was needed to confirm the apparent trend. As at HW1, only *Myriophyllum verticillatum* was consistently found and present at a few ditches, and showed no real change in frequency over the years, apart from a slight increase in 2009 (Table 7). Four species failed to appear after the 1980s – *Chara aspersa*, *C. hispida*, *Potamogeton coloratus* and *Oenanthe fistulosa*. Only one species, *Ranunculus baudotii*, was completely new to either site in 2009. The apparent and statistically unsupported trend in the SCS Score was therefore not matched by inspection of the raw data, which appear to suggest either no real change or even a decline in interest.

Habitat Quality Score (i.e. good water quality indicators), in contrast to the Species-richness and Species Conservation Status Scores, rose in the two 1980s surveys then fell below its earlier value in 1997 and 2009 (Figure 7). The species on which this metric is based were recorded most widely in the 1980s, often preceded in 1973 by lower occurrences (Table 8). The commonest species in this group, *Hippuris vulgaris*, had a stable population until 2009 when its frequency dropped. No *Chara* species were found after the 1980s. Only *Lemna trisulca* clearly followed a rising trend.

The Brackishness Score appeared to show a slow increase until 1997, followed by stabilisation or even a decline (Figure 7). The means did not differ significantly over time (although the medians did), but both the direction of this trend and the magnitude of the differences between sub-districts in each year suggested that there was a real change in the plant assemblage. Three of the plants contributing to the brackishness index are long-lived perennials that would not be expected to fluctuate much (*Bolboschoenus maritimus*, *Schoenoplectus tabernaemontani* and *Phragmites australis*) and these did show only small changes (Table 9). Two widespread submerged species, *Myriophyllum spicatum* and *Potamogeton pectinatus*, both showed a dip in the middle years. The only widespread taxon to show a marked change was filamentous alga, which was recorded far more often in 1997 and 2009 than previously. The inconsistency in the population levels of these plants indicated that there was probably no systematic change in brackishness at HW2.

No non-native species were recorded at HW2.

Comparison between sub-districts in each year

Species-richness was initially significantly higher at HW1 than at ‘control’ site HW2, but after arable conversion the numbers fell in HW1 and rose in HW2 so that they were similar in the 1980s. Numbers of species continued to fall in HW1 in the 1990s to a point where they were significantly lower than the fairly stable numbers in HW2, and finally appeared to show some recovery in the 2000s and were again similar to the ‘control’ site by 2009.

Species Conservation Status Score performed poorly owing to the numerous samples with no uncommon species, leading to many outliers (crosses and circles in Figure 6) and grossly non-normal distribution. Thus the apparent trends at each sub-district are poorly supported by the test for differences between years, although the high initial score at HW1 (reversion site) was probably responsible for the significant difference between years indicated by the Kruskall-Wallis test. There was no significant difference between years at HW2 (‘control’). The only significant between-site difference was at the beginning in 1973 when HW1 had a higher score.

Habitat Quality Score at HW1 (reversion site) showed no between-year differences, although it was highest at the beginning. At HW2 there was an apparent rise in the 1980s followed by a plunge to values well below those in the 1970s and 1980s, giving highly significant between-year F-values. This may have been an artefact since the only significant between-site difference was in 1982, and it seems improbable that 1982 should have been better than 1981 at the ‘control’ site. However, overall trend was for both sites starting with similar values, diverging in the middle years (HW1 falling, HW2 rising), then convergence at the end of the study to a value lower than that in 1973. This did suggest that the two assemblages responded to a real change in water quality.

Trends for brackishness mirrored those for total species. Both sub-districts started with similar values but while those at HW1 fell, those at HW2 rose, and in all years except 1973 the values at HW2 were significantly higher. It was not clear whether the downward trend at HW1 could be attributed to the changes in land-use.

Table 5. Aquatic plant species recorded in the sub-set of 59 ditches ranked by the number of total number of records.

Species	**Status Score**	**HW1 (reversion)** 1973	1981	1982	1997	2009	**HW2 (‘control’)** 1973	1981	1982	1997	2009	**total**
Number of ditches		33	33	33	32	30	26	26	21	26	26	286
Phragmites australis	1	32	30	29	32	30	26	25	21	26	26	277
Hippuris vulgaris	1	17	9	5	6	7	17	19	17	17	12	126
Potamogeton pectinatus	1	15	10	5	12	15	10	7	6	16	14	110
Myriophyllum spicatum	1	10	1	4		8	24	17	12	15	16	107
Callitriche sp	1	21	8	14	9	9	7	12	10	5	8	103
Schoenoplectus tabernaemontani	1	7	6	3	2	5	7	13	12	16	12	83
Potamogeton pusillus	1	1	12	14	12	6		7	2	7	12	73
Potamogeton natans	1	18	11	10	6	9	4	3	2			63
Zannichellia palustris	1		22	19	8	6		2	1	1		59
Filamentous algae	1	9	3	2	1	5	3	1	3	12	14	53
Myriophyllum verticillatum	5	13	4	5	2	6	2	4	4	4	9	53

Species	Status	HW1 (reversion)					HW2 ('control')					total
	Score	1973	1981	1982	1997	2009	1973	1981	1982	1997	2009	
Carex riparia	1	9	4	5	6	5	4	6	4	6	3	52
Lemna trisulca	1	8	3		1	2	2	7	9	8	11	51
Bolboschoenus maritimus	1	1	2	2		1	2	12	8	11	7	46
Lemna minor	1	10	6		6	4	2	1	1	1	1	32
Apium nodiflorum	1	8	5	7	2			2	2	2		28
Alisma plantago-aquatica	1	8	7	7	1	3						26
Rorippa nasturtium-aquaticum	1	7	5	7	1	5					1	26
Juncus subnodulosus	1	1	1	3	3	4	1	4	4	1	1	23
Elodea canadensis	0	13	1		3	4					1	22
Ranunculus circinatus	1	10		1		1	1	4	2		2	21
Sparganium erectum	1	2	2	5	7	5						21
Eleocharis palustris	1	1	1	1		2	1	6	7			19
Enteromorpha sp	1	10	3	4		1	1					19
Potamogeton crispus	1		8	6	2	2				1		19
Potamogeton perfoliatus	1	8	1	2			1	2	3	1		18
Glyceria maxima	1	8	3	4	1	1						17
Typha angustifolia	1					1	2	1	1	3	4	12
Ranunculus aquatilis	1			1		1	1	4	3	1		11
Iris pseudacorus	1	3	1		2			1	1			8
Ranunculus sceleratus	1		2	1	1	1			2		1	8
Typha latifolia	1	1		1	4	2						8
Berula erecta	1	1		1		3					2	7
Oenanthe fistulosa	5	3						2	2			7
Ceratophyllum demersum	1	3									3	6
Chara sp	1	2			2		1		1			6
Hottonia palustris	1	3	1			2						6
Veronica catenata	1		2	3		1						6
Chara globularis	1			1				2	1			4
Glyceria fluitans	1		2	2								4
Sparganium emersum	1		4									4
Chara aspersa	2							2	1			3
Groenlandia densa	5		1	1	1							3
Leptodictyum riparium	1	1				1		1				3
Persicaria amphibia	1	2	1									3
Ranunculus trichophyllus	1	3										3
Baldellia ranunculoides	4		1	1								2
Chara vulgaris	1			1		1						2
Potamogeton coloratus	3					1			1			2
Potamogeton sp	1	1					1					2
Ranunculus baudotii	1										2	2
Rumex hydrolapathum	1	1									1	2
Sagittaria sagittifolia	1	1	1									2
Carex pseudocyperus	1				1							1
Chara hispida	1							1				1
Riccia fluitans	1	1										1

Table 6. Mean and median numbers of plants and scores, with inter-quartile range, confidence limits, Kruskal-Wallis statistic, F (with p-values) and largest change for the ditches sampled in all years in IBD sub-districts Happisburgh-Winterton 1 and 2.

Column 'Test' has the Kruskal-Wallis statistic above, testing for differences in the medians across the four years, and F for 1-way ANOVA below, testing the means using untransformed data; p is the probability of the differences being due to chance; bold K-W and F values are significant. Largest percentage change is the biggest difference in mean values across the five sampling periods expressed as a percentage of the largest mean value.

HW1	Year	n	Mean	95% CI of Mean	Median	IQR	95% CI of Median	Test	p	Largest % change
All species	1973	33	8.27	6.86 - 9.68	7.00	4.00	6.00 - 9.00	**22.83**	0.0001	51
	1981	33	5.58	4.17 - 6.98	5.00	4.00	4.00 - 6.00	**5.91**	0.0002	
	1982	32	5.53	4.18 - 6.89	5.00	6.25	3.00 - 7.00			
	1997	32	4.19	2.92 - 5.45	3.00	4.25	2.00 - 5.00			
	2009	30	5.33	3.74 - 6.92	4.00	4.25	3.00 - 6.00			
Native Species Richness	1973	33	7.88	6.56 - 9.20	7.00	5.00	6.00 - 9.00	**21.86**	0.0002	52
	1981	33	5.55	4.18 - 6.91	5.00	4.00	4.00 - 6.00	**5.47**	0.0004	
	1982	32	5.53	4.18 - 6.89	5.00	6.25	3.00 - 7.00			
	1997	32	4.09	2.85 - 5.34	3.00	4.00	2.00 - 4.00			
	2009	30	5.20	3.70 - 6.70	4.00	4.25	3.00 - 6.00			
Species Conservation Status Score	1973	33	1.24	1.12 - 1.35	1.00	0.42	1.00 - 1.40	**11.67**	0.0200	85
	1981	33	1.11	1.01 - 1.21	1.00	0.00	1.00 - 1.00	2.22	0.0693	
	1982	32	1.10	1.03 - 1.16	1.00	0.00	1.00 - 1.00			
	1997	32	1.05	0.98 - 1.12	1.00	0.00	1.00 - 1.00			
	2009	30	1.11	1.01 - 1.21	1.00	0.00	1.00 - 1.00			
Habitat Quality Score	1973	33	1.76	1.65 - 1.87	1.73	0.45	1.55 - 1.92	8.49	0.0751	89
	1981	33	1.68	1.50 - 1.86	1.55	0.60	1.38 - 1.88	1.66	0.1626	
	1982	32	1.57	1.42 - 1.71	1.50	0.50	1.32 - 1.56			
	1997	32	1.60	1.49 - 1.71	1.50	0.46	1.50 - 1.75			
	2009	30	1.59	1.46 - 1.72	1.50	0.52	1.38 - 1.75			
Brackishness Score	1973	33	6.67	5.78 - 7.55	7.00	3.00	6.00 - 8.00	**15.28**	0.0041	64
	1981	33	6.18	5.11 - 7.25	6.00	4.00	4.00 - 8.00	**3.51**	0.0090	
	1982	32	5.56	4.56 - 6.57	5.00	3.00	4.00 - 7.00			
	1997	32	4.28	3.49 - 5.08	4.00	4.00	2.00 - 5.00			
	2009	30	5.67	4.55 - 6.78	5.50	4.75	4.00 - 7.00			

HW2	Year	n	Mean	95% CI of Mean	Median	IQR	95% CI of Median	Test	p	Largest % change
All species	1973	26	4.62	3.78 - 5.46	4.00	2.25	3.00 - 5.00	**11.90**	0.0181	68
	1981	26	6.46	5.39 - 7.53	6.00	4.00	5.00 - 9.00	**3.10**	0.0182	
	1982	21	6.81	5.80 - 7.82	7.00	3.00	5.00 - 8.00			
	1997	26	5.92	5.06 - 6.79	6.00	2.00	5.00 - 7.00			
	2009	26	6.27	5.15 - 7.39	6.00	2.75	5.00 - 7.00			
Native Species Richness	1973	26	4.62	3.78 - 5.46	4.00	2.25	3.00 - 5.00	**11.94**	0.0178	57
	1981	26	6.46	5.39 - 7.53	6.00	4.00	5.00 - 9.00	**3.18**	0.0159	
	1982	21	6.81	5.80 - 7.82	7.00	3.00	5.00 - 8.00			
	1997	26	5.85	5.00 - 6.69	6.00	2.00	5.00 - 7.00			

HW2	Year	n	Mean	95% CI of Mean	Median	IQR	95% CI of Median	Test	p	Largest % change
	2009	26	6.08	5.05 - 7.10	6.00	2.75	5.00 - 7.00			
Species Conservation Status Score	1973	26	1.04	0.98 - 1.10	1.00	0.00	1.00 - 1.00	8.89	0.0638	100
	1981	26	1.11	1.04 - 1.19	1.00	0.18	1.00 - 1.17	2.40	0.0535	
	1982	21	1.16	1.01 - 1.30	1.00	0.00	1.00 - 1.00			
	1997	26	1.09	1.01 - 1.18	1.00	0.00	1.00 - 1.00			
	2009	26	1.24	1.11 - 1.37	1.00	0.43	1.00 - 1.40			
Habitat Quality Score	1973	26	1.79	1.66 - 1.91	1.88	0.39	1.58 - 1.90	**26.04**	<0.0001	81
	1981	26	1.90	1.72 - 2.08	1.84	0.43	1.67 - 2.07	**7.46**	<0.0001	
	1982	21	2.00	1.83 - 2.18	1.94	0.51	1.70 - 2.21			
	1997	26	1.62	1.52 - 1.71	1.65	0.21	1.50 - 1.70			
	2009	26	1.59	1.51 - 1.66	1.57	0.13	1.50 - 1.63			
Brackishness Score	1973	26	6.88	5.66 - 8.11	6.00	3.25	5.00 - 8.00	**9.99**	0.0407	55
	1981	26	8.85	7.58 - 10.12	9.00	4.75	7.00 - 11.00	2.40	0.0534	
	1982	21	9.05	7.42 - 10.67	9.00	4.00	7.00 - 11.00			
	1997	26	10.04	8.39 - 11.68	11.00	5.00	7.00 - 12.00			
	2009	26	9.42	7.31 - 11.53	8.00	7.25	6.00 - 13.00			

Table 7. Plant species with conservation statuses greater than ‘common throughout Britain’ and the number of occurrences at each site in each year.

Status score	Conservation status	Species	HW1					HW2				
			1973	1981	1982	1997	2009	1973	1981	1982	1997	2009
1	Local	*Carex pseudocyperus*				1						
	(in areas	*Chara globularis*			1				2	1		
	other than	*Chara hispida*							1			
	E. Anglia)	*Hottonia palustris*	3	1			2					
		Ranunculus baudotii										2
		Ranunculus circinatus	10		1		1	1	4	2		2
		Riccia fluitans	1									
		Sagittaria sagittifolia	1	1								
2	Local (E. Anglia)	*Chara aspersa*							2	1		
3	NS	*Potamogeton coloratus*					1			1		
4	NT	*Baldellia ranunculoides*		1	1							
5	VU	*Groenlandia densa*		1	1	1						
		Myriophyllum verticillatum	13	4	5	2	6	2	4	4	4	9
	VU BAP	*Oenanthe fistulosa*	3						2	2		

NS – Nationally Scarce, NT – near threatened, VU – Red List Vulnerable, BAP – UK Biodiversity Action Plan. For an explanation of Species Conservation Status Scores see Palmer *et al.*, 2010.

Table 8. Plant indicators of good water quality and the number of occurrences at each site in each year.

Species	Habitat quality	HW1					HW2				
		1973	1981	1982	1997	2009	1973	1981	1982	1997	2009
Baldellia ranunculoides	5		1	1							
Chara aspersa	5							2	1		
Chara globularis	4			1				2	1		
Chara hispida	5							1			
Chara sp	5	2			2		1		1		
Chara vulgaris	5			1		1					
Eleocharis palustris	4	1	1	1		2	1	6	7		
Groenlandia densa	3		1	1	1						
Hippuris vulgaris	4	17	9	5	6	7	17	19	17	17	12
Hottonia palustris	3	3	1			2					
Juncus subnodulosus	4	1	1	3	3	4	1	4	4	1	1
Lemna trisulca	3	8	3		1	2	2	7	9	8	11
Potamogeton coloratus	3					1			1		
Potamogeton natans	4	18	11	10	6	9	4	3	2		
Potamogeton perfoliatus	3	8	1	2			1	2	3	1	
Ranunculus aquatilis	3			1		1	1	4	3	1	

Table 9. Plant species of completely brackish water or fresh to brackish water.

Species	Salinity score	HW1					HW2				
		1973	1981	1982	1997	2009	1973	1981	1982	1997	2009
Bolboschoenus maritimus	4	1	2	2		1	2	12	8	11	7
Enteromorpha sp	3	10	3	4		1	1				
Filamentous algae	2	9	3	2	1	5	3	1	3	12	14
Myriophyllum spicatum	2	10	1	4		8	24	17	12	15	16
Phragmites australis	2	32	30	29	32	30	26	25	21	26	26
Potamogeton pectinatus	2	15	10	5	12	15	10	7	6	16	14
Ranunculus baudotii	4										2
Ranunculus sceleratus	2		2	1	1	1			2		1
Schoenoplectus tabernaemontani	3	7	6	3	2	5	7	13	12	16	12
Zannichellia palustris	2		22	19	8	6		2	1	1	

(For an explanation of salinity scores see Palmer *et al.*, 2010.)

Table 10. Significance of the Kolmogorov-Smirnov statistic for each metric for plants in each year for the IDB sub-districts combined.

	1973	**1981**	**1982**	**1997**	**2009**
Native species	NS	NS	NS	NS	NS
Conservation Status Score	**	**	**	**	**
Habitat Quality Score	NS	NS	NS	NS	NS
Salinity score	NS	NS	NS	*	NS

Table 11. Tests comparing means for total native species, Habitat Quality Score and Brackishness Score and medians for Species Conservation Status Score for plants between IDB sub-districts in each year.

Test	**Statistic**	**1973**	**1981**	**1982**	**1997**	**2009**
t-test						
Native species	t	4.01	-1.04	-1.40	-2.27	-0.96
	p	0.0002	0.3040	0.1668	0.0270	0.3425
Habitat Quality Score	t	-0.40	-1.74	-3.93	-0.25	0.06
	p	0.6917	0.0870	0.0003	0.8054	0.9508
Brackishness Score	t	-0.30	-3.30	-3.98	-6.86	-3.36
	p	0.7628	0.0017	0.0002	<0.0001	0.0014
Mann-Whitney U test						
Mann-Whitney U statistic	Mann-Whitney U	284.5	474	351	457.5	482
Species Conservation Status Score	p	0.0048	0.3569	0.7098	0.2790	0.0632

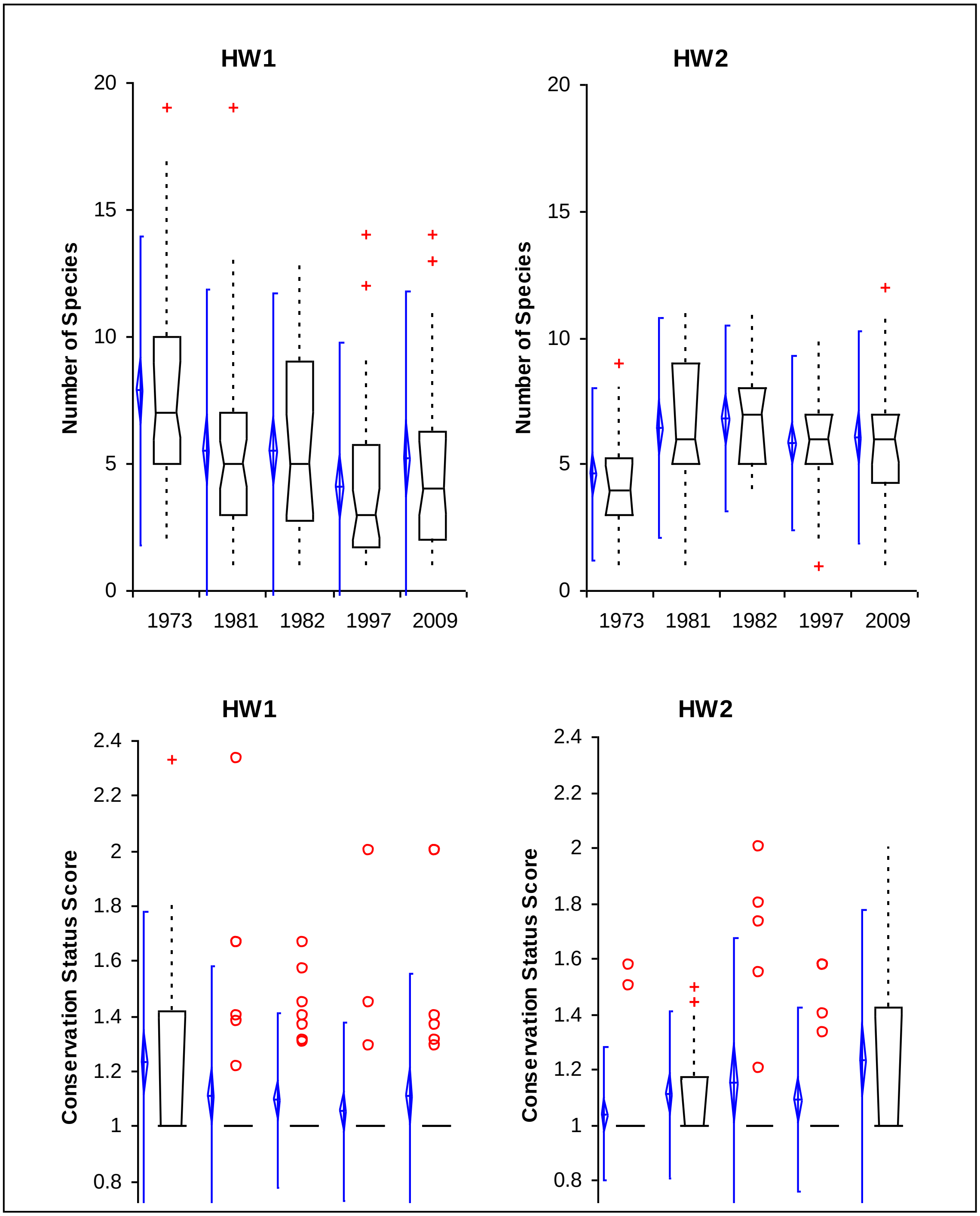


Figure 6. Median (whisker boxes) and mean (in blue; diamond gives 95% confidence limits) for species richness of aquatic plant and the Conservation Status Score in five years at IDB sub-districts Happisburgh-Winterton 1 and 2.

Values as in Table 6. 1973 samples are only those sampled in subsequent years. See Appendix 3 for an explanation of the diagrams.

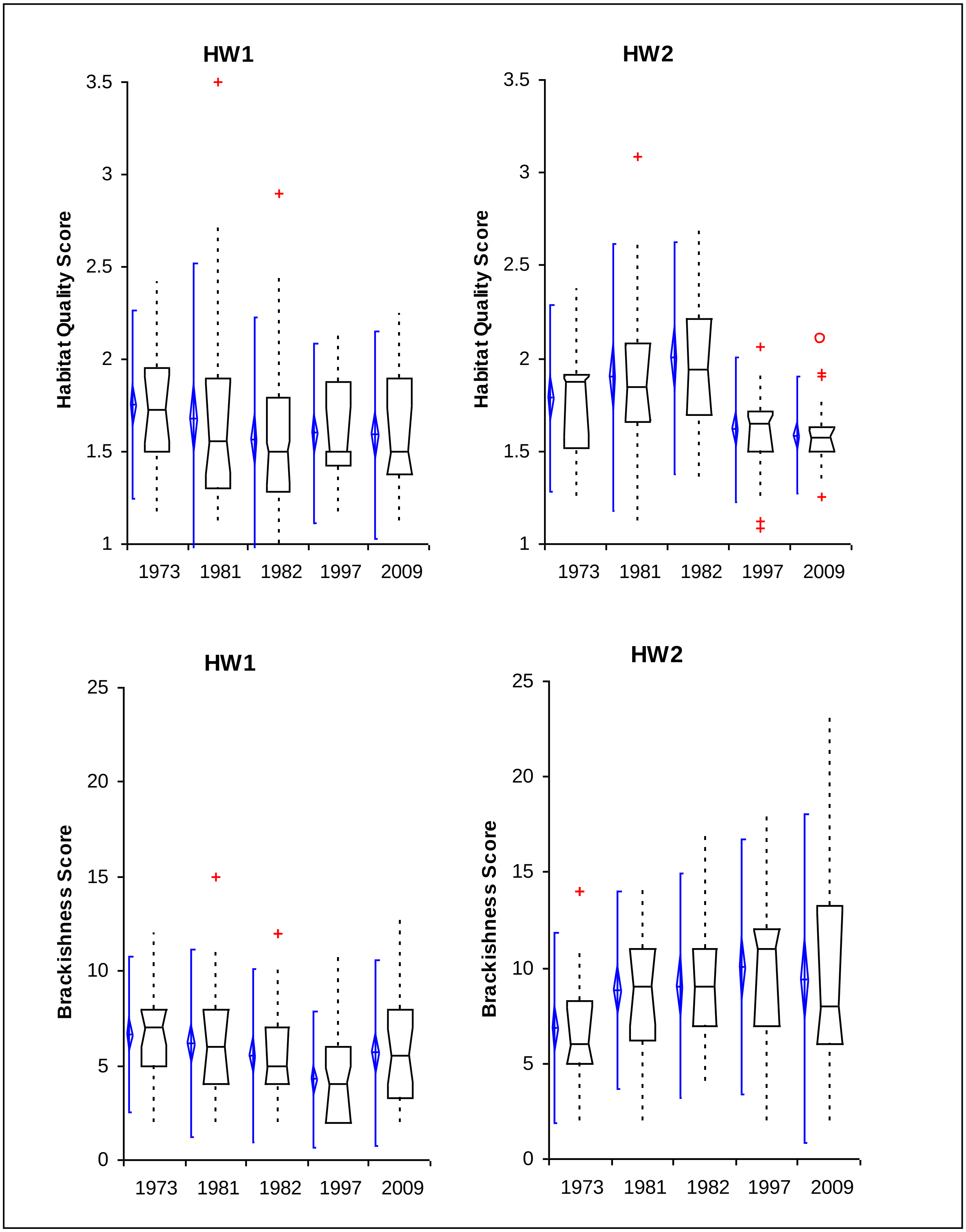

HW1
HW2
Habitat Quality Score
3.5
3
2.5
2
1.5
1
1973
1981
1982
1997
2009
Brackishness Score
25
20
15
10
5
0

Figure 7. Median (whisker boxes) and mean (in blue; diamond shows 95% confidence limits) of Habitat Quality Score and salinity score for plants in five years at IDB sub-districts Happisburgh-Winterton 1 and 2.

Values as in Table 6. 1973 samples are only those sampled in subsequent years.

3.2.3. Ordination

DECORANA was used since the data appeared to follow a unimodal distribution, as indicated by the long gradient length of the first axis in a trial run. This value, 4.06, indicated an almost complete turnover of species along this axis. An alternative ordination method, Multidimensional Scaling (MDS) was also tried but the stress (an indication of how well the data fit the model) was rather high for two dimensions (0.238) and still uncomfortably high using three dimensions (0.158), following the guidance given in the PRIMER manual quoted by Zuur *et al*. (2007).

Quantitative data were used after converting DAFOR values to equivalent integers (5 to 1, respectively). No downweighting was applied for species rare in the dataset. Samples were assigned to different groups according to year, site and land-use. Only the first two axes are shown in the ordination plots. These had high eigenvalues (0.46 and 0.34 for axes 1 and 2, respectively), so together these two axes explained 80% of the variance in the ordination.

The two IDB sub-districts separated clearly in ordination space (Figure 8). Points for HW2 (‘control’, almost entirely pasture) were more closely grouped than those in HW1 (reversion site), and this probably reflected the more stable conditions at HW2. Land-use alone appeared to explain some of the distribution of ditches in ordination space since those in arable land (red dots in Figure 9) were relatively closely clustered compared to the widely scattered ditches in pasture (green squares). Ditches with a mix of arable and another more benign land-use were particularly widely scattered (blue triangles). This is open to widely varying interpretations. One is that the effects of arable farming on the ditch flora may be offset by the presence of benign land-use, thus accounting for many more blue points and few red ones within the area dominated by green squares in pasture. Another explanation is that similar density of blue and red points in the lower left, where green pasture ditches are scarce, indicates that the effects of arable farming cannot be mitigated by having pasture on an opposite bank. Perhaps close examination of each point and its relationship with other factors could resolve these opposing interpretations.

Changes over time did appear to show up in the ordination of HW1 points which are shown for each year of sampling, while those for HW2 are included only a black points to reduce confusion (Figure 10). The points of each sampling occasion appear to form parallel diagonal bands (top left to bottom right), as do those for HW2. This suggests that the assemblage ‘moves’ across the diagram through time, starting close to the condition found at HW2 in 1973 (red dots), moving far away to the left in the 1980s when arable conversion took place (yellow and purple points), then gradually returning to its original position green and blue points). While there is still considerable scatter within each year class, especially in 1981 at the beginning of the perturbations, this does not seem to be a fanciful interpretation of the ordination.

The distribution of species on the first two axes showed a clear grouping of the brackish-water indicator species listed in Table 9, excluding the two algal taxa *Enteromorpha* and filamentous alga, as these all fall on the right of the ordination where few other species occur (Figure 11). In contrast, species associated with water of good quality (listed in Table 8) were widely scattered in ordination space. There was no pattern in the distribution of nationally rare or local species, nor would one have been expected.

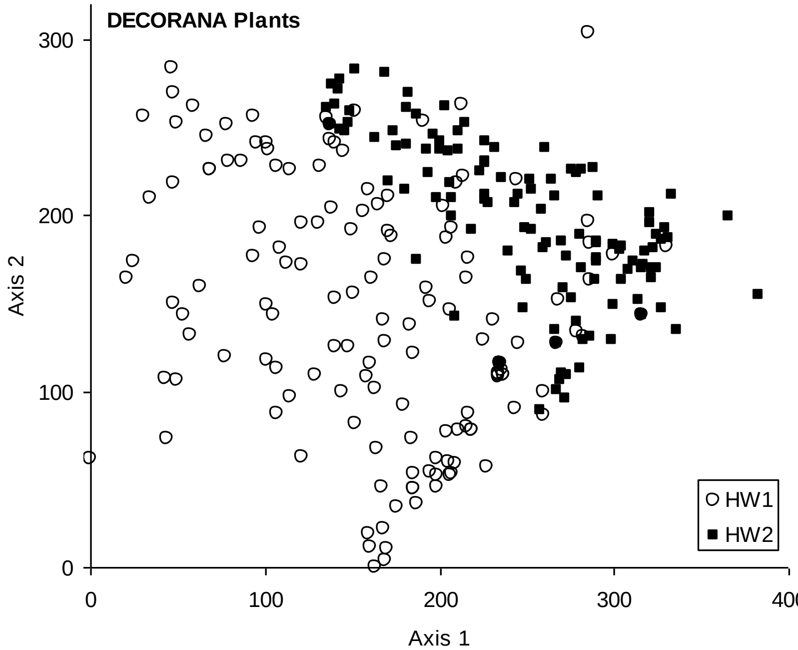


Figure 8. DECORANA ordination of plants, with samples distinguished by IDB sub-district.

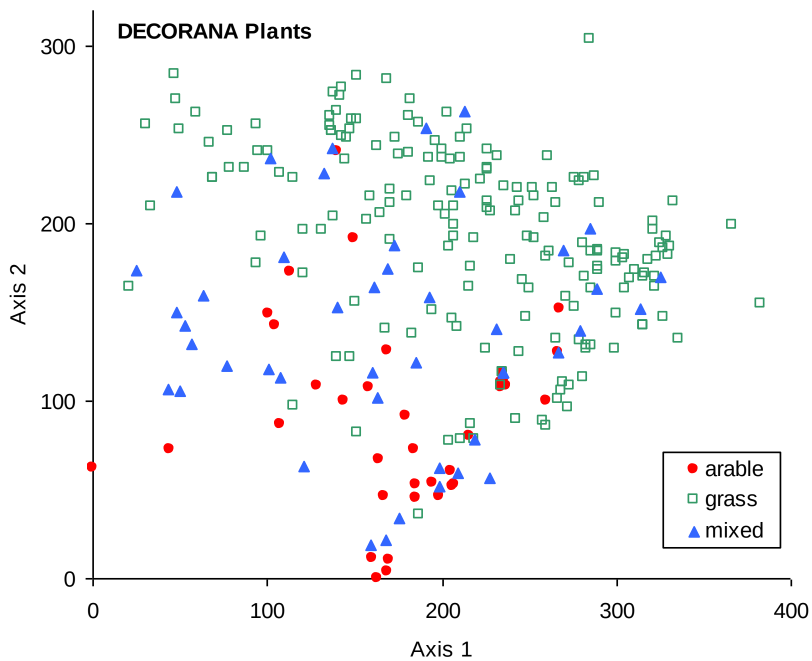


Figure 9. DECORANA ordination of plants, with samples distinguished by land-use.

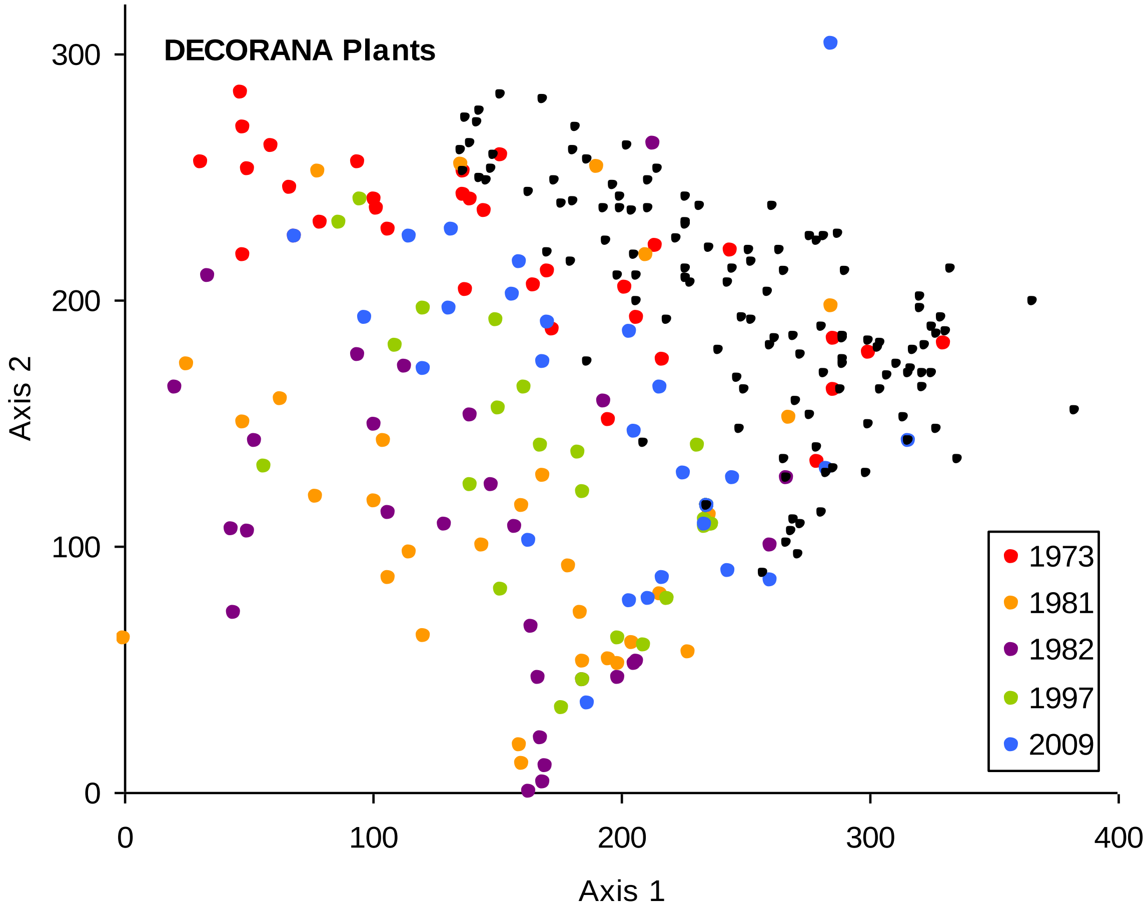


Figure 10. DECORANA ordination of plants, with samples from HW1 distinguished by year of survey. All samples from HW2 are shown as small black dots.

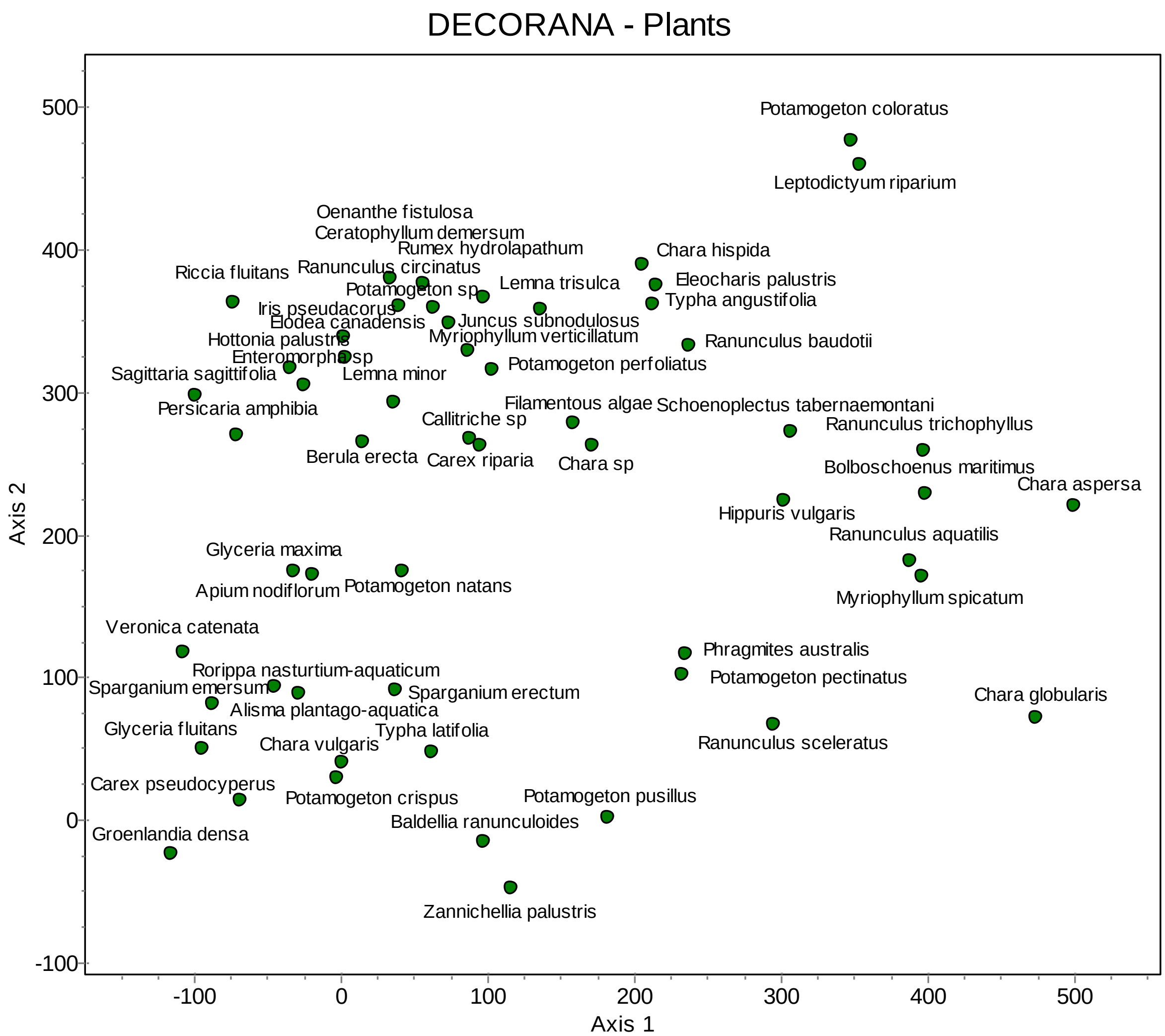


Figure 11. DECORANA ordination of plant species.

3.3. *Invertebrates*

3.3.1. Species representation

The total number of unique taxa recorded in all four years was 131. As usual in ditch systems, beetles dominated in terms of numbers of species, followed by bugs and then molluscs. Nearly all the taxa occurred at HW1 (reversion site) but there were considerably fewer at HW2 ('control'), and this difference was probably only partly explained by the larger number of ditches sampled at HW1 (161 compared to 125 at HW2). Many more taxa of beetles and molluscs occurred at HW1 but similar numbers of bugs and dragonflies were found at both sites (Table 12).

Despite the higher representation of species of beetles, other groups were seen to be dominant when their abundance was expressed as the frequency of occurrence. Among the most frequent species were the two snails *Radix balthica* (=*Lymnaea peregra*) and the non-native *Potamopyrgus antipodarum*, both found in about two thirds of ditches, the brackish-water crustaceans G*ammarus zaddachi* and *Gammarus duebeni* in about a third to half of ditches, and the bugs *Sigara dorsalis*, *Gerris odontogaster* and *G. lacustris* (Table 13). The most frequent beetle was *Noterus clavicornis*, which was present in only 16% of ditches, although a few more beetles ranked among the top 30 species in about 10% of ditches.

A few species were unexpected in a ditch system but their presence can be explained. The specimen of *Aeshna juncea* was a male and may have originated from shallow ponds created for Natterjack toads within a few kilometres on the Winterton dunes. *A. juncea* is rare in East Anglia where it is known from fens in Broadland. It is an acidophile that is unlikely to breed in circum-neutral ditches. The water skater *Aquarius paludum* is a nationally scarce species found mainly on running water in a small area of the Home Counties and south-east England. It was a fully winged male and may have been a migrant, as it was found on a day when a mass immigration of butterflies had been recorded on the Norfolk coast about 1km from the *Aquarius* site. It was unlikely to breed in the ditches. I have not found the water beetles *Helophorus flavipes* (a common acidophile) and the nationally scarce *Ilybius subaeneus* in ditches but the specimens had been picked out by Dr Garth Foster (who identified them) as being curious records, so they certainly will have been scrutinised. The presence of *H. flavipes* was not unexpected since a small proportion (8%) of the ditches had a pH of between 4,2 and 5.8 in 1973, and the species has been recorded sparsely in north-east Norfolk (NBN Gateway). Both species of the large caddis *Phryganea* (*grandis* and *bipunctata*) were recorded, but owing to the difficulty of identifying even large larvae they have been aggregated at genus level.

3.3.2. Patterns of change in the main IDB sub-districts

Changes through the years at the two sub-districts are described for species-richness of all taxa and for the three main taxonomic groups, beetles, bugs and molluscs, and for the scores. Both median and mean numbers are given in Table 14 and as histograms (Figures 12-15), although the confidence limits of means are invalid since the distribution of the data was shown to be not normal.

Happisburgh-Winterton 1 (reversion site)

The total species list for all ditches dropped markedly in 1981 but the following year was back to the 1973 value, where it remained until a marked rise in 2009 (Table 12). The rapid restoration of numbers from 1981 to 1982 during the arable period appears to be unlikely but, as the arable conversion took place just one to two year before (between 1979 and 1980), colonisation by flying species after the initial period of upset is quite possible. This suggestion is supported by much of the change being attributable to beetles, which can fly and colonise quickly. It was noted that 1982 was a particularly good year for beetles at both sites. By comparison, the species-richness of molluscs halved in 1981 and failed to return to 1973 values until 2009. This poor rate of recovery is typical of molluscs.

Median numbers of all taxa fell after conversion to arable farming, although the sudden fall in 1981 was quickly restored the following year to close to the original levels (Figure 12). Thereafter there was no change in species until a large number was recorded in 2009. This pattern of change was seen in all three major taxonomic groups, which may therefore be responding similarly to environmental influences. In all cases, the differences in the medians across the years were highly significant (p-values <0.001 for the Kruskall-Wallis statistic).

The Species Conservation Status Score fluctuated within narrow limits during the three decades spanning the change from pasture to arable and back to pasture, but in 2009 it rose higher than previously recorded (Figure 14). These differences in the medians across the years were highly significant. The median SCS Score rose above 1.0 in only two of the five sampling occasions, which showed that in the three 'poor' years over half the ditches had only common species of no conservation concern at all. Ten scarcer species, with individual SCS values of 3 or 4, were recorded over the whole project but they were rarely represented by more than one occurrence each year, so their contribution to the interest of the whole sub-district was low (Table 15). The number of these rarer species reached a maximum (5 species) in 1982 when the detrimental effects of arable conversion would have been expected to be considerable. The two rarest species in the entire project, the soldierfly *Odontomyia ornata* and Great silver water beetle (*Hydrophilus piceus*), occurred only in 2009.

The Habitat Fidelity Score (equivalent to the botanical Habitat Quality Score) showed an initial fall in the 1980s followed by slow restoration to the original level by 2009 (Figure 14). The differences in medians across the years was significant but at only p=0.05, which was smaller than seen in other metrics. The range of values in any year also appeared to be smaller than for other metrics, reflected in the medians' narrow 95% confidence limits. The species contributing to the Habitat Fidelity Score were scarce, usually represented at one ditch in any year and few of them being consistently recorded from year to year (Table 16). Similar numbers of them were found in 1982, when conversion had taken place, to those in 2009, although in 2009 two of the 'flagship' species of grazing marshes made their first appearance (*Odontomyia ornata* and *Hydrophilus piceus*).

Only two non-native species were recorded, the snail *Potamopyrgus antipodarum* which was a widespread species in the Thurne catchment, and the amphipod shrimp *Crangonyx pseudogracilis*, of which there was a single record in 2009. Therefore only the snail contributed to the Naturalness Score until 2009, when the contribution of the amphipod was negligible. *Potamopyrgus* appeared to have been adversely affected by the arable conversion, before returning to its 1973 levels. Despite the apparently large fluctuation in this score, the medians were not significantly different across the years. This is one of the few molluscs tolerant of brackish conditions so its abundance here is not typical of freshwater grazing marshes.

The median score for brackishness was low and showed no change from 1973 until 1997, but then increased to a high level in 2009 (Figure 15). Eight species characteristic of brackish or saline water were recorded altogether, and their occurrence and the frequency of each of them did not show much change for most of the time (Table 17). However, the shrimp *Gammarus duebeni* and water boatman *Sigara stagnalis* did show an increase, and both reached a peak in 2009.

Happisburgh-Winterton 2 (‘control’ site)

At HW2 (the pasture ‘control’ site), the total species list increased steadily throughout the study, and had doubled from 29 in 1973 to 60 taxa by 2009 (Table 12). However, the biggest rate of increase appeared to take place over one year between 1981 and 1982, and may be explained by the same reasoning as given for the same increase seen at HW1. Variation between samples from the 1980s and 1997 was low but the final number in 2009 was sufficiently larger, so a real improvement in the fauna did seem the best explanation. A similar increase was also seen at HW1 (reversion site). Individual taxa did not follow this apparent improvement in total species richness; for example, beetles peaked strongly in 1982, molluscs and dragonflies showed only trivial fluctuations, and the representation of bugs was only slightly greater in 2009 than in 1981.

Median species richness increased dramatically between the first sampling session in 1973 and the 1980s, then gradually levelled out to a similar mean in 1997 and 2009 (Figure 12). The medians were significantly different across the years but this was almost certainly due to the low initial value. The main taxa also showed significant differences in medians across the years, and for beetles and bugs this could also be attributed to the initial rise. Fluctuations in the median numbers of molluscs were more erratic and did not match trends shows by beetles and bugs.

Species Conservation Status Score was higher in the 1980s than at the start or in 1997 and 2009, and this may have reflected a real change in the occurrence species of conservation concern (Figure 14). Only six rarer species, with SCS scores of 3 or 4, were found in the entire survey, ranging from 1 to 3 species in any year (Table 15). The rare soldierfly *Odontomyia ornata* appeared for the first time in 2009, as at HW2.

Habitat Fidelity Score showed the opposite trend, being lowest in the 1980s than at the start and ending with the highest value (Figure 14). The changes in its value across the years were slight and probably only the final high value in 2009 was responsible for the significant difference in the Kruskall-Wallis test. Although nine species with fidelity scores of 2 or 3 occurred over the years, their appearance was erratic and inconsistent, and this gave little confidence in the yearly averages.

The median occurrence of *Potamopyrgus antipodarum*, the only non-native species at HW2, fluctuated non-significantly over the years, but was marginally more frequent by 2009 than earlier (Figure 15).

The Brackishness Score increased significantly over time (Figure 15). This appeared to be due to both a slight increase in the number of brackish-tolerant species and to an increase in the frequency of occurrence of the shrimp *Gammarus duebeni* and the slater *Sphaeroma hookeri* (Table 17).

Comparisons between IDB sub-districts each year

Medians for the five main metrics for the two sub-districts were compared using a Mann-Whitney U-test for each year of sampling (Table 18). At HW1 (reversion site), total taxa, SCS Score and Habitat Fidelity Score were initially higher than at HW2 (‘control’ site), significantly so for taxa and SCS Score, but then fell to often significantly lower values in the 1980s before rising again in 1997 or 2009 to values that were often not significantly different from those at HW2. The similarity of this trend in these three metrics strongly suggested a real effect.

The percentage change from the smallest to largest mean across the study far exceeded the threshold that would suggest a real change (rather than one due to unmeasured or chance effects) for species richness and Habitat Fidelity at both sites, and for SCS Score at HW2 (‘control’ site), but was at the threshold of 7% for SCS Score at HW1 (reversion site) (compare values in Table 14, last column, with those in Table 3; although median are used for the Thurne invertebrate metrics, the same conclusion is reached if these are compared with the suggested thresholds for medians). Thus the variations in SCS Score at HW1 (reversion site) may not be particularly meaningful, despite the differences between years being significant. The threshold was derived from species-rich sites but there is no reason to suppose that values close to the ones used here are unrealistic.

Naturalness effectively measured only the occurrence of *Potamopyrgus antipodarum*, which was more widespread at HW2 in all years except 1973.

Brackishness Score was consistently higher at HW2 (‘control’) in all years, although significantly so only between 1981 and 1997. The pattern of change differed between the sites, the Brackishness Score at HW1 (reversion site) rising only in 2009, whereas at HW2 it rose gradually through the study. While conductivity also rose at HW1, there was only a marginal increase by 2009 at HW2, so the patterns of change in the two measures of brackishness did not match each other well.

Table 12. Total number of invertebrate taxa and those in each of the main orders for Happisburgh-Winterton sub-districts 1 and 2.

	HW1						HW2					
	1973	1981	1982	1997	2009	all years	1973	1981	1982	1997	2009	all years
All taxa	62	47	61	63	85	130	29	46	56	53	60	94
Coleoptera	18	18	30	24	28	52	8	14	26	18	19	38
Hemiptera	13	12	13	17	17	25	10	13	10	16	15	22
Odonata	2	3	5	6	4	7	2	5	5	6	6	9
Mollusca	14	7	7	6	13	17	6	7	6	4	7	8
Others	15	7	6	10	23	29	3	7	9	9	13	17

Table 13. Percentage occurrence of the 30 most frequent invertebrate taxa ranked by their occurrence in both sites, and with their occurrence in each of the IDB sub-districts.

			Site	
		Both	HW1	HW2
Mollusca	*Radix balthica*	62	55	72
Mollusca	*Potamopyrgus antipodarum*	62	53	72
Amphipod	*Gammarus zaddachi*	53	42	68
Hemiptera	*Sigara dorsalis*	44	47	41
Amphipod	*Gammarus duebeni*	37	30	46
Odonata	*Ischnura elegans*	27	20	35
Hemiptera	*Gerris odontogaster*	24	7	46
Hemiptera	*Gerris lacustris*	24	29	17
Mollusca	*Planorbis planorbis*	22	20	25
Hemiptera	*Ilyocoris cimicoides*	19	12	26
Hemiptera	*Corixa punctata*	17	21	13
Odonata	*Sympetrum striolatum*	17	16	19
Mollusca	*Lymnaea palustris*	17	17	17
Hemiptera	*Noterus clavicornis*	16	8	27
Isopoda	*Asellus aquaticus*	16	21	10
Mollusca	*Bithynia tentaculata*	15	26	0
Hemiptera	*Hesperocorixa linnaei*	14	7	22
Odonata	*Lestes sponsa*	13	2	26
Coleoptera	*Haliplus ruficollis* group females	13	14	11
Hemiptera	*Gerris thoracicus*	12	16	6
Hemiptera	*Gerris* sp	11	9	13
Odonata	Zygoptera	10	7	15
Coleoptera	*Gyrinus substriatus*	10	12	7
Coleoptera	*Haliplus lineatocollis*	10	8	12
Coleoptera	*Hydrobius fuscipes*	10	6	14
Coleoptera	*Hygrotus inaequalis*	9	10	9
Coleoptera	*[Noterus crassicornis =clavicornis]*	9	2	19
Odonata	*Aeshna grandis*	9	8	11
Hemiptera	*Sigara stagnalis*	9	9	9

Table 14. Mean and median numbers of invertebrates and scores, with inter-quartile range, confidence limits for the median and Kruskal-Wallis statistic for the ditches sampled in all years in the two main IBD sub-districts.

Kruskal-Wallis statistic tests for differences in the medians across the five years; p is the probability of the differences being due to chance.

	Year	n	Mean	Median	IQR	95% CI of median		Kruskal -Wallis	p	Largest % change
					Happisburgh-Winterton 1					
Taxa	1973	33	9.21	8.00	5.00	6.00	to 11.00	37.68	<0.0001	67
	1981	30	4.50	4.00	4.25	2.00	to 5.00			
	1982	31	7.48	7.00	5.50	6.00	to 10.00			
	1997	32	7.94	8.00	6.25	5.00	to 11.00			
	2009	30	13.63	12.50	9.00	10.00	to 18.00			
Coleoptera	1973	33	1.45	1.00	2.00	1.00	to 2.00	24.33	<0.0001	75
	1981	30	0.87	0.00	1.00	0.00	to 1.00			
	1982	31	2.26	2.00	4.00	1.00	to 4.00			
	1997	32	1.50	1.00	2.00	0.00	to 2.00			
	2009	30	3.40	3.00	3.75	2.00	to 5.00			
Hemiptera	1973	33	1.76	1.00	2.00	1.00	to 2.00	22.52	<0.0001	56
	1981	30	1.43	1.00	1.75	1.00	to 2.00			
	1982	31	2.42	3.00	2.00	1.00	to 3.00			
	1997	32	2.16	2.00	2.00	2.00	to 3.00			
	2009	30	3.23	3.00	2.25	2.00	to 4.00			
Mollusca	1973	33	3.27	3.00	2.00	2.00	to 4.00	32.30	0.0065	73
	1981	30	0.90	0.00	2.00	0.00	to 1.00			
	1982	31	1.16	1.00	2.00	0.00	to 2.00			
	1997	32	1.94	2.00	3.75	0.00	to 3.00			
	2009	30	2.87	2.00	3.25	1.00	to 4.00			
SCS Score	1973	33	1.10	1.00	0.16	1.00	to 1.14	15.46	<0.0001	7
	1981	30	1.10	1.00	0.00	1.00	to 1.00			
	1982	31	1.12	1.09	0.18	1.00	to 1.17			
	1997	32	1.09	1.00	0.14	1.00	to 1.11			
	2009	30	1.17	1.14	0.13	1.11	to 1.20			
Fidelity Score	1973	33	1.28	1.22	0.26	1.14	to 1.30	23.89	0.0268	14
	1981	30	1.14	1.00	0.17	1.00	to 1.14			
	1982	31	1.11	1.08	0.21	1.00	to 1.18			
	1997	32	1.18	1.17	0.25	1.08	to 1.22			
	2009	30	1.29	1.23	0.23	1.17	to 1.30			
Naturalness Score	1973	33	1.64	2.00	0.00	2.00	to 2.00	20.11	0.0838	59
	1981	30	0.67	0.00	2.00	0.00	to 2.00			
	1982	31	0.71	0.00	2.00	0.00	to 2.00			
	1997	32	1.25	2.00	2.00	0.00	to 2.00			
	2009	30	1.03	1.00	2.00	0.00	to 2.00			
Brackishness	1973	33	1.39	2.00	2.00	0.00	to 2.00	14.68	0.0003	53

	Year	n	Mean	Median	IQR	95% CI of median	Kruskal -Wallis	p	Largest % change
Score									
	1981	30	1.30	2.00	2.00	0.00 to 2.00			
	1982	31	1.45	2.00	2.00	1.00 to 2.00			
	1997	32	1.56	2.00	2.00	0.00 to 2.00			
	2009	30	2.77	2.00	2.00	2.00 to 4.00			
Happisburgh-Winterton 2									
Taxa	1973	26	4.00	3.00	2.50	2.00 to 4.00	45.99	<0.0001	66
	1981	26	9.00	10.00	4.00	7.00 to 11.00			
	1982	21	10.62	10.00	4.00	8.00 to 12.00			
	1997	26	11.73	11.50	7.75	8.00 to 15.00			
	2009	26	11.88	11.50	6.75	9.00 to 15.00			
Coleoptera	1973	26	0.35	0.00	0.00	0.00 to 0	31.66	<0.0001	87
	1981	26	1.58	2.00	1.00	1.00 to 2.00			
	1982	21	2.62	2.00	2.00	1.00 to 3.00			
	1997	26	2.62	1.00	3.25	1.00 to 4.00			
	2009	26	2.46	2.00	3.00	1.00 to 4.00			
Hemiptera	1973	26	1.04	1.00	1.25	0.00 to 1.00	32.38	<0.0001	71
	1981	26	2.88	3.00	2.00	2.00 to 4.00			
	1982	21	2.05	2.00	2.00	1.00 to 3.00			
	1997	26	3.04	2.50	2.00	2.00 to 4.00			
	2009	26	3.54	4.00	2.75	3.00 to 5.00			
Mollusca	1973	26	1.35	1.50	1.75	1.00 to 2.00	14.25	0.0065	51
	1981	26	2.19	2.00	0.25	2.00 to 2.00			
	1982	21	2.76	2.00	2.00	2.00 to 4.00			
	1997	26	1.69	2.00	1.00	1.00 to 2.00			
	2009	26	2.15	2.00	1.25	1.00 to 2.00			
SCS Score	1973	26	1.05	1.00	0.00	1.00 to 1.00	31.65	<0.0001	17
	1981	26	1.18	1.20	0.20	1.08 to 1.22			
	1982	21	1.27	1.20	0.21	1.17 to 1.38			
	1997	26	1.10	1.11	0.14	1.00 to 1.14			
	2009	26	1.10	1.09	0.14	1.00 to 1.13			
Fidelity Score	1973	26	1.24	1.17	0.33	1.00 to 1.33	10.98	0.0268	14
	1981	26	1.18	1.14	0.14	1.10 to 1.22			
	1982	21	1.20	1.17	0.16	1.13 to 1.29			
	1997	26	1.25	1.20	0.12	1.17 to 1.27			
	2009	26	1.38	1.27	0.24	1.20 to 1.42			
Naturalness Score	1973	26	1.15	2.00	2.00	0.00 to 2.00	8.22	0.0838	35
	1981	26	1.38	2.00	2.00	0.00 to 2.00			
	1982	21	1.24	2.00	2.00	0.00 to 2.00			
	1997	26	1.62	2.00	0.00	2.00 to 2.00			
	2009	26	1.77	2.00	0.00	2.00 to 2.00			
Brackishness Score	1973	26	1.69	2.00	0.00	2.00 to 2.00	20.93	0.0003	55
	1981	26	2.38	2.00	1.00	2.00 to 3.00			
	1982	21	2.57	2.00	0.00	2.00 to 2.00			

	Year	n	Mean	Median	IQR	95% CI of median		Kruskal -Wallis	p	Largest % change
	1997	26	2.88	2.00	2.00	2.00	to 4.00			
	2009	26	3.73	4.00	3.25	2.00	to 5.00			

Table 15. Invertebrate species of conservation concern, with Species Conservation Status Scores of 3 or 4 at the two IDB sub-districts, giving the numbers of occurrences each year.

Status codes: N and NS – nationally scarce (JNCC and IUCN, respectively), NT – near threatened, RDB2 Red Data Book 2 (Vulnerable). For an explanation of Species Conservation Status Scores see Palmer *et al.*, 2010.

SCS	Status	Order	Species	HW1					HW2				
				1973	1981	1982	1997	2009	1973	1981	1982	1997	2009
3	N	Diptera	*Phalacrocera replicata*					1					
	N	Hemiptera	*Aquarius paludum*				1						
	NS	Coleoptera	*Agabus conspersus*			1	1						
	NS		*Enochrus quadripunctatus*			1					1		
	NS		*Hydaticus seminiger*										1
	NS		*Hygrotus parallellogrammus*		2	1							
	NS		*Ilybius subaeneus*		1								
	NS		*Peltodytes caesus*								1		1
	NS		*Rhantus frontalis*			1	1	3		1		2	1
4	RDB2	Diptera	*Odontomyia ornata*					1					4
	NT	Coleoptera	*Hydrophilus piceus*					1					

Table 16. Invertebrate species with Fidelity Scores greater than zero at the two IDB sub-districts, giving the numbers of occurrences each year.

Fidelity Score	Order	Species	HW1					HW2				
			1973	1981	1982	1997	2009	1973	1981	1982	1997	2009
2	Coleoptera	*Agabus conspersus*			1	1						
		Dytiscus circumflexus					1					
		Graptodytes pictus	2		1	1	4					1
		Gyrinus caspius	1				4		1			
		Haliplus immaculatus	1				1			1		1
		Hygrotus parallellogrammus		2	1							
		Ilybius ater			1	1	1			1		2
		Laccobius colon	3		1							
		Laccobius minutus		1	3	1	1					1

		Laccophilus minutus	1	1	3	2						
		Rhantus suturalis								1		
3	Coleoptera	*Hydrophilus piceus*					1					
		Peltodytes caesus								1		1
	Diptera	*Odontomyia ornata*					1					4

Table 17. Invertebrate species with Brackishness Scores of 1 and 2 at the two IDB sub-districts, giving the numbers of occurrences each year.

Brackish Score	Order	Species	HW1					HW2				
			1973	1981	1982	1997	2009	1973	1981	1982	1997	2009
1	Coleoptera	*Agabus conspersus*			1	1						
		Gyrinus caspius	1				4		1			
		Hygrotus parallellogrammus		2	1							
		Ochthebius marinus						1				
	Hemiptera	*Sigara stagnalis*		1	3	2	8	1	3	2	2	3
2	Amphipoda	*Gammarus duebeni*	4	9	7	13	16	5	12	6	16	18
		Gammarus zaddachi	18	9	13	10	18	16	16	19	16	18
		Gammarus	1			1	1				1	
	Decapoda	*Palaemonetes varians*							1	1	1	2
	Isopoda	*Sphaeroma hookeri*									3	8
	Mysidacea	*Neomysis integer*										1
	Hemiptera	*Sigara selecta*					1					

Table 18. Mann-Whitney U-tests comparing medians for total invertebrate taxa and scores between IDB sub-districts for each year of sampling.

U = Mann-Whitney statistic (bold when significant), p – probability.

Metric	Statistic	1973	1981	1982	1997	2009
Taxa	U	**126**	**675.5**	**466.5**	**590.5**	329
	p	<0.0001	<0.0001	0.0083	0.0063	0.3150
SCS	U	**317.5**	**558**	**495**	499	**269.5**
	p	0.0467	0.0027	0.0013	0.1710	0.0449
Fidelity	U	344.5	497.5	**445.5**	540.5	428.5
	p	0.1938	0.0670	0.0230	0.0506	0.5265
Naturalness	U	**325.5**	**530**	411.5	492	**528.5**
	p	0.0440	0.0079	0.0633	0.1318	0.0057
Brackishness	U	500.5	**555.5**	**458**	**614**	494
	p	0.1948	0.0035	0.0052	0.0010	0.0777

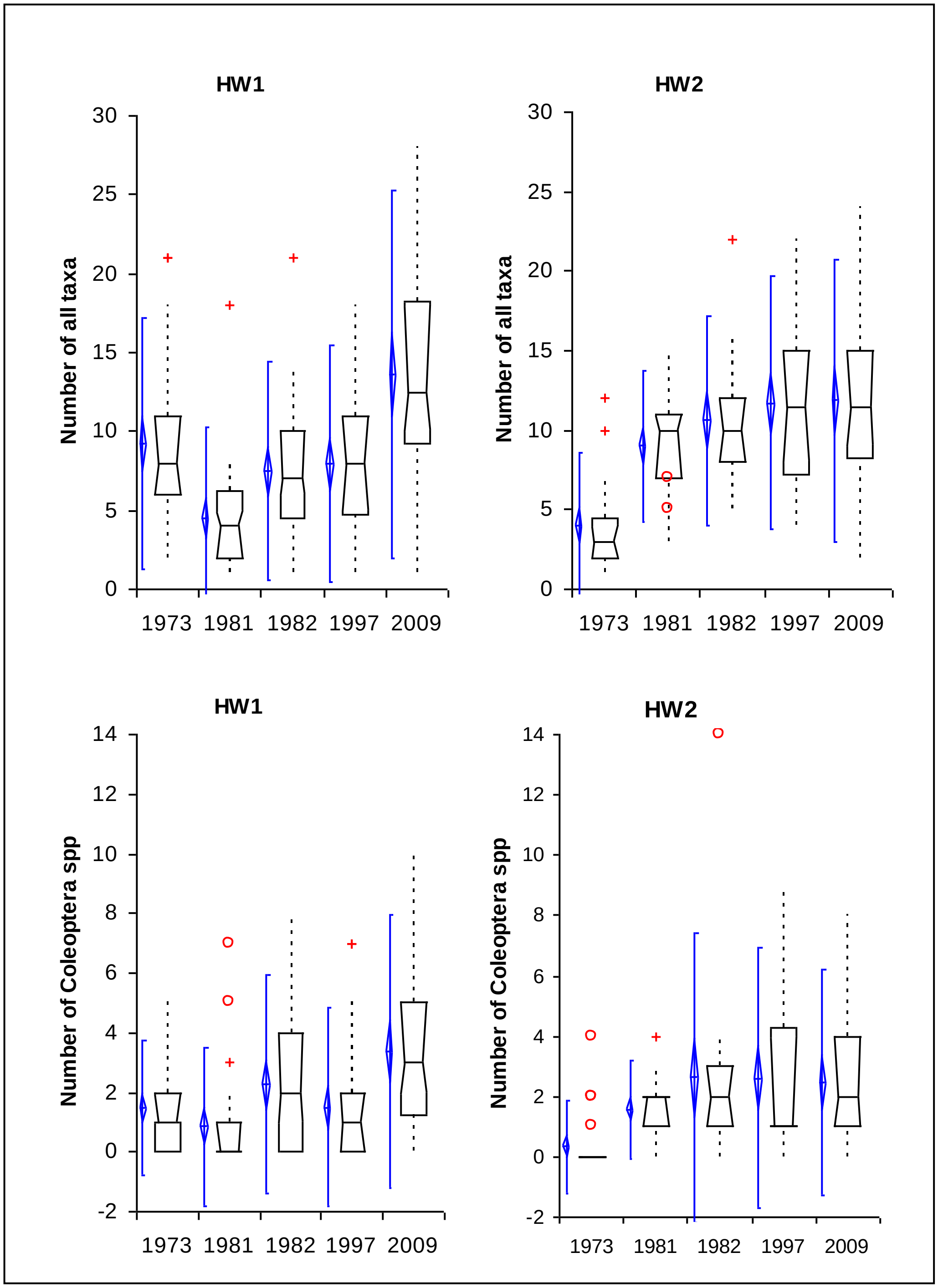


Figure 12. Median and mean for the number of all invertebrate taxa and Coleoptera in the two IDB sub-districts Happisburgh-Winterton 1 and 2 between 1973 and 2009.

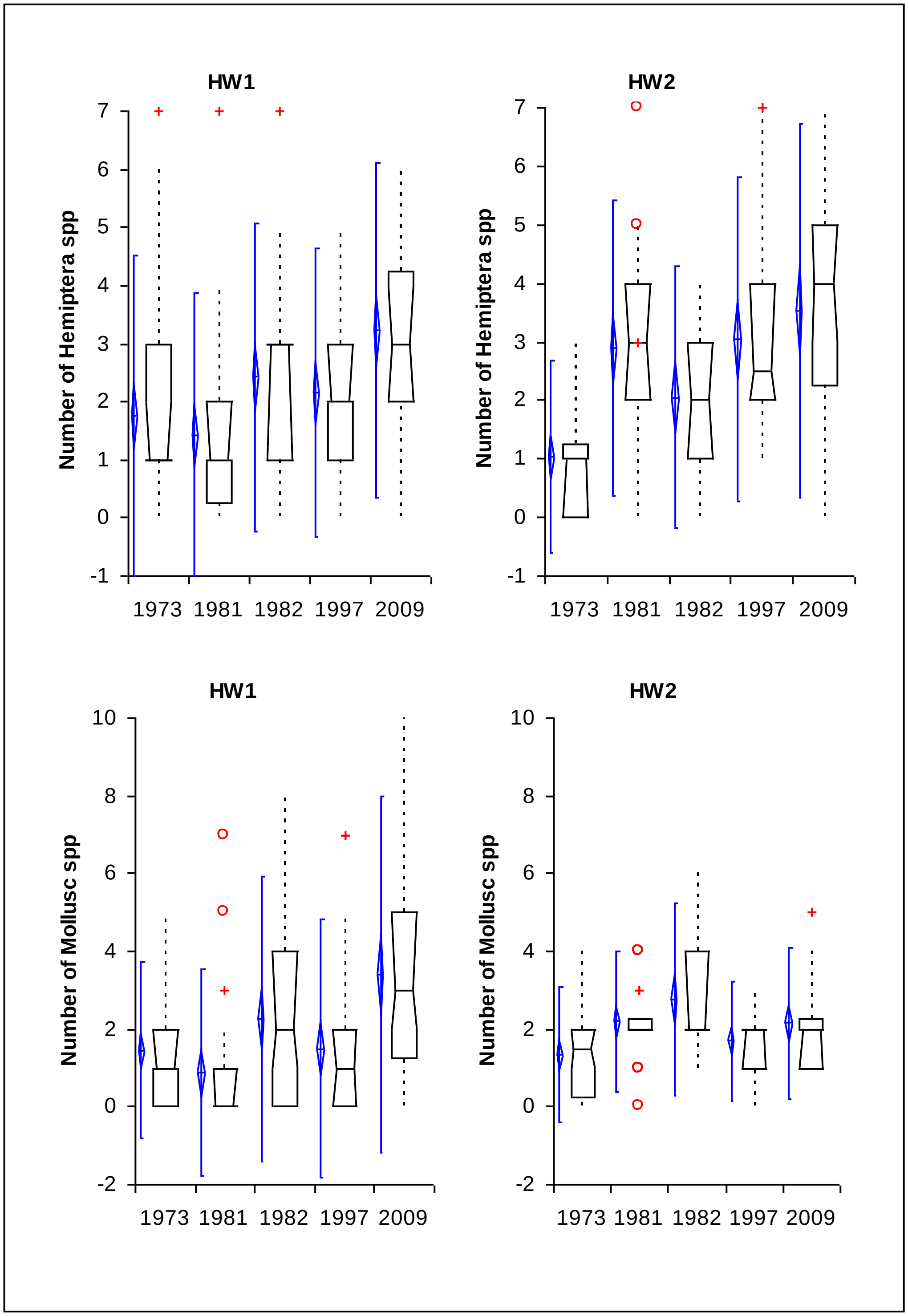


Figure 13. Median and mean for the number of Hemiptera and Mollusca in the two IDB sub-districts Happisburgh-Winterton 1 and 2 between 1973 and 2009.

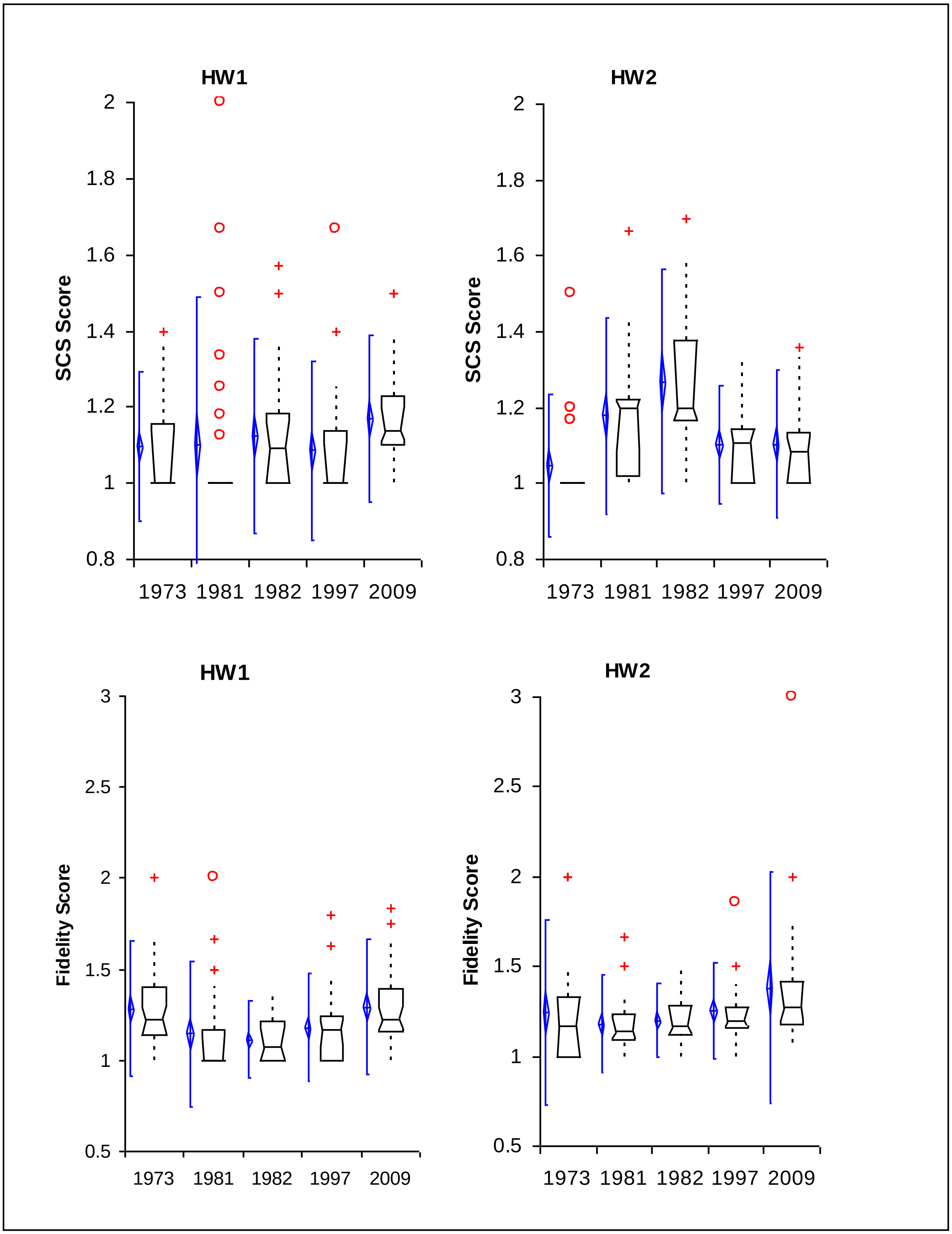


Figure 14. Median and mean for the scores for Species Conservation Status and Habitat Fidelity for invertebrates in the two IDB sub-districts Happisburgh-Winterton 1 and 2 between 1973 and 2009.

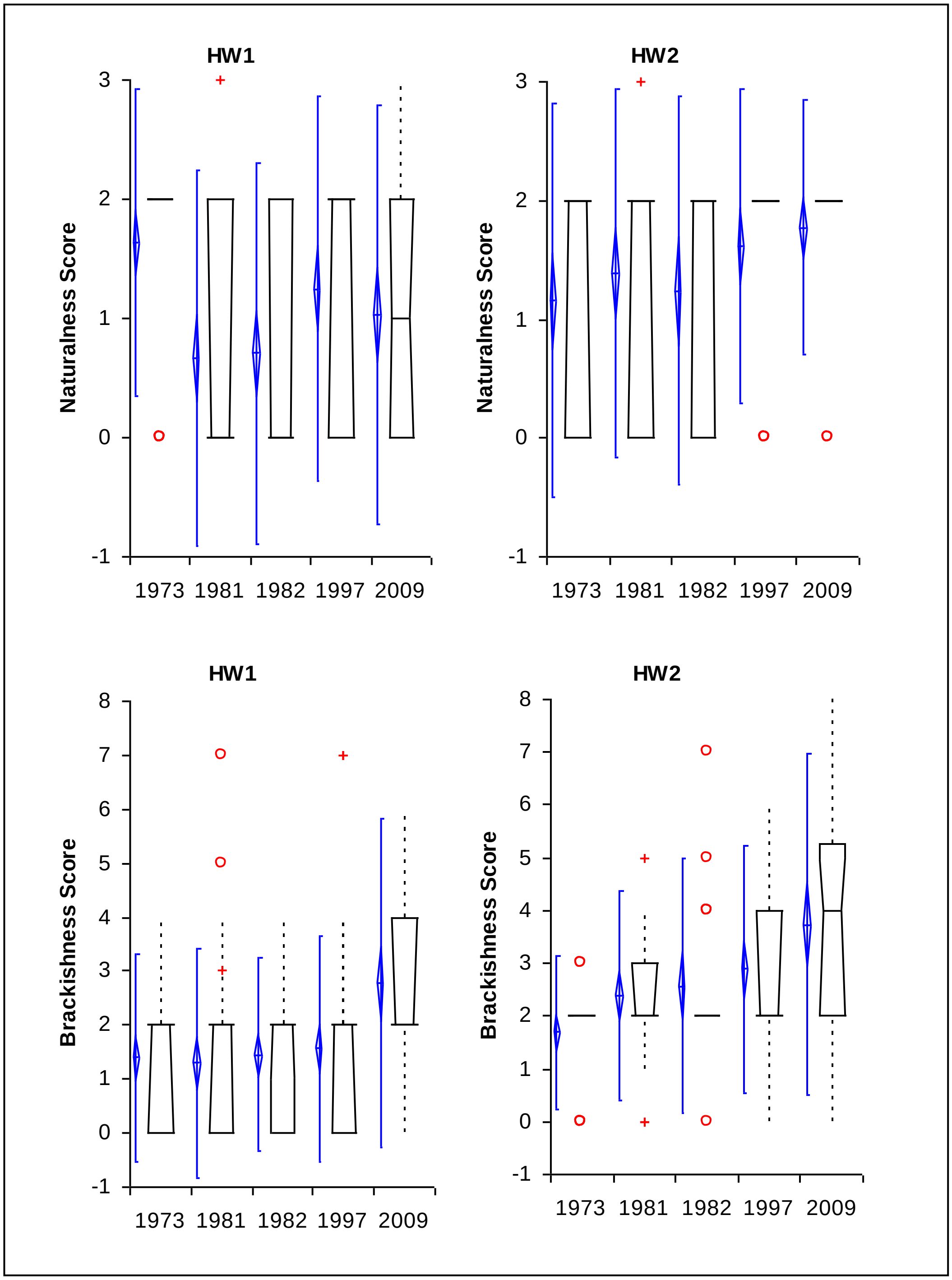


Figure 15. Median and mean Naturalness Score and Brackishness Score in the two IDB sub-districts (Happisburgh-Winterton 1 and 2) in the four years.

3.3.3. Ordination

A problem with the Thurne data was the small number of species in many samples, leaving 94% zero cells in the data matrix. This can lead to unhelpful results in ordination since samples with very impoverished faunas tend to form outliers that cannot be associated with the parent assemblages from which they were derived, and results in compressing the more species-rich samples into a central cluster where differences cannot be disentangled.

For the interim report (Drake 2009), several runs were made with datasets that differed by:

- excluding samples with few taxa
- excluding taxa that occurred rarely
- using presence/absence data
- using abundance data after taking the cube of the ordinals that DAFOR had been converted to reflect more realistically the relative spread of values (64 for A, 27 for F, 89 for O and 1 for R – no species was rated as D)
- downweighting of taxa that were still rare in the dataset (using DECORANA's default)

No analysis appeared to be consistently better, so the current analysis was run using both presence/absence data and abundance data (using the same 'cube of DAFOR' conversion), excluding samples with fewer than 5 taxa, and using DECORANA's downweighting of taxa that were rare in the dataset. Sixty-six samples were excluded (including many from 1973) and two taxa that were found only in these excluded samples, leaving 215 samples and 156 taxa on which to base the analysis.

The first run using these settings for abundance data resulted in a gradient length of 4.24 units, which is long enough to justify using DECORANA rather than PCA. The gradient length using presence-absence data was 3.18, which suggested more linear than unimodal distribution, for which DECORANA is less suited. However, for consistency of approach, only DECORANA was used.

When samples were differentiated by IDB sub-district, there was very little separation into discrete parts of the ordination, although slightly greater distinction was found using presence-absence data than with abundance data (Figure 16). This may reflect small differences in the representation of species that were rather uncommon in the dataset but which would have more influence on the presence-absence ordination. In contrast, a few species that were more numerous at both sites would dominate the abundance-data ordination, leading to poorer separation of the samples.

Changes through time showed no distinct pattern using either dataset so, to reduce confusion, just the presence-absence data are discussed. There appeared to be a slow drift from right to left across the ordination, mainly corresponding to a shift along axis 1, from 1973 (red), through the 1980s (orange, purple) to 1997 (green), and then a return to the centre (blue) (Figure 16). Regardless of differences between the two IDB sub-districts, there did appear to be a shift in the assemblage through time.

As this ordination does not distinguish the two IDB sub-districts, it may be confounding differences that would appear within each sampling occasion. The same ordination was therefore disentangled into each occasion but also distinguishing sub-districts (Figure 17). This is the same analysis just teased apart, and not separate ones for each year of sampling. On all dates, the assemblage at HW2 (pasture 'control') was slightly more tightly clustered that that at HW1. Sometimes the HW2 assemblage occupied a slightly different part of ordination space but with so much overlap with the HW1 assemblage that this could not be ecologically meaningful. Thus the differences between years for the entire Thurne area appeared to be greater than between the two IDB sub-districts on any one year.

Land-use had no influence on the assemblage when presence-absence data were used (Figure 18). This may be due to infrequent species occurring rather randomly in samples and, since they have undue weight in this analysis, may thus blur the contribution of more widespread residents. Using abundance data, there was a slightly greater clustering of ditches within arable land from those in pasture, although with very large overlap. This may be due to a real difference in the numerous species between ditches in arable and in pasture, although this possibility was not investigated. Ditches classed as mixed were scattered throughout both ordinations.

Environmental variables were correlated with the sample scores for the first two axes of the DECORANA runs using both abundance data and presence / absence data (Table 19). The assemblage scores were not related to ditch dimensions, recent cleaning of a ditch or the land-use class of ‘mixed’. Both datasets gave significant correlations with turbidity, pH, conductivity, ferruginous dykes, edges damaged by cattle, and the land-uses arable and grass. Of these variables, conductivity was the most strongly correlated in all tests. Land-use, exemplified by the two opposing groups of variables arable + ferruginous dykes and grass + edges damaged by cattle, was also clearly important. Turbidity acted in concert with arable in most of the correlations and this may be explained by it reflecting nutrient enrichment resulting in algal blooms or iron deposition. Some cross-correlation between the variables probably explains the significant correlations of all variables, except conductivity, with both axes, although this is unusual as it implies that all the variables affected both axes to some extent; normally one or two are important on different axes. The significant correlation with pH may not be important since it was measured only in 1973 and 1981 at one site. The result is also largely at variance with that obtained in the interim report using data before the 2009 survey, in which there were few significant correlations. In that analysis, for presence-absence data, land-use correlated with axis 1 scores and ditch dimension, chloride and cattle-affected edges with axis 2 scores; for abundance data, land-use correlated with axis 1 scores, turbidity, pH, and ferruginous and recently dykes. The only consistent trends were therefore with the two clear land-use categories of arable and grass, and with pH, turbidity, ferruginous dykes and cattle-damaged edges appearing in both analyses but not consistently so.

Table 19. Spearman’s rank coefficient (r) for environmental variables correlated with sample scores of the first two DECORANA axes, for analyses using abundance data or presence-absence data of invertebrates.

p – probability of the result being by chance (significant rs values in bold). N- number of samples (some samples had missing values).

Variable	**Abundance data**				**Presence / absence data**				**N**
	Axis 1		Axis 2		Axis 1		Axis 2		
	rs	p	rs	p	rs	p	rs	p	
width	0.01	0.920	-0.15	0.920	-0.02	0.920	-0.30	0.920	211
depth	-0.13	0.053	0.10	0.053	-0.08	0.053	-0.28	0.053	208
turbidity	**0.32**	<0.001	**-0.16**	<0.001	**-0.11**	<0.001	**-0.10**	<0.001	200
pH	**-0.29**	0.049	**0.01**	0.049	**0.17**	0.049	**-0.13**	0.049	48
conductivity	**0.47**	<0.001	**0.35**	<0.001	**-0.67**	<0.001	-0.12	0.202	122
ferruginous dykes	**0.38**	<0.001	**-0.18**	<0.001	**-0.05**	<0.001	**0.19**	<0.001	215

recently cleaned dykes	0.13	0.054	-0.21	0.054	-0.02	0.054	-0.10	0.054	215
edges damaged by cattle	**-0.17**	0.014	**0.24**	0.014	**-0.16**	0.014	**-0.19**	0.014	213
arable	**0.26**	<0.001	**-0.23**	<0.001	**-0.05**	<0.001	**0.08**	<0.001	215
grass	**-0.19**	0.006	**0.27**	0.006	**-0.10**	0.006	**-0.14**	0.006	215
mixed	0.00	0.984	-0.13	0.984	0.17	0.984	0.10	0.984	215

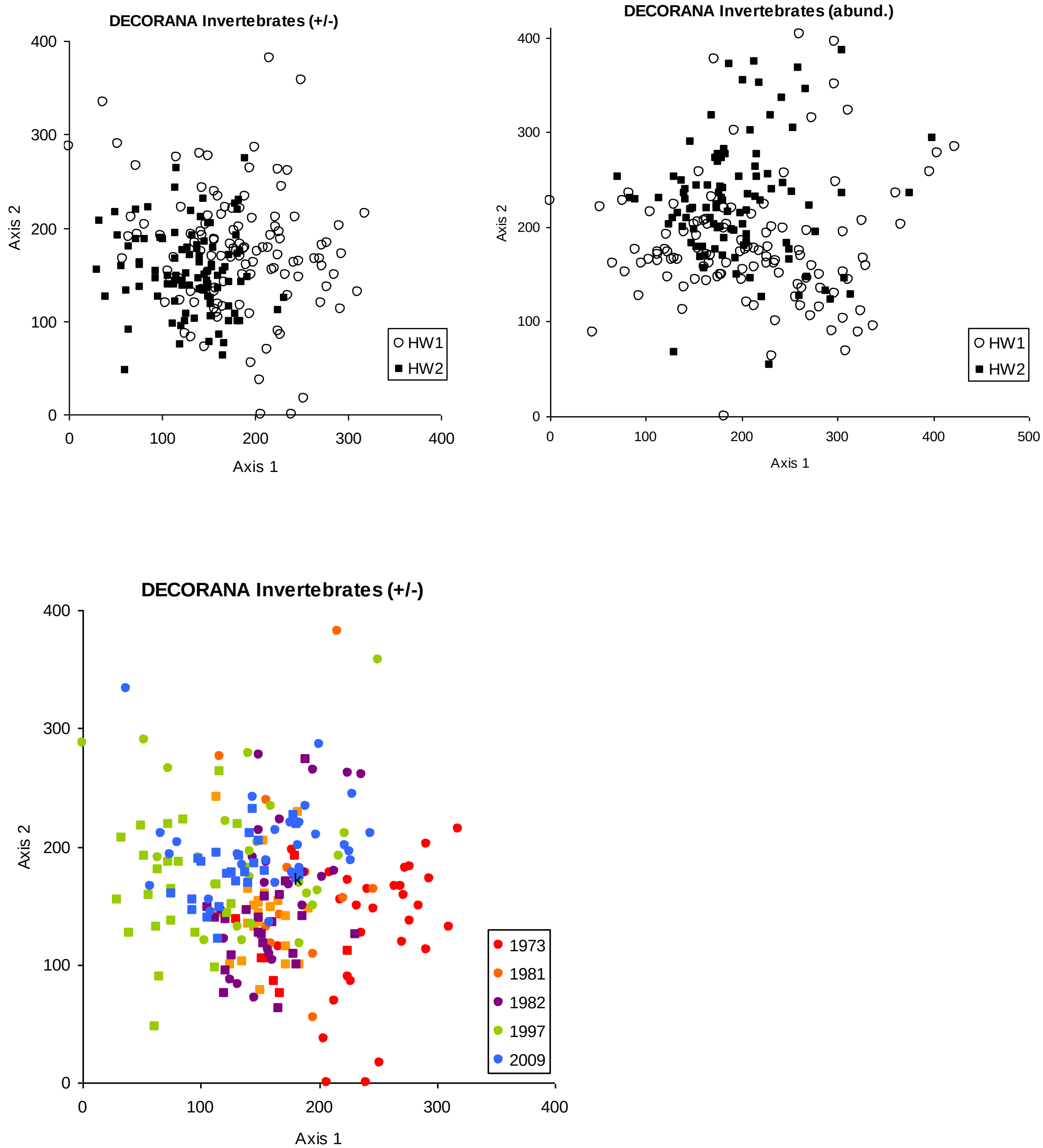


Figure 16. First two axes of DECORANA ordination for invertebrates (presence–absence data) differentiated by IDB sub-district (above) and by year (below).

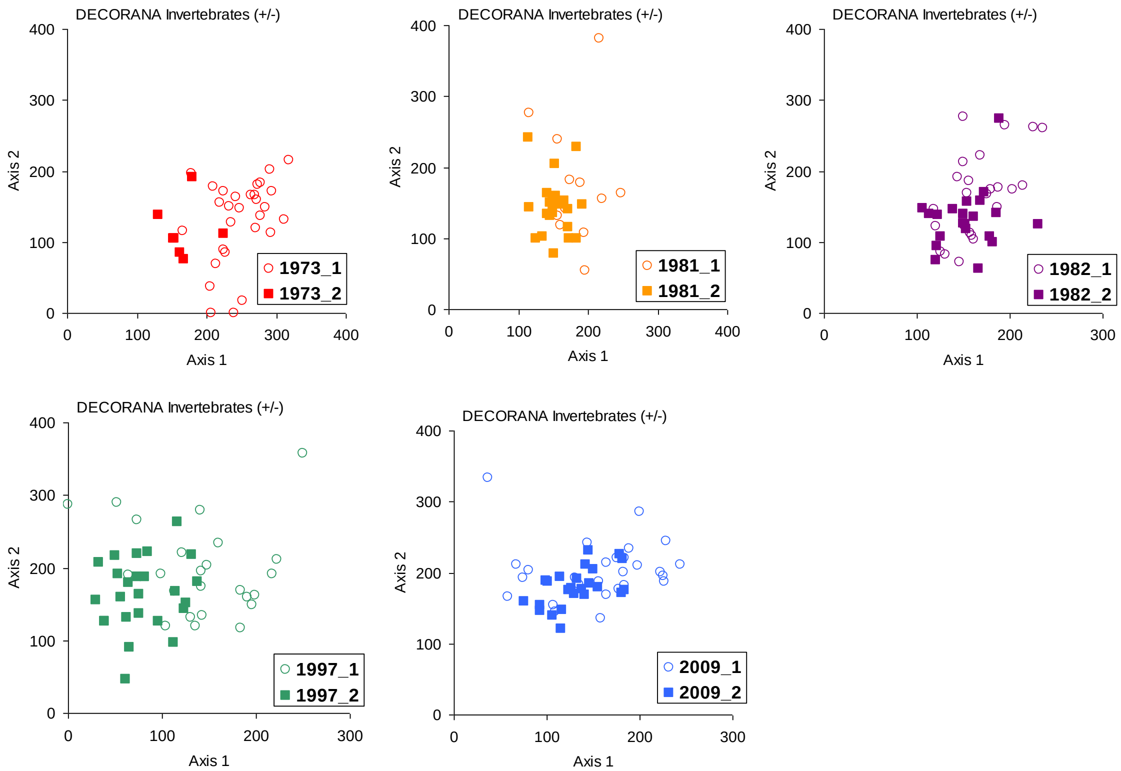


Figure 17. First two axes of DECORANA ordination for invertebrates (presence–absence data) in each year, with IDB sub-districts differentiated (HW1 open circles, HW2 solid squares).

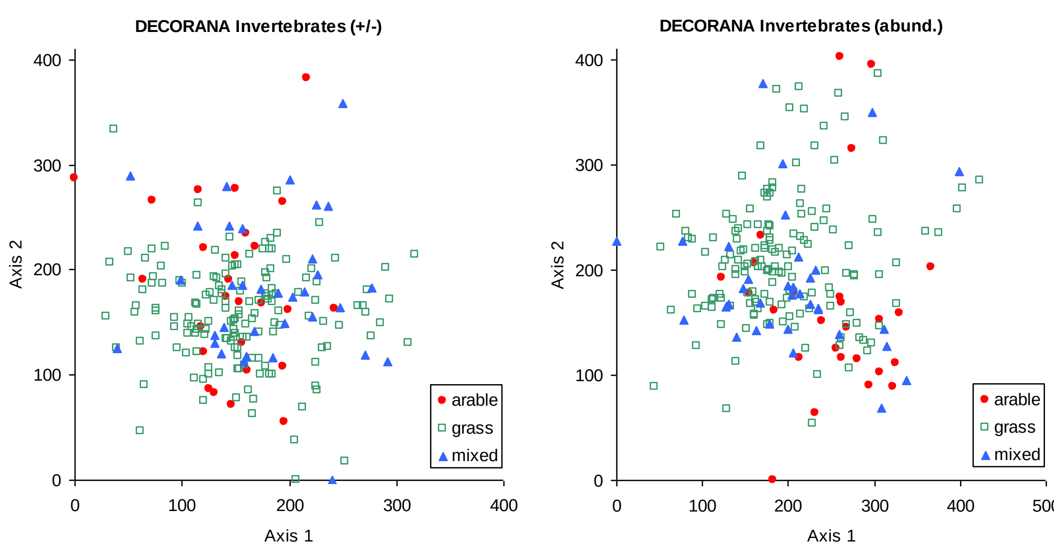


Figure 18. First two axes of DECORANA ordination for invertebrates differentiated by land-use, for both presence–absence data (left) and abundance data (right).

4. Discussion

This project followed the response of the aquatic plants and invertebrates at ditches in a block of grazing marsh that underwent conversion to arable then restoration to pasture, and compared the results with those from an adjacent ‘control’ site that remained as pasture. The work was serendipitous, arising from Rob Driscoll noticing pasture that he had surveyed in 1973 had become arable in the 1980s, which prompted his re-survey. While fortunate, in retrospect the site would not have been chosen for such a study since the fauna and flora of the marshes was considerably less interesting than found on most Norfolk marshes. Some historical information will help to put the results in context.

There were several differences in the environmental conditions at the two sites before agricultural improvement began. Both sites had limited water supply by derived from land towards the coastal dunes but the reversion site was also spring-fed, so suffered less water shortage than the ‘control’ site. This may account for the ‘control’ site being more brackish. In contrast, the ‘control’ site was considered by local farmers to have suffered less problem with iron oxide deposition which was a major issue at the future ‘arable’ site, to the extent that here water had to be piped for livestock as the ditch water was considered to be of too poor quality for livestock to drink. Under-drainage during the arable period made the iron oxide problem worse.

The ‘control’ site was mostly in the ownership of the National Trust whose conservation management in the early years of the survey was orientated towards birds, with the result that the ditches were neglected so that they became overgrown with reed, most of which was cleaned out in one session between 1972 and 1973. This undoubtedly was the reason for the poor results at the ‘control’ at the start of the project. Ditch management has become increasingly sympathetic to aquatic communities, so that, although the site was nominally continuously pasture, the site’s management has not been constant over the three decades of the project.

Despite this inconstancy in the ‘control’ site, the results showed a clear deterioration in the vegetation following conversion to arable, then recovery once pasture was re-instated. The invertebrate assemblages also showed a decline and recovery but their response was less clear-cut.

Overview of vegetation

The ditch system in the Upper Thurne catchment was dominated by brackish-water species, and this was particularly obvious in the invertebrates at HW2 (pasture ‘control’). It was therefore not surprising that the site was species-poor, even in the 1970s when the whole area was predominantly pasture. To put the site’s richness into context, the average numbers of species were compared with those found in the Buglife survey of many grazing marshes of high quality in England and Wales (Drake *et al*., 2010, tables 5.2 and 6.2). Native plant species-richness was close to the national average of 6.5 for brackish ditches, but at HW1 the mean dropped from a high starting value of 7.9 to a low of 4.1 in 1997, and failed to recover even at the end of the study. The mean values at HW2 (pasture ‘control’) started well below this national average in 1973 but fluctuated around it in succeeding years. The mean Species Conservation Status Scores for plants were close to the national mean of 1.1, at HW1 ranging from a high starting value of 1.24 in 1973 to a low of 1.05 during the arable period (and again failing to recover completely by 2009), and at HW2 from a low value of 1.04 at the start to a maximum of 1.24 at the end of the study.

Overview of invertebrates
By contrast, the invertebrates were exceptionally poor when compared with the national median value (with interquartile range) of 39[(29-46) taxa for brackish sites. At HW1 (reversion site), medians were in the range 4.5 after conversion to arable to 13.6 at the end of the study, and at HW2 ('control') they started at 4.0 in 1973 and ended at 11.9 in 2009. Species Conservation Scores for invertebrates were similarly very low, barely rising above a median of 1.0, which indicates only common species, and having the highest median of 1.27 (HW2 in 1982), which can be compared with the national median (with interquartile range) of 1.50 (1.41-1.62). The Happisburgh-Winterton values included a few taxa that were excluded from the national survey, such as flatworms, in order to make most use of the information, but their inclusion still did not raise the numbers of all taxa to anywhere close to those found on high quality marshes.

Vegetation changes
As the plants appeared to be similar in richness and conservation status to those in other brackish marshes, the changes recorded at Happisburgh-Winterton are likely to be real. The overall pattern of change from a starting point in 1973, was of the flora at HW1 reversion site being clearly better in many respects to that at HW2 'control' site, but deteriorating at HW1 after arable conversion to a condition worse than at HW2, and finally a slow recovery to match HW2. Superimposed on this appeared to be an increase in salinity and possible deterioration in water quality indicated by the plant assemblage. This was more apparent at the 'control' site HW2 but any effect at HW1 may have been confounded by the radical changes in land-use.

Invertebrate changes
Changes in the invertebrates need to be viewed with caution since the numbers of species were very small, so that the addition or loss of a few species would make a large impact on the metrics. For example, the 1981 and 1982 values were often more different from one another than between other pairs of values separated by many years. It is possible that sampling error or just year-to-year fluctuations in the fauna may be responsible for such irregularities. However, there was still sufficient pattern in the metrics when considered altogether to suggest some real changes.

At HW1 (reversion site), all the metrics for invertebrates followed approximately the same pattern of change, falling slightly from their initial level after conversion to arable, then rising again, sometimes to a level higher than in 1973. As these differences were significant and matched the changes seen in the plants, it seems that that the invertebrates were also detrimentally affected by arable conversion, and responded positively to restoration to pasture. Changes at HW2 'control' site were more pronounced. Here, Species richness and Species Conservation Status Score rose markedly and diverged from the downward trend at HW1, which again reinforced the reality of the negative impact of arable land-use. It is not clear why the SCS Score rose in 1982 to well above the other years, but despite the current apparently sympathetic land-use, the overall quality of the fauna was no better in 2009 than in 1973. As HW2 was the control area, such large changes would not have been expected but, although the land-use remained as grass, ditch management may not have been ideal. For many years the conservation emphasis was on birds, and management of the ditches tended to be neglected, and this is seen in the deterioration of the ditch flora since the 1970 in many parts of Broadland. Brackishness Score rose in both sub-districts, as was noted for plants, and at the HW1 reversion site was clearly related to the increasing electrical conductivity. Increasing salinity by itself is unlikely to depress the SCS Score since many uncommon ditch invertebrates are associated with brackish conditions.

Assemblage changes
Ordination of both plants and invertebrates showed the same apparent slow change in the assemblages through time, starting at one side of ordination space, and drifting across it until 1997, then returning again to close to the centre. The plants showed the effect most strongly, since the unaffected HW2 samples remained clustered in the same part of ordination space while the HW1 samples drifted back and forth through time. This was not seen with the invertebrates in which, in simplified terms, the combined HW1 and HW2 points moved through time as a single undifferentiated block. This may have been an artefact of ordination, which usually places samples with small values to one side of the space, so that 1973 samples would fall to one side, and the notably richer 2009 samples would be close to the centre. However, both plants and invertebrates showed the same pattern, and it would seem quite likely that both assemblages were responding to the changes in land-use or perhaps to other effects such as the increase in salinity or more benign management.

Environmental attributes
It would have been remarkable if no changes had been recorded in the plants and animals at HW1, given the large changes in the few physical variables that were measure. Mean water depth halved to about 30cm, the number of ditches with iron oxide deposits rose nearly five-fold, cleaning became far more frequent and the water was slightly more turbid. None of these changes occurred at the ‘control’ site HW2.

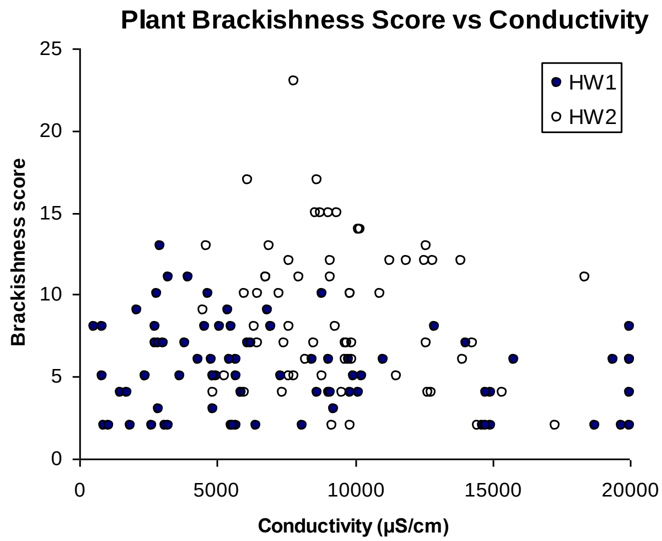
The sites were particularly brackish, and almost no ditches were considered ‘fresh’ using the criterion of electrical conductivity being less than 2000 $\mu S\ cm^{-1}$. Brackishness had the largest impact on both plant and animal assemblages over time, and trends in conductivity and the species richness of plants were similar. However, there was a disappointing lack of relationship between conductivity and the brackishness scores of both plants and animals (Figure 19). The Pearson correlation coefficient between conductivity and either plants and animals was not significant for either site or for the sites combined. If other factors were affecting the assemblages and species metrics, it would be difficult to detect a meaningful relationship if this none could be found for salinity whose effect appeared to be greater than any other measured variable.

5. Conclusions

- Ditch management in arable land is detrimental to the aquatic plants and invertebrates. The reasons for this cannot be deduced with certainty from this study but among the likely damaging factors are low water levels at the bottom of deep ditches (leading to a small volume of water susceptible to high concentrations of nutrients and salt, and narrow water width that can be completely shaded by rank bank vegetation), frequent cleaning, increased deposition of iron oxides in peat soils, and the absence of edge disturbance by grazing animals.
- The detrimental effects can be reversed, although the aquatic flora and fauna may take many years to return to its original condition. It took much more than ten years in this study.
- Restoration means more than putting the grass back, and pasture alone does not equate with sympathetic ditch management. Even when the land-use was pasture, fencing that prevents animals from grazing and trampling the water margins, and too strict control of

water levels (keeping them moderately low) were reasons for the fauna and flora remaining rather poor compared to that found at other Norfolk marshes.

- A more species-rich (if not rarity-rich) flora and fauna can probably survive in arable ditches providing the water levels are not kept permanently very low, and the water width is sufficient that rank marginal vegetation does not entirely shade the water surface. It is difficult to see how nutrient enrichment can be avoided if the fields are under-drained since a buffer strip would be by-passed.



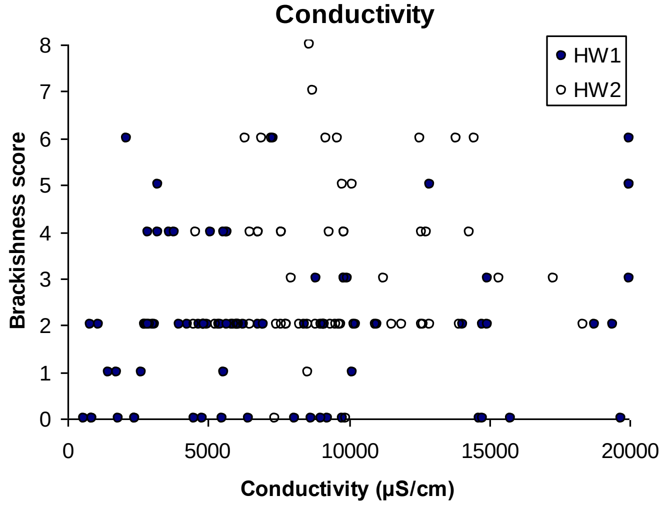


Figure 19. Relationship between electrical conductivity and the brackishness scores of plants and invertebrates for the two sites.

6. Acknowledgements

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Appendix 1. Plants recorded at each site and in each year.

Values are numbers of ditches.

Species	Status score	Conservation status	Habitat quality score	Salinity score	HW1					HW2					total
					1973	1981	1982	1997	2009	1973	1981	1982	1997	2009	
Alisma plantago-aquatica	1	Common	1	0	8	7	7	1	3						26
Apium nodiflorum	1	Common	1	0	8	5	7	2			2	2	2		28
Baldellia ranunculoides	4	NT	5	0		1	1								2
Berula erecta	1	Common	1	0	1		1		3					2	7
Bolboschoenus maritimus	1	Common	1	4	1	2	2		1	2	12	8	11	7	46
Callitriche sp	1	-	1	0	21	8	14	9	9	7	12	10	5	8	103
Carex pseudocyperus	1	Local	2	0				1							1
Carex riparia	1	Common	1	0	9	4	5	6	5	4	6	4	6	3	52
Ceratophyllum demersum	1	Common	1	1	3									3	6
Chara aspersa	2	Local E	5	1							2	1			3
Chara globularis	1	Local	4	0			1				2	1			4
Chara hispida	1	Local	5	1							1				1
Chara sp	1	-	5	0	2			2		1		1			6
Chara vulgaris	1	Common	5	0			1		1						2
Eleocharis palustris	1	Common	4	1	1	1	1		2	1	6	7			19
Elodea canadensis	0	Alien	0	0	13	1		3	4					1	22
Enteromorpha sp	1	Common	1	3	10	3	4		1	1					19
Filamentous algae	1	Common	1	2	9	3	2	1	5	3	1	3	12	14	53
Glyceria fluitans	1	Common	2	0		2	2								4
Glyceria maxima	1	Common	1	0	8	3	4	1	1						17
Groenlandia densa	5	VU	3	1		1	1	1							3
Hippuris vulgaris	1	Common	4	1	17	9	5	6	7	17	19	17	17	12	126
Hottonia palustris	1	Local	3	0	3	1			2						6
Iris pseudacorus	1	Common	1	1	3	1		2			1	1			8
Juncus subnodulosus	1	Common	4	0	1	1	3	3	4	1	4	4	1	1	23
Lemna minor	1	Common	2	0	10	6		6	4	2	1	1	1	1	32
Lemna trisulca	1	Common	3	0	8	3		1	2	2	7	9	8	11	51
Leptodictyum riparium	1	Common	1	0	1				1		1				3

Species	Status score	Conservation status	Habitat quality score	Salinity score	HW1					HW2					total
					1973	1981	1982	1997	2009	1973	1981	1982	1997	2009	
Myriophyllum spicatum	1	Common	1	2	10	1	4		8	24	17	12	15	16	107
Myriophyllum verticillatum	5	VU	1	0	13	4	5	2	6	2	4	4	4	9	53
Oenanthe fistulosa	5	VU BAP	2	0	3						2	2			7
Persicaria amphibia	1	Common	2	0	2	1									3
Phragmites australis	1	Common	1.5	2	32	30	29	32	30	26	25	21	26	26	277
Potamogeton coloratus	3	NS	3	0					1			1			2
Potamogeton crispus	1	Common	2	1		8	6	2	2				1		19
Potamogeton natans	1	Common	4	0	18	11	10	6	9	4	3	2			63
Potamogeton pectinatus	1	Common	1	2	15	10	5	12	15	10	7	6	16	14	110
Potamogeton perfoliatus	1	Common	3	1	8	1	2			1	2	3	1		18
Potamogeton pusillus	1	Common	2	1	1	12	14	12	6		7	2	7	12	73
Potamogeton sp	1	Unknown	1	0	1					1					2
Ranunculus aquatilis	1	Common	3	0			1		1	1	4	3	1		11
Ranunculus baudotii	1	Local	2	4										2	2
Ranunculus circinatus	1	Local	1	0	10		1		1	1	4	2		2	21
Ranunculus sceleratus	1	Common	1	2		2	1	1	1			2		1	8
Ranunculus trichophyllus	1	Common	1	0	3										3
Riccia fluitans	1	Local	2	0	1										1
Rorippa nasturtium-aquaticum	1	Common	1	0	7	5	7	1	5					1	26
Rumex hydrolapathum	1	Common	2	0	1									1	2
Sagittaria sagittifolia	1	Local	2	0	1	1									2
Schoenoplectus tabernaemontani	1	Common	1	3	7	6	3	2	5	7	13	12	16	12	83
Sparganium emersum	1	Common	2	0		4									4
Sparganium erectum	1	Common	1	0	2	2	5	7	5						21
Typha angustifolia	1	Common	1	1					1	2	1	1	3	4	12
Typha latifolia	1	Common	1	0	1		1	4	2						8
Veronica catenata	1	Common	1	0		2	3		1						6
Zannichellia palustris	1	Common	1	2		22	19	8	6		2	1	1		59

Appendix 2. Invertebrates recorded at each site and in each year.

Values are numbers of ditches.

Order	Family	Species	SCS	Fidelity	Brackish	HW1					HW2					Total
						1973	1981	1982	1997	2009	1973	1981	1982	1997	2009	
Coleoptera	Dytiscidae	*Agabus bipustulatus*	1	1	0		2	2	5	4		2		2	1	18
		Agabus conspersus	3	2	1			1	1							2
		Agabus sturmii	1	1	0	1	2	6	3	5			1		2	20
		Colymbetes fuscus	1	1	0			1								1
		Dytiscus circumflexus	2	2	0					1						1
		Dytiscus marginalis	1	1	0			2	1	1		2				6
		Graptodytes pictus	2	2	0	2		1	1	4					1	9
		Hydaticus seminiger	3	1	0										1	1
		Hydroporus	0	1	0					4					2	6
		Hydroporus angustatus	1	1	0				1				1	1		3
		Hydroporus erythrocephalus	1	1	0								1			1
		Hydroporus palustris	1	1	0	1	2	7	2	3	1		1	1	1	19
		Hydroporus planus	1	1	0		1		1				1			3
		Hygrotus impressopunctatus	1	1	0				1				1			2
		Hygrotus inaequalis	1	1	0	5		2	2	6		3	1	1	6	26
		Hygrotus parallellogrammus	3	2	1		2	1								3
		Hygrotus versicolor	2	1	0	1										1
		Hyphydrus ovatus	1	1	0	8				4		1	1	1	4	19
		Ilybius ater	1	2	0			1	1	1			1		2	6
		Ilybius fuliginosus	1	1	0		2	2		1				1		6
		Ilybius subaeneus	3	1	0		1									1
		Laccophilus hyalinus	2	1	0	1		1								2
		Laccophilus minutus	1	2	0	1	1	3	2							7
		Nebrioporus assimilis	2	1	0		1									1
		Nebrioporus elegans	1	1	0		1	1								2
		Rhantus frontalis	3	1	0			1	1	3		1		2	1	9
		Rhantus suturalis	2	2	0								1			1
	Gyrinidae	*Gyrinus*	0	1	0	9				1				2	1	13
		Gyrinus caspius	2	2	1	1				4		1				6

Order	Family	Species	SCS	Fidelity	Brackish	HW1					HW2					Total
						1973	1981	1982	1997	2009	1973	1981	1982	1997	2009	
		Gyrinus marinus	2	1	0	1		1		1	1	6	6			16
		Gyrinus substriatus	1	1	0	3	2	8	3	3		2	4	2	1	28
	Haliplidae	*Haliplus*	0	1	0	3	1	5	1	11	1	2	3	1	7	35
		Haliplus confinis	2	1	0		1						1			2
		Haliplus flavicollis	2	1	0					1						1
		Haliplus fulvus	2	1	0		1									1
		Haliplus heydeni	2	1	0					2						2
		Haliplus immaculatus	1	2	0	1				1			1		1	4
		Haliplus lineatocollis	1	1	0	2	2	4	1	3		1	3	6	5	27
		Haliplus obliquus	2	1	0					1						1
		Haliplus ruficollis	1	1	0	2	1			7	1	2	1	1	4	19
		Haliplus sibiricus	1	1	0	1		1		1						3
		Peltodytes caesus	3	3	0								1		1	2
	Helophoridae	*Helophorus*	0	1	0				4	5				9	3	21
		Helophorus flavipes	1	1	0							2	1			3
		Helophorus griseus	2	1	0			3					1			4
		Helophorus obscurus	1	1	0			1								1
	Hydraenidae	*Ochthebius marinus*	2	1	1						1					1
	Hydrophilidae	*Anacaena globulus*	1	1	0				2	1						3
		Anacaena limbata	1	1	0	1		1	5				1	1	1	10
		Cymbiodyta marginellus	2	1	0			1					1	2		4
		Enochrus quadripunctatus	3	1	0			1					1			2
		Enochrus testaceus	2	1	0				1	5	1		1	2		10
		Enochrus? sp	0	0	0									5		5
		Helochares sp?	0	0	0				1							1
		Hydrobius fuscipes	1	1	0			2	4	4	1	1	5	11		28
		Hydrophilus piceus	4	3	0					1						1
		Laccobius bipunctatus	1	1	0		1	2	2			5	1	1	1	13
		Laccobius colon	2	2	0	3		1								4
		Laccobius minutus	1	2	0		1	3	1	1					1	7
		Laccobius striatulus	2	1	0		1	3								4
	Noteridae	*Noterus clavicornis*	1	1	0	1		1	1	12	2	10	13	16	17	73
Diptera	Chaoboridae	*Chaoborus*	0	1	0					1						1
	Culicidae	Culicidae	0	1	0				2							2

Order	Family	Species	SCS	Fidelity	Brackish	HW1					HW2					Total
						1973	1981	1982	1997	2009	1973	1981	1982	1997	2009	
	Cylindrotomidae	*Phalacrocera replicata*	3	1	0					1						1
	Dixidae	Dixidae	0	1	0					1						1
	Stratiomyidae	*Odontomyia ornata*	4	3	0					1					4	5
	Syrphidae	Eristalini	0	1	0				1					1		2
	Tipulidae	Tipulidae	0	1	0									1		1
Ephemeroptera	Baetidae	*Cloeon dipterum*	1	1	0	1	3	1	3	9					2	19
		Cloeon simile	2	1	0	1										1
Hemiptera	Corixidae	*Callicorixa praeusta*	1	1	0	3	3	3	2		1	1		4		17
		Corixa	0	1	0					1				1		2
		Corixa panzeri	2	1	0			1	1	2			2		5	11
		Corixa punctata	1	1	0	10	8	10	3	1	4	3	1	7	1	48
		Corixidae	0	1	0					3				1	1	5
		Cymatia bonsdorffii	2	1	0	1										1
		Cymatia coleoptrata	2	1	0	6								1		7
		Hesperocorixa linnaei	1	1	0	3	1	3	3	2	1	8	3	5	10	39
		Hesperocorixa sahlbergi	1	1	0					1						1
		Paracorixa concinna	2	1	0	1		1	2					2		6
		Sigara dorsalis	1	1	0	8	14	19	17	16	7	17	9	5	13	125
		Sigara falleni	1	1	0										2	2
		Sigara fossarum	1	1	0	1					2					3
		Sigara lateralis	1	1	0		1			1					4	6
		Sigara limitata	2	1	0		1				1					2
		Sigara nigrolineata	1	1	0	1	3	1	3			1		1		10
		Sigara selecta	2	1	2					1						1
		Sigara stagnalis	2	1	1		1	3	2	8	1	3	2	2	3	25
	Gerridae	*Aquarius paludum*	3	1	0				1							1
		Gerris	0	1	0			1	3	11				1	15	31
		Gerris lacustris	1	1	0		4	21	13	9		8	4	5	4	68
		Gerris odontogaster	1	1	0	9			1	2	8	16	6	20	7	69
		Gerris thoracicus	1	1	0	8	4		8	4	1	2		4		31
	Hydrometridae	*Hydrometra stagnorum*	1	1	0			2	3	2		2		1	1	11
	Naucoridae	*Ilyocoris cimicoides*	1	1	0			7		13		1	14	8	13	56
	Nepidae	*Nepa cinerea*	1	1	0		2	2	1	6		5	1	3	5	25
		Ranatra linearis	2	1	0				1	3			1	1	4	10

Order	Family	Species	SCS	Fidelity	Brackish	HW1					HW2					Total
						1973	1981	1982	1997	2009	1973	1981	1982	1997	2009	
	Notonectidae	*Notonecta*	0	1	0				2	5					1	8
		Notonecta glauca	1	1	0	6	1	1	2	2		8			1	21
		Notonecta viridis	1	1	0	1			1	4	1			7	2	16
Lepidoptera	Pyralidae	*Nymphula nymphaeata*	0	1	0					3						3
Megaloptera	Sialidae	*Sialis lutaria*	1	1	0		5	2	3	3		3	1			17
Odonata	Aeshnidae	*Aeshna*	1	1	0			1						1	2	4
		Aeshna cyanea	1	1	0				1					1		2
		Aeshna grandis	1	1	0		2	4	3	4		3	4	1	6	27
		Aeshna juncea	1	1	0							1				1
		Aeshna mixta	2	1	0			2	6	1			1	11		21
	Coenagrionidae	*Coenagrion*	1	1	0				1							1
		Coenagrion puella	1	1	0	15					3				1	19
		Ischnura elegans	1	1	0	7	3	7	2	12	8	10	8	4	15	76
		Pyrrhosoma nymphula	1	1	0										1	1
	Lestidae	*Lestes sponsa*	1	1	0			2	2			9	10	12	2	37
	Libellulidae	*Sympetrum*	1	1	0			1	1	3						5
		Sympetrum striolatum	1	1	0		3	6	12	4		1	1	16	6	49
	Zygoptera	Zygoptera	0	1	0				5	6				18	1	30
Trichoptera	Limnephilidae	*Limnephilus lunatus*	1	1	0		1			3						4
	Phryganeidae	*Agrypnia pagetana*	2	1	0					3					1	4
		Phryganea	1	1	0					3			9	1	1	14
Araneae	Cybaeidae	*Argyroneta aquatica*	2	1	0	2				2		1	3	4	4	16
Amphipoda	Crangonycitidae	*Crangonyx pseudogracilis*	0	1	0					1						1
	Gammaridae	*Gammarus*	1	1	1	1			1	1				1		4
		Gammarus duebeni	1	1	2	4	9	7	13	16	5	12	6	16	18	106
		Gammarus zaddachi	1	1	2	18	9	13	10	18	16	16	19	16	18	153
Decapoda	Palaemonidae	*Palaemonetes varians*	1	1	2							1	1	1	2	5
Isopoda	Asellidae	*Asellus*	1	1	0										1	1
		Asellus aquaticus	1	1	0	15	2	3	6	6	1	3	1	6	1	44
		Asellus meridianus	1	1	0	6	2	2		6			1		1	18
	Sphaeromatidae	*Sphaeroma hookeri*	1	1	2									3	8	11
Mysidacea	Mysidae	*Neomysis integer*	1	1	2										1	1
Mollusca	Bithyniidae	*Bithynia leachii*	2	1	0	6										6
		Bithynia tentaculata	1	1	0	17	1	3	8	11						40

Order	Family	Species	SCS	Fidelity	Brackish	HW1					HW2					Total
						1973	1981	1982	1997	2009	1973	1981	1982	1997	2009	
	Hydrobiidae	*Potamopyrgus antipodarum*	0	1	0	27	10	11	20	14	15	18	13	21	23	172
	Lymnaeidae	*Lymnaea palustris*	1	1	0	3	1	2	8	12	1	2	7	4	7	47
		Lymnaea stagnalis	1	1	0					6						6
		Radix auricularia	2	1	0					2						2
		Radix balthica	1	1	0	23	11	15	18	16	16	23	19	15	17	173
	Physidae	*Physa fontinalis*	1	1	0	9	1	1		1	1	1	5		1	20
	Planorbidae	*Anisus vortex*	1	1	0	6	1	2		6					1	16
		Bathyomphalus contortus	2	1	0	1										1
		Gyraulus crista	1	1	0	2				1	1	2	4		1	11
		Hippeutis complanatus	2	1	0					1						1
		Planorbarius corneus	1	1	0							1				1
		Planorbis carinatus	1	1	0	2				3						5
		Planorbis planorbis	1	1	0	9	2	2	7	12	1	10	10	4	6	63
	Sphaeriidae	*Musculium lacustre*	1	1	0	1			1							2
		Sphaerium corneum	1	1	0					1						1
	Valvatidae	*Valvata piscinalis*	2	1	0	2										2
Hirudinea	Erpobdellidae	*Erpobdella octoculata*	1	1	0	1			2	2						5
	Glossiphoniidae	*Glossiphonia complanata*	1	1	0					2						2
		Theromyzon tessulatum	1	1	0	4				4		1	2			11
	Piscicolidae	*Piscicola geometra*	1	1	0										1	1
Tricladida	Dendrocoelidae	*Dendrocoelum lacteum*	0	1	0	1				1						2
	Dugesiidae	*Dugesia polychroa*	0	1	0	2				4						6
	Planariidae	*Planaria torva*	0	1	0	2				1						3
		Polycelis nigra	0	1	0	7										7
		Polycelis nigra/tenuis	1	1	0				1							1
		Polycelis tenuis	1	1	0	3				2						5
Non-target Taxa																
Coleoptera	Coleoptera	Coleoptera	0	1	0				1					1		2
Diptera	Ceratopogonidae	Ceratopogonidae	0	1	0					2						2
	Chironomidae	Chironomidae	0	1	0	2	12	7	6	16	1	3	2	5	13	67
Trichoptera	Limnephilidae	Limnephilidae	0	1	0					1						1
	Phryganeidae	Phryganeidae	0	1	0					1					1	2
	Trichoptera	Trichoptera	0	1	0					3						3
Hydracarina	Hydracarina	Hydracarina	0	1	0	5	1			12					5	23

Order	Family	Species	SCS	Fidelity	Brackish	HW1					HW2					Total
						1973	1981	1982	1997	2009	1973	1981	1982	1997	2009	
Crustacea	Cladocera	Cladocera	0	1	0	8							2		1	11
Oligochaeta	Oligochaeta	Oligochaeta	0	1	0					1					1	2
Anura	Ranidae	*Rana temporaria*	0	1	0		1		2				1		1	5
Pisces	Cyprinidae	*Rutilus rutilus*	0	0	0									1		1
	Esocidae	*Esox lucidus*	0	0	0	1										1
	Gasterosteidae	*Gasterosteus aculeatus*	0	1	0	2	14	6	20	19	6	18	9	16	22	132
		Pungitius pungitius	0	1	0	5	22	20	17	23	9	15	13	19	13	156
Urodela	Salamandridae	*Lissotriton*	0	1	0					2			1	1	1	5
		Lissotriton vulgaris	0	1	0					1						1

Appendix 3. Explanation of boxplots

Information from Analyse-it Help

Box-plots were obtained from Analyse-it add-in to Excel. They graphically show the central location and scatter/dispersion of the observations of a sample(s).

The blue line series shows parametric statistics:
the blue diamond shows the mean and the requested confidence interval around the mean.
the blue notched lines show the requested parametric percentile range.

The notched box and whiskers show non-parametric statistics:
the notched box shows the median, lower and upper quartiles, and confidence interval around the median.
the dotted-line connects the nearest observations within 1.5 IQRs (inter-quartile ranges) of the lower and upper quartiles.
red crosses (+) and circles (o) indicate possible outliers - observations more than 1.5 IQRs (near outliers) and 3.0 IQRs (far outliers) from the quartiles.