RSPB/NE Countdown 2010: Bringing Reedbeds to Life Project

Wildlife surveys

CHAPTER 8: Aquatic macrophyte surveys

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With helpful comments on draft report from Tim Pankhurst (PlantLife)

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Summary

- These surveys found 22 floating or submerged aquatic macrophyte species in total across three reedbed reserves, with 8 ditch and 8 open water sampling points at each reserve.
- Aquatic macrophyte diversity did not vary greatly across the range of environmental variables measured and no one environmental factor had an overwhelming influence.
- Many environmental factors were site specific.
- Trends that emerged included higher aquatic macrophyte diversity being associated with shallower silt depths and more distant scrub. These trends were true for all sites analysed together, and for some but not all sites analysed separately.

Background information

We would expect ditches with and clear water and depths that allow sufficient light to reach plants to support high aquatic macrophyte diversity. Management advice for aquatic macrophytes in reedbeds recommends providing a range of conditions, from shallow to deep water bodies and from open water to vegetation choked ditches. Species presence is known to depend on water pH, salinity and trophic status. Most aquatic plant species prefer mesotrophic-eutrophic conditions with a neutral to slightly acidic pH. Nutrient–rich substrates should be avoided in reedbed creation (White, G. 2004). We would expect reedbed ditches to be less species rich than ditches in more open systems, due to shade, but this does not mean reedbed ditches are devoid of species.

A Buglife report on grazing marsh ditch systems in England and Wales surveyed aquatic macrophytes (Drake et al 2010). This survey was at a larger scale than our study, sampling over three years (2007-2009) and over 500 ditches in coastal grazing marshes in Gwent, Anglesey, Somerset and Avon, Sussex, Kent, Essex, Suffolk and Norfolk. In total, 174 plant species were recorded from ditches in the marshes surveyed. However only 48 of these species were predominantly floating or submerged forms. The Buglife study found salinity, water depth, substrate and hydroseral stage to be the key environmental factors influencing aquatic macrophyte species composition in freshwater ditches. The Buglife study used a different type of analysis that uses environmental variables to separate out species assemblages, rather than associating habitat variables with total number of species as in our analysis.

METHODS

Field methods

Field surveys were conducted by Anna Doeser, Heather Kingsley and Donna Harris. Analysis was carried out by Elizabeth Mackley. Surveys were carried out between 27th July and 6th August 2009. We surveyed 8 ditch points and 8 open water (pond, pit, mere etc.) points at each reserve (Hickling Broad, Stodmarsh and Ham Wall). These surveys were mostly conducted at the same survey points as visited by Andy Godfrey for the aquatic invertebrate surveys. Macrophyte sampling was sometimes undertaken at slightly different locations to the aquatic invertebrate sampling if transect access was more suitable for the macrophyte raking methods (macrophytes needed a 16m transect, aquatic invertebrates needed a 10m transect). Surveys were designed by Donna Harris.

Macrophyte sampling

With each surveyor moving outwards from the centre of the transect, standardised rake pulls of macrophytes were taken every 2m along a 16m bank-side transect (so 8 samples in total). A rake head on a cord was used to take samples of vegetation from the bottom of the water body. The rake was dropped and pulled for one metre along the bed of the water body. The plants were then transferred to a sorting tray and identified. The volume of plant material collected was identified using a graduated bucket. This was repeated at metre intervals until eight samples had been collected, four either side of the transect. Total number of species in a transect and mean plant volume was calculated. We took care to clean plant fragments off the rake between points and reserves to prevent species introductions.

Habitat variables

The date, weather and time were recorded as well as the location ID code at the midpoint of the survey transect.

At the centre of each transect we recorded:

Turbidity (using a turbidity tube)

Bank gradient (in degrees)

Silt depth (measured with metre rule: push in as far as possible - in cm)

Distance to scrub (in m, using rangefinder)

Direction of scrub (note compass direction – in degrees)

Ditch width (estimate by eye or use rangefinder – in m) – ditch points only

Ditch aspect (compass direction looking across ditch – in degrees)

Water depth (using a metre rule – in m)

At the point of dropping the rake we recorded:

Shading, density of trees/scrub and density of emergent plants.

Preparing data for analysis

Discrepancies between sample point GPS locations taken by the RSPB team and Andy Godfrey were clarified by Anna Doeser and Andy Godfrey. The GPS locations, often taken on banks, were not accurate enough for measurement of distance to bank.

Response variable: Total number of macrophyte species recorded over the 8 rake pulls making up a transect (excluding algae/moss).

Explanatory variables:

Table 8.1: Explanatory variables used in analysis

Explanatory variable	Unit	Description
Site		3 levels: Ham Wall, Hickling Broad, Stodmarsh
Turbidity category	Categories	2 levels: low / high(er) than 500 - to allow for sampling points where accurate measurements were not taken (*Note* only 1 value above 500 – SM Open 1)
Turbidity continuous	Turbidity units	Continuous for all values below 500
Bank gradient	Degrees	Slope of the bank nearest to sampling location.
Water depth	Metres	Continuous for all values below 1 metre
Water depth category	Categories	2 levels: shallower / deeper than 1 metre - to allow for sampling points where accurate measurements were not taken (*Note* only 4 values for deeper)
Silt depth	Metres	2 levels: shallower / deeper than 1 metre - to allow for sampling points where accurate measurements were not taken (*Note* only 2 values for deeper)
Silt depth category	Metres	Continuous for all values below 1 metre
Distance to nearest scrub	Metres	Continuous
Scrub direction	Degrees	Continuous
Aspect	Categories	4 levels: all-day / evening / morning / partial
Ditch width	Metres	Ditches only
Emergent vegetation density	Categories	4 levels: dense / medium / sparse / none, from the mean transect score
Plant volume	Cubic cm	Total volume of plants collected over rake pulls.
TDS	ppm	From Andy Godfrey's measurements at the corresponding aquatic invertebrate sample point
pH		From Andy Godfrey's measurements at the corresponding aquatic invertebrate sample point
Area	Square Metres	Calculated from aerial photographs using MapInfo
Perimeter	Metres	Calculated from aerial photographs using MapInfo

Openness	Ratio	Area/Perimeter
Connectivity	Categories	2 levels: partial / full
Algae/moss	Categories	2 levels: yes / no for presence on the transect

Variables that were not included in the final analysis were:

Rain – the effect of rain could not be tested because the differences in occurrence coincided with different sites or were unrecorded. Note rain may affect sampling effort / success.

Sun – the effect of sun could not be tested because the differences in occurrence coincided with different sites.

Water body type – designation as 'ditch' or 'open' was relatively subjective and characteristics differed between sites, therefore actual measurements for water body dimension data (area, perimeter, openness) were used.

Tree / scrub score – this was removed for replicating information in scrub distance.

Minimum, maximum lengths and symmetry of water body-not included as area, perimeter and openness captured this information.

Date/surveyor-no differences worth investigating were found in exploratory analyses

Tree/scrub density-Insufficient variation for analysis

Refining the list of explanatory variables for modelling

Connectivity

To estimate connectivity, the managers for each site made an assessment based on the three criteria: *isolated* = no pipes, no seasonal flooding; *partial* = seasonal flooding, no pipes and *full* = pipes and or open water connection. No water body was designated as isolated.

Plant volume

Volume of plant material collected at each sampling point varied. Larger samples may contain more species (but a strong correlation was not shown). Furthermore, bootstrapping could not be used to control for variation in plant volume, because number of individual plants was not available. Therefore plant volume was included in the models as an explanatory variable.

Ditch width – water body dimension data was used to allow comparisons between 'ditches' and 'open water'. This is more reliable than water body type categories; because some points classed as open water were in large ditches and in reality there are many water bodies between the extremes of linear ditch and large open lake.

Turbidity (categorical) – there was only one example of >500. Turbidity comparisons were limited to those below 500.

Water depth (categorical) – there were insufficient examples of deeper water to allow a comparison. Water level comparisons were limited to those below 1m.

Silt (categorical) – there were insufficient examples of deeper silt to allow a comparison. Silt depth comparisons were limited to those below 1m.

Aspect calculations

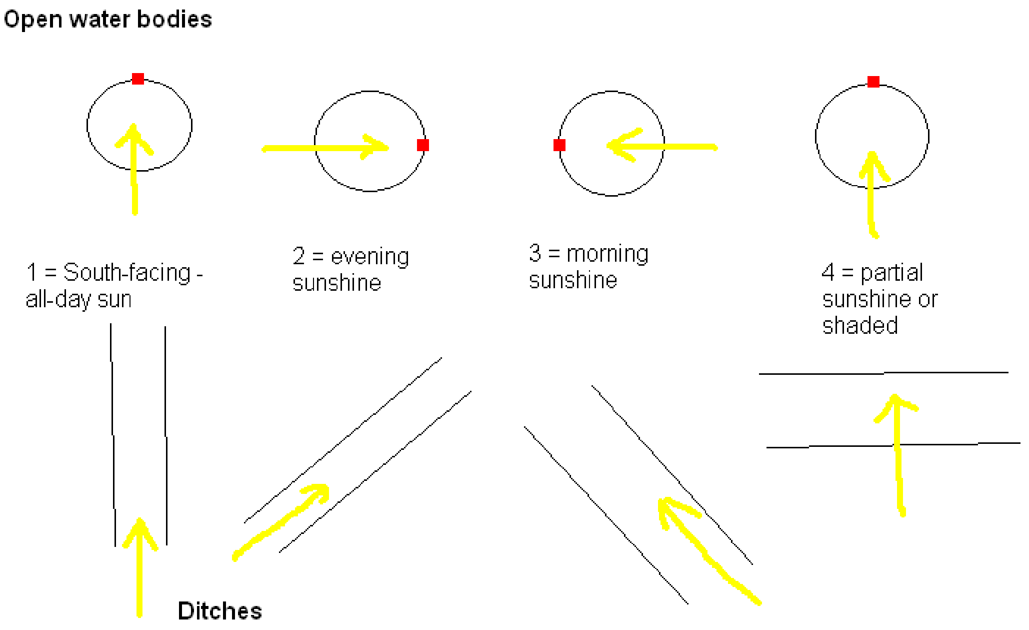

Figure 8.1: How aspect was categorised for aquatic macrophyte transects

To allow comparisons between ditches and open water bodies a four-level variable was created (see diagram above). These groupings were chosen to indicate relative timing and probable warmth of the water through exposure to sunshine, i.e. south facing sample points on open water bodies and ditches running north-south will be fully exposed to sunshine all day and should be warmest etc. The aspect (in degrees) taken at 90º to the sample point were converted as follows:

Table 8.2: Categorisation of aspect for aquatic macrophyte transects

Category	Open water measurement	Open water Orientation	Ditch measurement	Ditch orientation
All day	135-225°	SE - SW	67.5-112.5° or 247.5-292.5°	N - S
Evening	225-315°	SW - NW	112.5-157.5° or 292.5-337°	NE - SW
Morning	45-135°	NE - SE	22.5-67.5° or 202.5-247.5°	NW - SE
Partial	315-45°	NW - NE	157.5-202.5° or 337-22.5°	E - W

Area, perimeter and openness calculations

Polygons of habitat type were drawn by RSPB's CDMU in MapInfo and given a unique identification. The area and edge of these polygons gave "area" and "perimeter". Where water bodies were fragmented into several polygons, these were added. Openness (= area / perimeter), is a relative measure of water-reed edge. These measurements are based upon water body dimensions from the aerial photos and may not reflect prevailing site conditions or conditions at time of sampling as water-levels fluctuate.

Data exploration

Plots of response and explanatory variable were checked for outliers, data distribution and number of zeros. The relationship between each response and explanatory variable were plotted. These were to check for general trends, outliers and whether there were sufficient data for comparisons. To check for interactions the relationships between all explanatory variables were either plotted or tested using chi-square.

Analysis methods

Random Forest models

Random forest is a machine learning algorithm that builds an ensemble of regression trees (i.e. a forest) (Breiman et al 1984). These models were considered to be most suitable for the data as they:

1- Do not require a prior specification of a model to relate explanatory and response variables
2- Have high classification accuracy
3- Can include a large number of predictor variables
4- Automatically include all interactions and variables do not need to be normally distributed
5- Cope well with missing values, outliers and irrelevant predictor variables
6- Comparatively easy to apply and interpret

Random forest uses a subset of the data to build the model (training data) and the remainder to test the model (test data). At each node, (four) variables are tried and the variable that best splits the data is chosen. The process is repeated for these two groups, and so on.

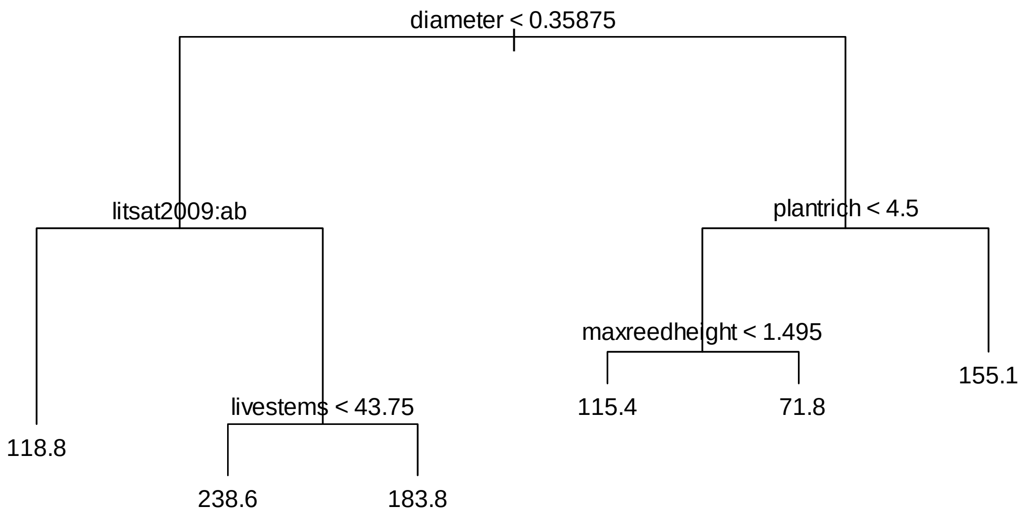

Figure 8.2: Example of a decision tree from a random forest model

To find the importance of each variable, the function rearranges the values, for example by replacing the 3rd row with the 5th, and checks whether the mean squared error increases or not. An increase in the 'percentage increase in mean standard error' indicates that the variable is important; a decrease (negative value) indicates that they are not. In this analysis, a random forest with 4 variables tested at each node (mtry=4), and 500 trees was used. The relationship between each habitat variable and the response variable can be found using the partial plot function, which plots the marginal contribution of each habitat variable to explaining variation in the response variable. Partial plots are presented here alongside plots of the raw data, to view whether any outliers remain in the data that could be skewing the trends.

Explanatory interactions

Explanatory variables with interactions were tested by removing individually from the model (area, perimeter, openness). The effect was compared using changes in the variable importance and model mean R^2 values. Connectivity was strongly linked to site and considered too subjective and was therefore removed from the final model. The explanatory variables were limited by poor weather recording, and only single water depth measurements that did not reflect seasonal variations. Minimum, mean and maximum values of water depths throughout the year may have been more informative.

Map of sampling locations

Figure 8.3: Map of sampling points for aquatic macrophytes at Ham Wall. (n=16, 8 in ditches, 8 in open water)

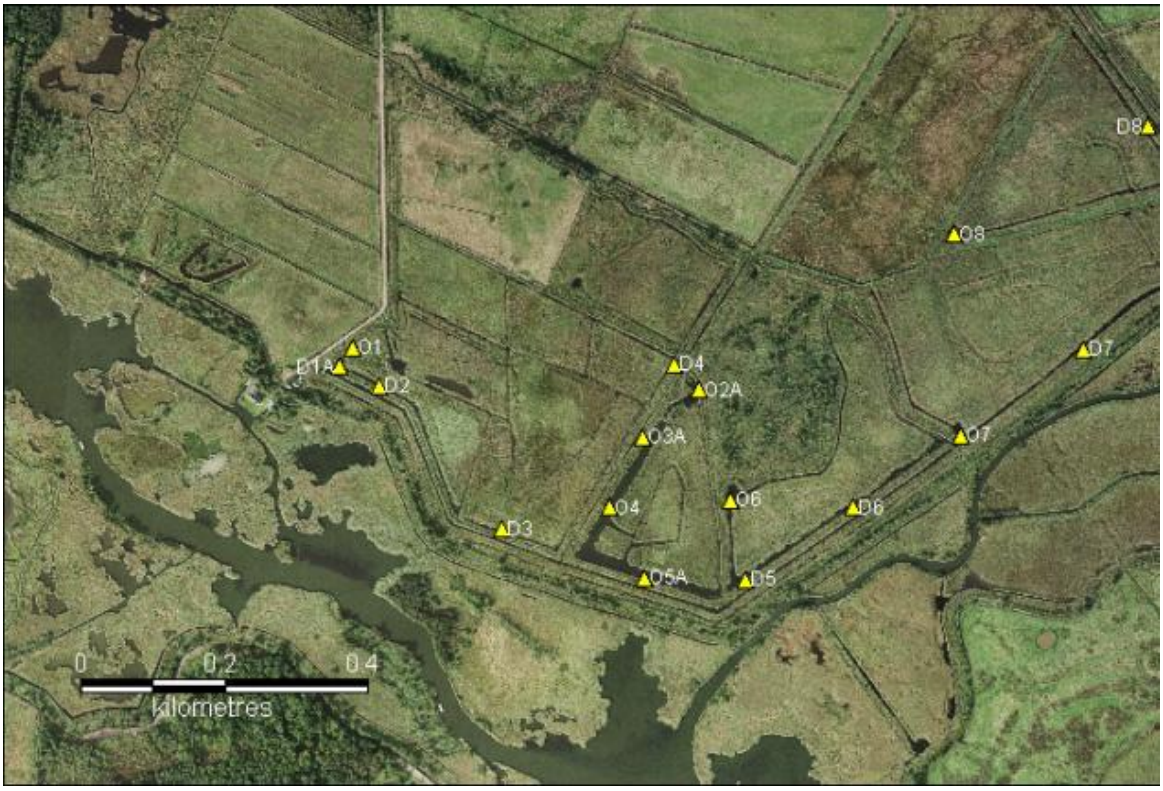

Figure 8.4: Map of sampling points for aquatic macrophytes at Hickling Broad. Note samples were only taken from the Hundred Acre reedbed area not the reedbed surrounding the broad. (n=16, 8 in ditches, 8 in open water)

Figure 8.5: Map of sampling points for aquatic invertebrates at Stodmarsh. Note three additional points were surveyed here (n=19)

RESULTS

What aquatic macrophyte species were found at the reedbed survey sites?

In total, 22 aquatic macrophyte species were identified, as listed below by site. No species with a conservation or rarity status were found.

Table 8.3: Aquatic macrophytes encountered in surveys at each of the three reedbed sites (* species found just at one site)

Ham Wall	Hickling Broad	Stodmarsh
Ceratophyllum demersum	*Ceratophyllum demersum*	*Ceratophyllum demersum*
Ceratophyllum submersum	*Ceratophyllum submersum*	** Chara vulgaris var. papillata*
Elodea nuttallii	*Elodea canadensis*	** Crassula helmsii*
Hydrocharis morsus-ranae	** Hippuris vulgaris*	*Elodea canadensis*
Juncus bulbosus	** Hottonia palustris*	*Elodea nuttallii*
Lemna minor	*Juncus bulbosus*	*Hydrocharis morsus-ranae*
Lemna minuta	*Lemna minuta*	*Juncus bulbosus*
Lemna trisulca	*Lemna trisulca*	** Lemna gibba*
** Persicaria amphibia*	*Myriophyllum spicatum*	*Lemna minor*
Potamogeton natans	*Potamogeton compressus*	*Lemna minuta*
Potamogeton obtusifolius	*Potamogeton natans*	*Lemna trisulca*
** Spyradella polyrhiza*	*Potamogeton obtusifolius*	*Myriophyllum spicatum*
	Utricularia vulgaris	*Potamogeton compressus*
		Potamogeton natans
		** Potamogeton pusillus*
		Utricularia vulgaris

The total number of species was highest at Stodmarsh (16) and lower at Hickling Broad (13) and Ham Wall (12). The number of aquatic macrophyte species raked at each sample point was Ham Wall 3.8 ± 1.5, range: 2-6; Hickling Broad 3.5 ± 1.9, range: 0-7; Stodmarsh 4.1 ± 2.6, range: 0-9. These results show botanical diversity of reedbeds to be limited and this may have impeded the analysis in terms of there only being a small amount of variation in the response variable to explain.

In our study, a total of 22 floating or submerged macrophyte species were identified over 51 sampling points at three sites. This compares to 48 floating or submerged macrophyte species over 565 sampling points in the Buglife survey of grazing marsh ditches at 12 geographic sites.

What habitat conditions are associated with maximum aquatic macrophyte diversity?

The table below summarising the ranges and averages of the different habitat variables measured at each site.

Table 8.4: Habitat variables measured at aquatic invertebrate survey points

Site	Ham Wall		Hickling Broad		Stodmarsh	
	Mean +- SE	**Range**	**Mean +- SE**	**Range**	**Mean +- SE**	**Range**
Area (m^2)	33868 +- 2673.56	11 960 - 58 902	5 309.23 +- 549.38	363.2 - 10 780	68991.2 +- 11072.69	76.87 - 172 100
Aspect (°)	145 +- 12.82	30 - 300	178.44 +- 16.29	30 - 340	185.16 +- 15.27	40 - 330
Bank gradient (°)	40.94 +- 2.36	15 - 80	30.63 +- 2.27	10 - 70	20.76 +- 2.11	3 - 50
Scrub direction (m)	203.75 +- 10.46	30 - 350	168.13 +- 15.81	20 - 350	165.79 +- 4.19	0 - 320
Distance to scrub (m)	49.19 +- 7.19	2 - 132	26 +- 1.75	4 - 44	25.55 +- 0.27	0 - 126
Ditch width (m)	13.38 +- 0.42	9 - 18	6.75 +- 0.19	5 - 9	4.64 +- 0.14	3 - 10
Emergent vegetation (%)	1.98 +- 0.12	0.125 - 3	2.2 +- 0.07	1.125 - 2.875	1.45 +- 2.52	0 - 3
Openness (ratio)	7.62 +- 0.43	4.38 - 14.7	3.29 +- 0.25	1.62 - 6.34	16.81 +- 775.45	0.60 - 48.02
Perimeter (m)	5022.11 +- 362.67	812.9 - 7 490.6	2 487 +- 368.2	83.84 - 6 664	4045.93 +- 0.11	128 - 15 798.8
pH	7.25 +- 0.16	5.3 - 10.2	9.13 +- 0.14	7.8 - 11.6	7.58 +- 0.2	6.7 - 8.7
Plant volume (cm^3)	1.34 +- 0.33	0.004 - 7	1.09 +- 0.18	0.04 - 4.44	1.03 +- 13.52	0 - 4.5
Silt depth (cm)	19.8 +- 2.51	0 - 59	12.71 +- 1.35	0 - 25	18.25 +- 2.24	2 - 55.5
TDS (ppm)	50.38 +- 1.24	35 - 69	38.94 +- 3.05	11 - 90	72.94 +- 2.62	47 - 117
Turbidity (turbidity units)	1.67 +- 0.63	0 - 17	0.38 +- 0.21	0 - 6	87.82 +- 17.76	0 - 500
Water depth (m)	0.54 +- 0.02	0.31 - 0.73	0.5 +- 0.03	0.22 - 0.84	0.34 +- 0.05	0.01 - 1.22

The following habitat variables differed between sampling points at the three sites:

- Hickling Broad points were closer to scrub
- Water body areas around sampling points were highest at Stodmarsh, then Ham Wall, then Hickling Broad
- Sampling points at Ham Wall were in wider ditches
- Turbidity only reached high values at Stodmarsh
- TDS was highest at Stodmarsh and lowest at Hickling Broad

All other variables were over a similar range at the three sites.

Range of habitat variables measured

The maximum ditch depth sampled was 1.22 m. I would expect there to be ditches deeper than this around the site, and perhaps if they had been sampled, a greater effect of water depth would have been seen. A good range of all other variables were sampled. Habitat variables that were not measured that would be considered important are water flow and ditch history. Flow, even temporary flow, can wash away silt and organic matter and disperse plant diaspores. Dispersal is very important in ensuring that long-lived perennial species like pondweeds can recolonise after over-zealous dredging. Ditch history is very important since the best ditches are the ones that were good before. In some cases ditches have acquired species over many decades and these will take a long time to recolonise. Reinvasion will require material from populations upstream flowing into the ditch again, and these populations may no longer exist. Clonal stands of species may have survived from before the ditch was cut and once gone they may never recolonise. Therefore ditch cleaning should not be done without great care.

Habitat variables associated with number of aquatic macrophyte species

The relative importance of each habitat variable is shown in the figure below, for all sites analysed together and for each site analysed individually. No habitat variables were consistently important across analysis of all three sites together and each site separately in explaining variation in number of aquatic macrophyte species between sampling points. This implies that within the range surveyed, no single overwhelming habitat variable influences the diversity of aquatic macrophytes.

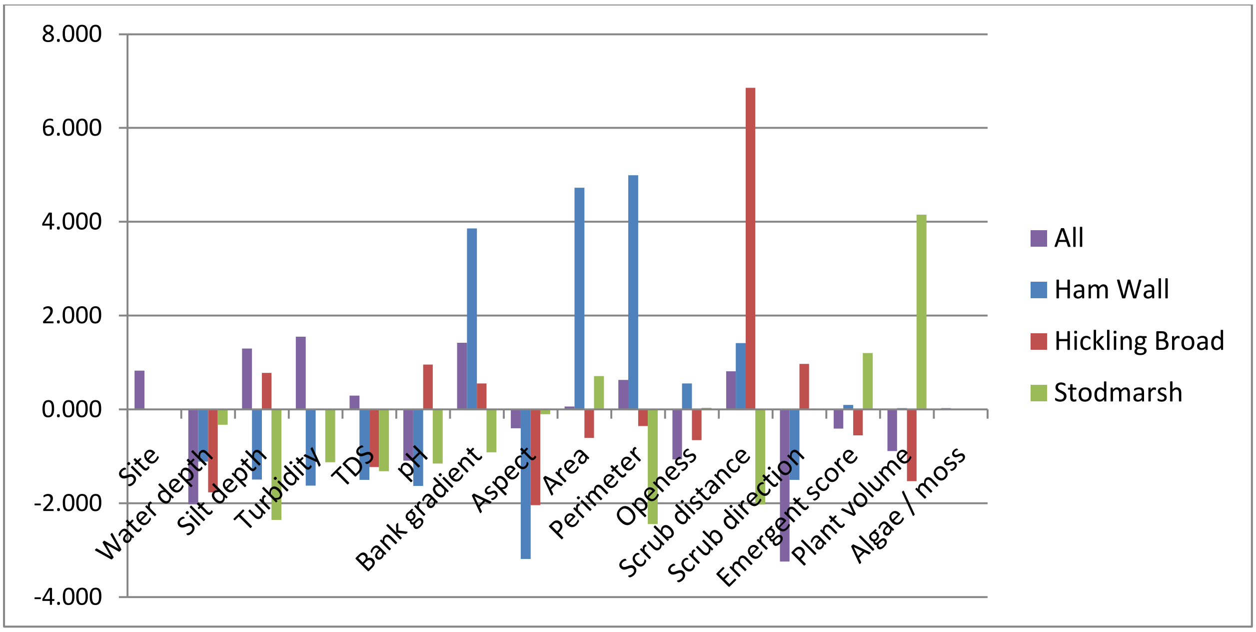

Figure 8.6: The importance of each habitat variable from the mean % increase in mean standard error (from ten Random Forest models) by site.

Table 8.5: The mean % increase in mean standard error (from ten Random Forest models) by habitat variable and site for the number of aquatic macrophyte species

Habitat variable	**Ham Wall**	**Hickling Broad**	**Stodmarsh**	**All**	**Comments**
Site	NA	NA	NA	0.825	***
Water depth (m)	-1.110	-1.770	-0.325	-2.019	Not important
Silt depth (cm)	-1.494	0.776	-2.355	1.299	*
Turbidity	-1.621	0.000	-1.124	1.552	Site interaction
TDS	-1.500	-1.231	-1.314	0.298	Site interaction
pH	-1.634	0.955	-1.154	-1.095	Inconclusive
Bank gradient (º)	3.860	0.551	-0.912	1.424	Inconclusive
Aspect	-3.186	-2.040	-0.100	-0.399	Not important
Area (m^2)	4.724	-0.607	0.709	0.063	Inconclusive
Perimeter(m)	4.989	-0.353	-2.442	0.629	Inconclusive
Openness	0.556	-0.655	0.034	-1.064	**
Scrub distance (m)	1.418	6.854	-2.030	0.814	**
Scrub direction (º)	-1.502	0.972	0.010	-3.243	Inconclusive
Emergent score	0.097	-0.552	1.205	-0.408	**
Plant volume (cm^3)	0.026	-1.525	4.154	-0.887	**
Algae / moss	0.000	0.000	0.000	0.025	Site interaction
Mean R^2 value	**0.926**	**0.933**	**0.954**	**0.889**	

Habitat variables that were not important

Surprisingly, water depth and aspect were not important in explaining variation in aquatic macrophyte diversity either when all sites were analysed together or for each site separately. This may be due to the range of depths and aspects measured all being favourable to aquatic macrophyte growth. It may also be due to the limited variation within the response variable reducing our ability to detect trends. There is also a possibility that long-term changes in water level, which were not measured, are more important than water depth at one particular point in time. We would have expected aspect to be important since sufficient light is important for aquatic plant growth.

Factors important when all sites were analysed together

A number of variables were important when all sites were analysed together: turbidity, bank gradient, silt depth, site, scrub distance, perimeter, TDS, algae/moss, area. Bank gradient, silt depth, scrub distance, perimeter and area appeared to show relationships with aquatic macrophyte diversity that were not confounded by site. However turbidity, total dissolved solids and algae/moss reflected inter-site differences and were not important within sites. Turbidity was minimal at Ham Wall and Hickling Broad but moderate at Stodmarsh. Total dissolved solids increased, step-wise, from Hickling Broad to Ham Wall to Stodmarsh where the highest levels were found.

At Ham Wall algae was present at all sample points, only 5 of 16 sample points had algae at Stodmarsh and none had algae Hickling Broad. These habitat variables may be important but being confounded by site, they could not be adequately tested here.

Bank gradient

The partial plot showing the relationship between bank gradients and aquatic macrophyte diversity across all sites suggests steeper bank gradients were associated with higher aquatic macrophyte diversity. However this trend did not hold at the individual site level. Bank gradient was important at Ham Wall where both shallow and steep banks were associated with high diversity, and at Hickling Broad where steep banks were associated with high diversity. It is probable that shallower waters experience more sunshine and warmth, beneficial to plant growth, and are therefore optimum habitat. However, in order to minimise competition, species exploit niches that minimise overlap. Therefore a range of depths would be good to provide the maximum number of niches. By clumping all aquatic macrophyte species, regardless of their type (floating, emergent, submerged), this may have prevented a clear pattern of species diversity with gradient. Also it may be the bank gradient under the water which is important rather than the gradient above land, since we are looking at submerged plants.

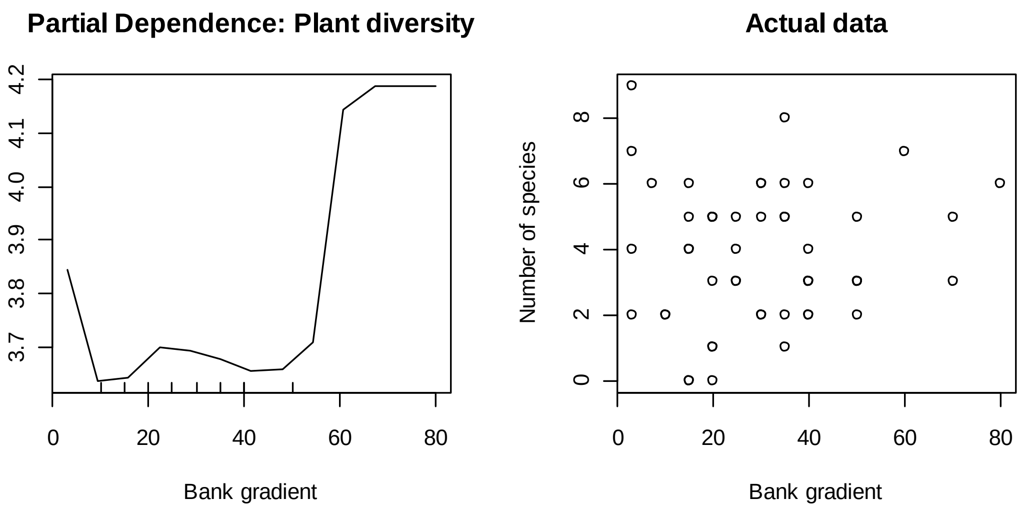

Figure 8.7: relationship between bank gradient and number of aquatic macrophyte species across all sites

Silt depths below 20 cm were associated with higher aquatic macrophyte diversity, but this may have been because more sampling points fell into this range. This trend was also seen at Hickling Broad alone, but silt depth was not an important factor at the other two sites. Silt depth depends upon the rate of accretion, and thereby time since the water body was established or dredged. This pattern may therefore reflect changes in species colonisation, dominance and succession. We would expect silt depth to be inversely correlated with aquatic macrophyte diversity especially when silt includes organic matter. Free-floating and rooted perennial plants survive in silt but the latter struggle to reproduce. Open substrates are needed for germination (including all the annuals, especially stoneworts) and for the establishment of vegetative ramets. The whole raft of species can potentially be excluded by silt. Organic matter, such as leaves can also break down anaerobically and release methane which kills off rooted plants (Tim Pankurst, pers. comm.).

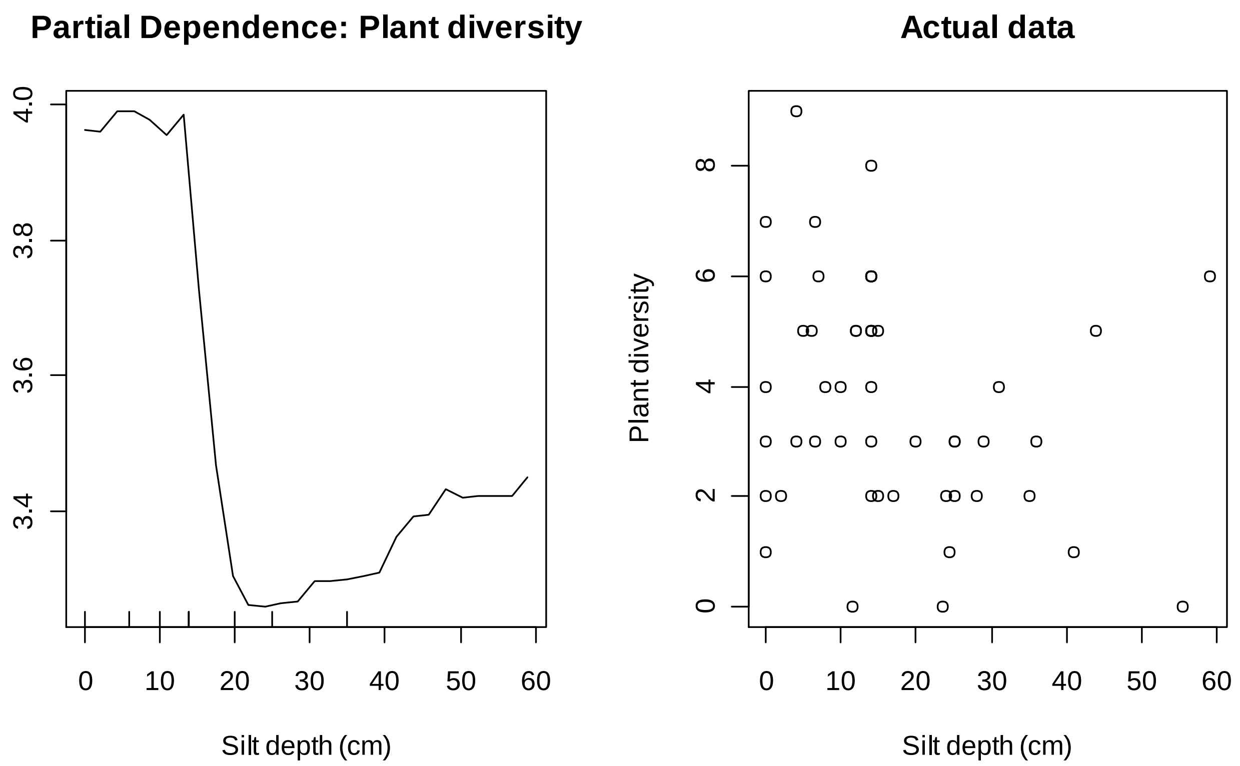

Figure 8.8: Relationship between silt depth and number of aquatic macrophyte species across all sites

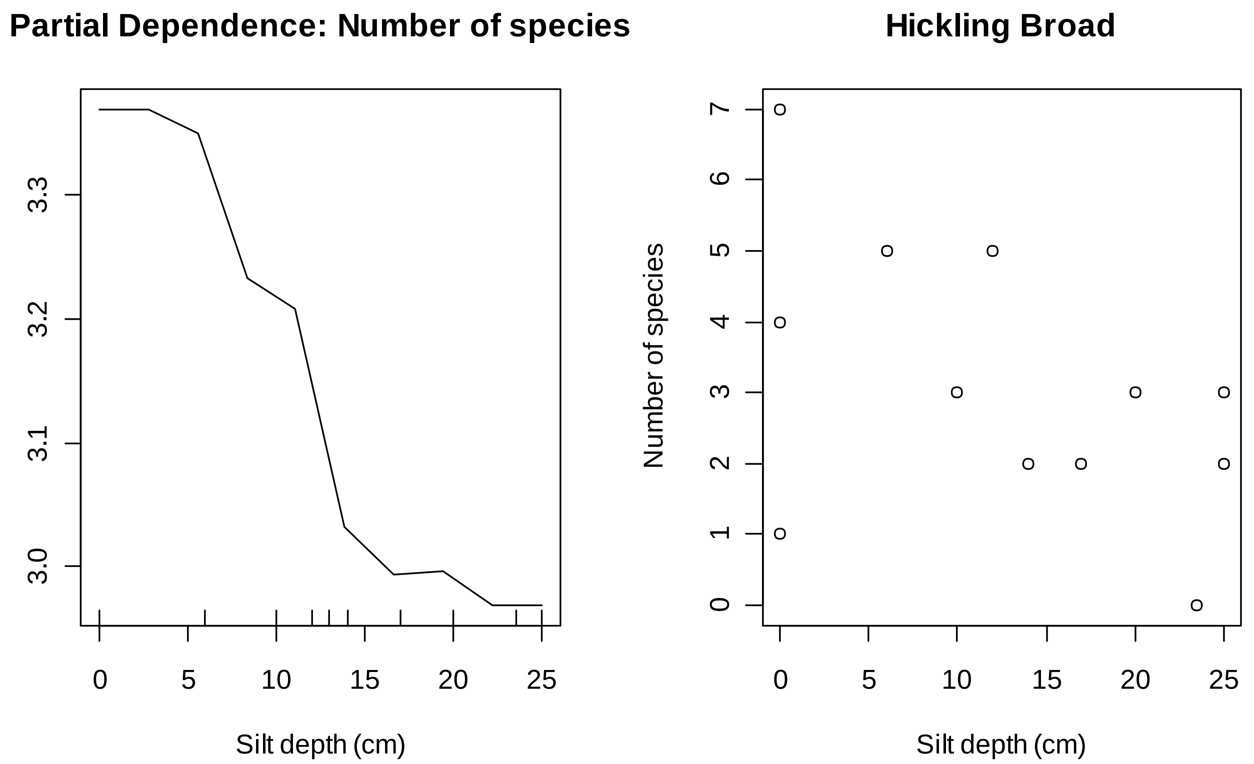

Figure 8.9: For silt depth (cm), the partial and scatter plots of the data for the number of aquatic macrophyte species at Hickling Broad.

Site was one of the most important explanatory variables, showing how each site had different characteristics. Aquatic macrophyte species diversity was, on average, highest at Stodmarsh and lowest at Hickling Broad (figure 8.10).

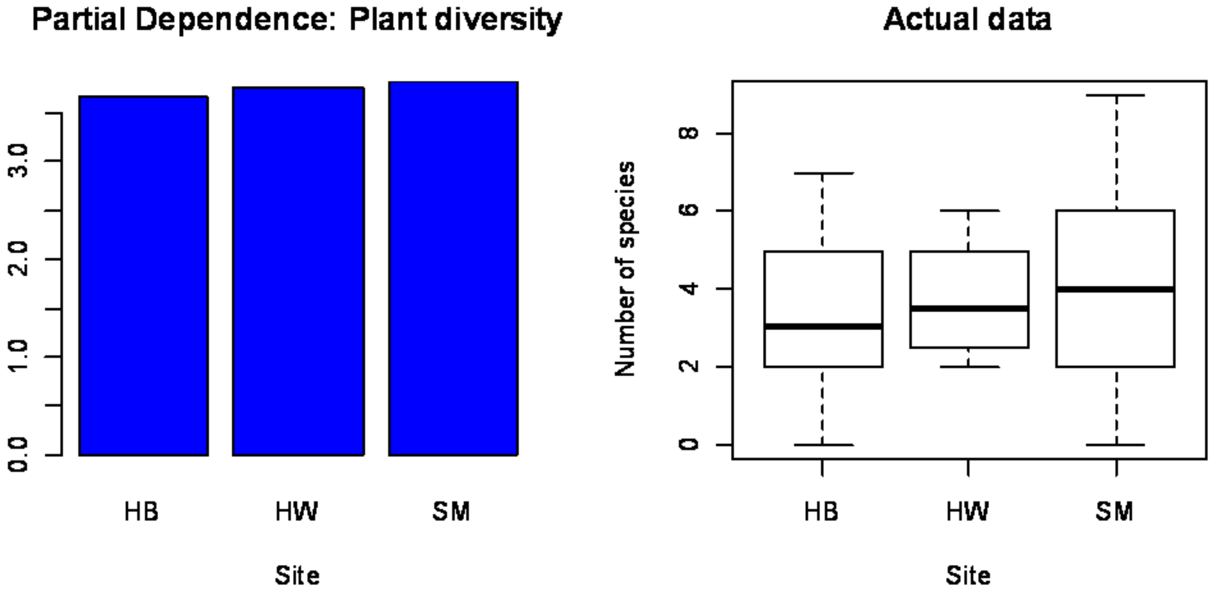

Figure 8.10: For site, the partial plot (left) and box-and-whisker-plot of the data (right) for the number of species.

Scrub distance

Aquatic macrophyte diversity was greater when scrub was further from the sampling point, at all sites except Stodmarsh. The number of aquatic macrophyte species was predicted to be lowest beneath scrub and to rapidly increase with distance up to 40 metres with little further affect (figure 8.11). This pattern may reflect succession from wetland to scrub. The proximity of trees and scrub can have a negative effect due to shading and build up of organic debris leading to methane production.

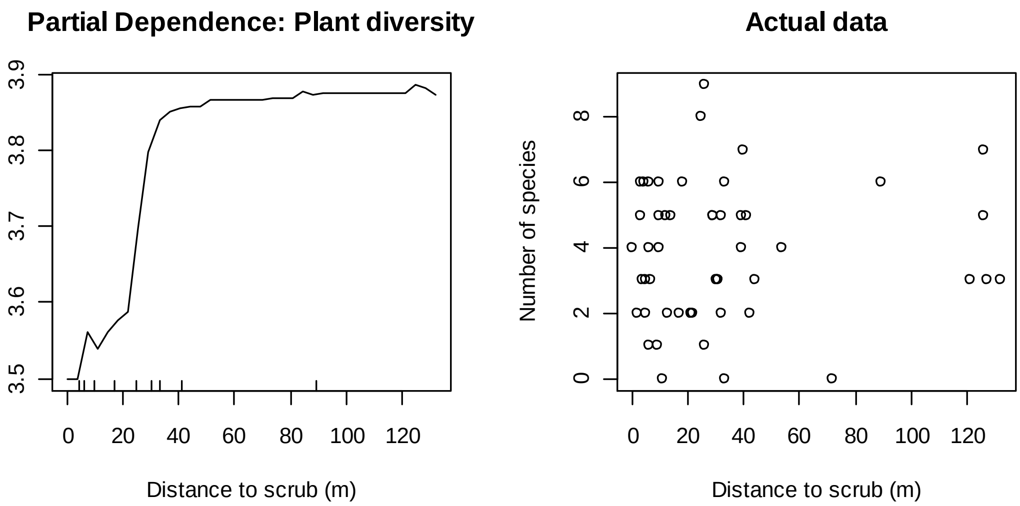

Figure 8.11: Relationship between distance to scrub and number of aquatic macrophyte species at all sites together

Given the negative relationships with silt depths and scrub, management that involves desilting and removing scrub would seem sensible. Work at Woodwalton Fen (Pankhurst 2002) showed that the time since last dredge had a large effect on the ditch flora. Ditches that had been dredged 3-4 years ago supported particularly high aquatic macrophyte diversity. Ditches that were left undredged for longer were also valuable in supporting a different range of species. Therefore management that achieves a range of age-classes with 3-4 year old ditches being most prevalent would be optimal.

Perimeter

Across all sites analysed together, points in water bodies with shorter perimeters were associated with higher diversity of aquatic macrophytes. At an individual site level this was only important at Ham Wall, where the same trend was also seen. This implies water bodies with less edge could be associated with higher aquatic macrophyte diversity, but further study is needed to confirm this. Openness (ratio of edge to area) was not very important in explaining variation in aquatic macrophyte diversity.

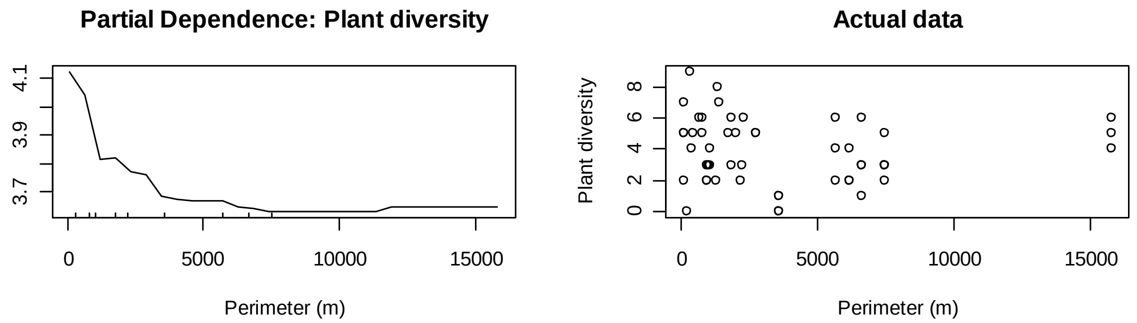

Figure 8.12: Relationship between perimeter and aquatic macrophyte diversity

Area

The plots show high aquatic macrophyte diversity could be found across a range of water body areas. No optimal area emerged. Area was also important in explaining diversity at Ham Wall and Stodmarsh, but no clear optimal area of water body was found either.

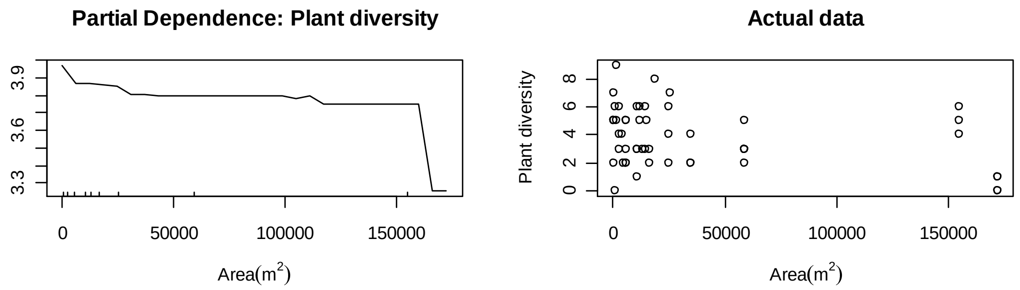

Figure 8.13: Relationship between water body area and aquatic macrophyte diversity

Most important habitat variables at individual sites

Since site was such an important factor, each site was analysed individually, however only 16 data points are available for each site, so this analysis is limited by small sample size.

Ham Wall

Perimeter, area and bank gradient were the most important factors describing variation in aquatic macrophyte diversity. The marginal contribution of these factors to explaining overall variance is given in the partial plots below. Smaller areas and shorter perimeters appeared to be associated with high aquatic macrophyte diversity, along with both steep and shallow bank gradients. However high aquatic macrophyte diversity was found for a wide range of values for these habitat variables and a larger sample size would be needed to verify these results.

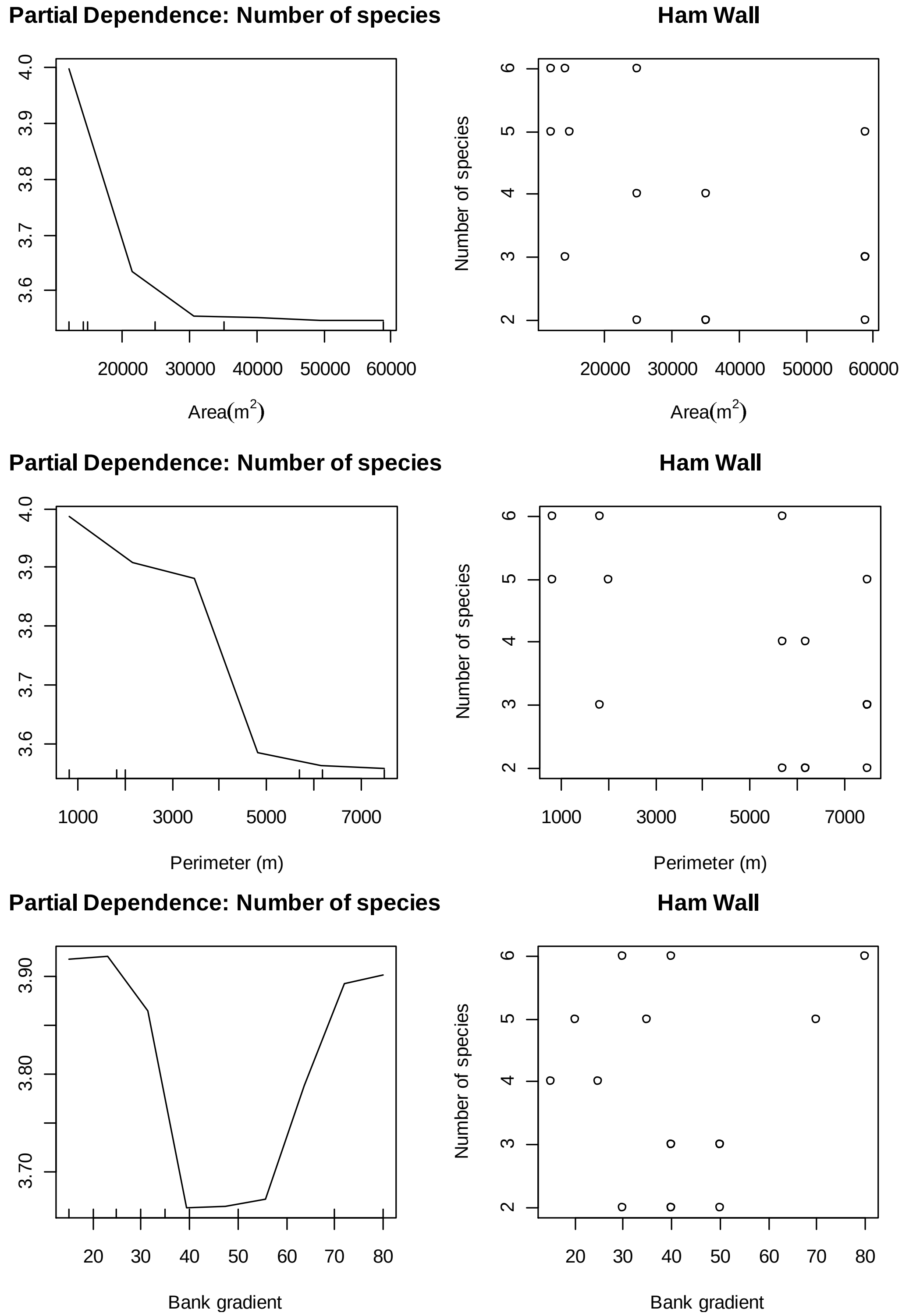

Figure 8.14: partial plots and scatter plots of the top three habitat variables in explaining variation in aquatic macrophyte diversity at Ham Wall

Hickling Broad

Scrub distance had a large influence at Hickling Broad, perhaps because sampling points were closer to scrub at this site. Points more than 30 m away from scrub were associated with lower aquatic plant diversity (as in the analysis of all sites together). However the influence of scrub at this distance is negligable so this is either a spurious result or indicative of some other change in succession. Scrub direction, pH and silt depth were also important, but much less so than scrub distance. Scrub in a direction that gave evening shade (135-225) rather than morning or all day shade was associated with higher macrophyte diversity. However only three sampling points in the direction that would give evening shade were considered close enough to have a shading influence (10 m or less away from water body) so with such a small sample size, valid conclusions cannot be drawn. Shallower silt depths allowed but did not guarantee higher aquatic macrophyte diversity. There was not a clear trend between pH and aquatic macrophtye diversity.

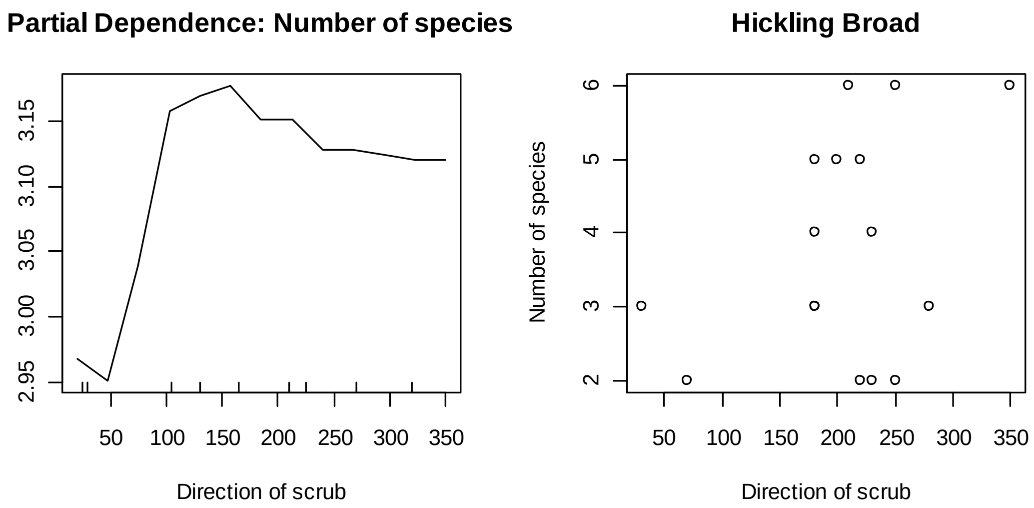

Figure 8.15: partial plots and scatter plots of direction of scrub and aquatic macrophyte diversity at Hickling Broad

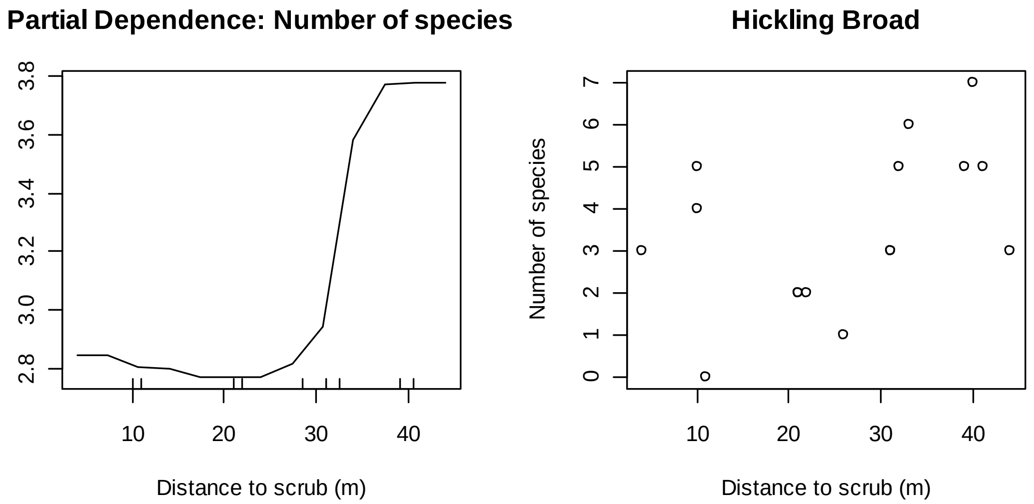

Figure 8.16: partial plots and scatter plots of distance to scrub and aquatic macrophyte diversity at Hickling Broad

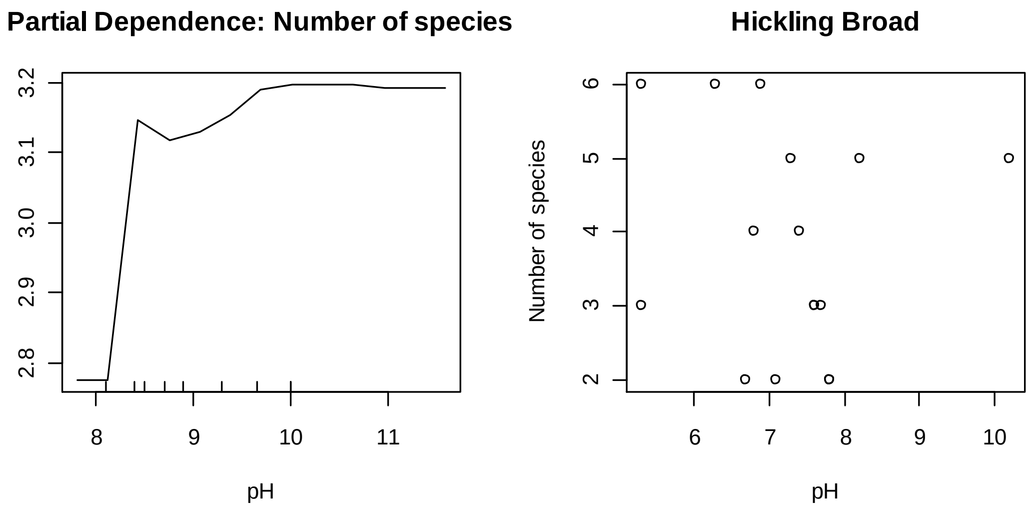

Figure 8.17: partial plots and scatter plots of pH and aquatic macrophyte diversity at Hickling Broad

Stodmarsh

Plant volume was the most important factor at Stodmarsh, followed by emergent score and area. Plant volume was included as an explanatory variable to evaluate its influence on the number of aquatic macrophytes sampled. At Stodmarsh, samples over 0.5cm^3 had greater aquatic macrophyte diversity. This trend was also seen at Ham Wall and over all sites together. The rake sampling was standardised so this is unlikely to be an effect of more sampling effort. It is more probable that plant volume is a function of the number of species present. Therefore water bodies with a greater volume of plants in them were more likely to contain more plant species.

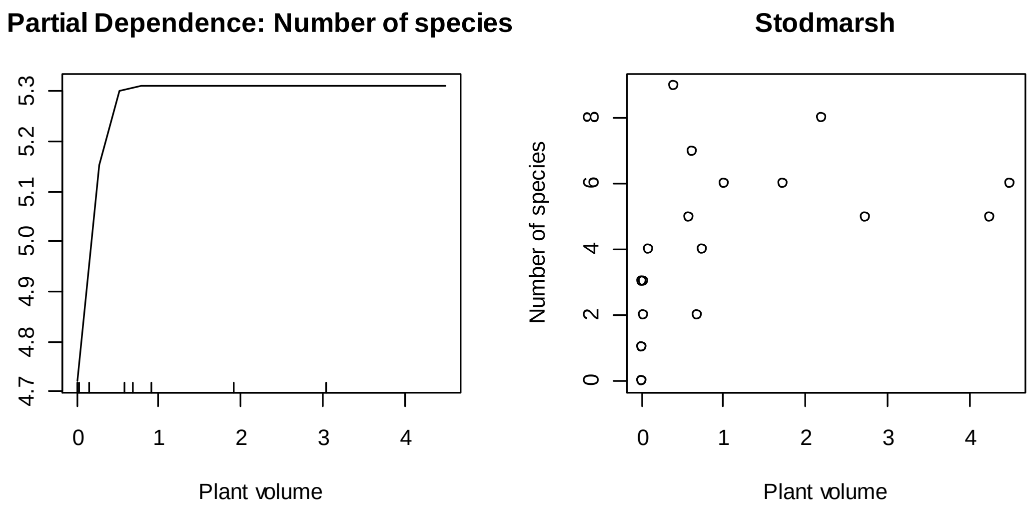

Figure 8.17: For plant volume (cm^3), the partial and scatter plots of the data for the number of species at Stodmarsh

Two extremes of water body area were sampled at Stodmarsh, and fairly high diversity was seen in both, however slightly higher diversity was seen in smaller water body areas.

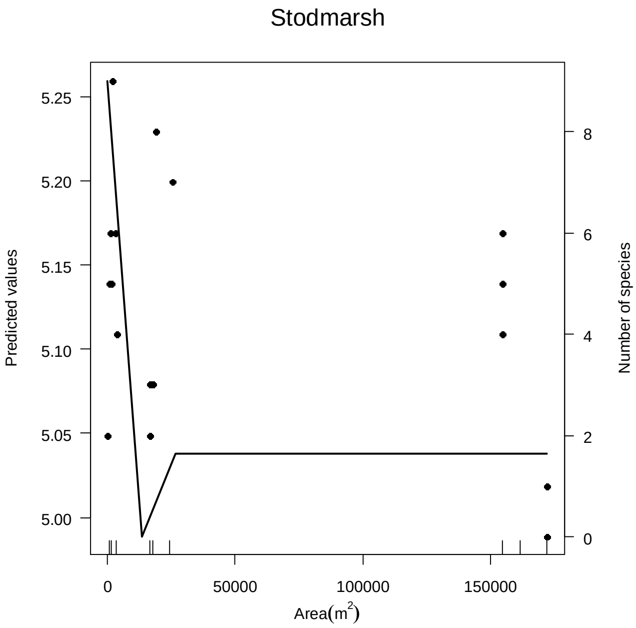

Figure 8.18: Relationship between area of water body and number of aquatic macrophyte species (raw data and partial plot from random forest analysis are shown)

Aquatic macrophyte diversity was higher at points where emergent diversity (density of reed, rush and sedge above the water) was not classified as dense. This fits with expectations. At Ham Wall the category "sparse" emergent vegetation had a higher score than "dense" "medium" or "none". That the category 'none' was not important may be due to the limited data for this category (Ham Wall, n=1; Stodmarsh, n=5).

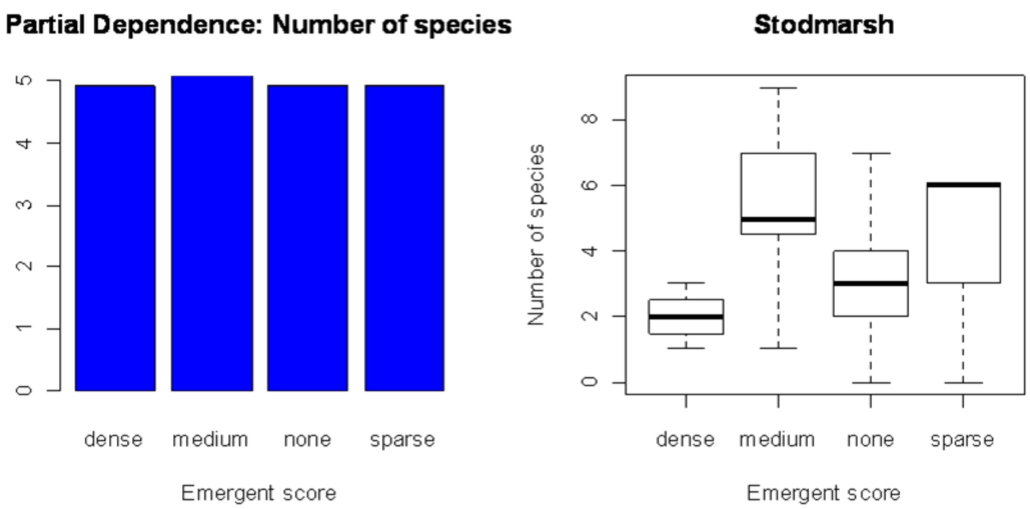

Figure 8.19: For emergent score, the partial plot (left) and box-and-whisker-plot of the data (right) at Stodmarsh.

Although turbidity was more varied at Stodmarsh than other sites, it was not an important factor in explaining variation in aquatic macrophyte diversity and did not show clear trends.

References

Breiman, L., Friedman, J. H., Olshen, R. A., & Stone, C. J. (1984). *Classification and regression trees.* Monterey, CA: Wadsworth & Brooks/Cole Advanced Books & Software.

Drake, C.M, Stewart, N.F., Palmer, M.A. & Kindemba, V. L. (2010) The ecological status of ditch systems: an investigation into the current status of the aquatic invertebrate and plant communities of grazing marsh ditch systems in England and Wales. Technical Report. Buglife – The Invertebrate Conservation Trust, Peterborough.

Pankhurst (2002) Ditches of Woodwalton Fen NNR - Botanical Survey. Report to Natural England

White, G. (2004) Reedbed design and establishment. RSPB Advice Note.

GPS locations of aquatic macrophyte sampling points

Sampling point code	Easting	Northing	Date
HWAISD1	346812	140207	13-Jul-09
HWAISD2	346960	140347	13-Jul-09
HWAISD3	346538	140392	13-Jul-09
HWAISD4	346750	140695	13-Jul-09
HWAISD5	346521	140619	13-Jul-09
HWAISD6	346351	140606	13-Jul-09
HWAISD7	346042	140388	13-Jul-09
HWAISD8	345682	140519	13-Jul-09
HWAISO1	346618	140696	13-Jul-09
HWAISO2	346541	140694	13-Jul-09
HWAISO3A	346174	139720	03-Aug-09
HWAISO4	345901	139977	13-Jul-09
HWAISO5	345840	139950	13-Jul-09
HWAISO6	345801	140148	13-Jul-09
HWAISO7	345770	140177	13-Jul-09
HWAISO8A	345650	140213	03-Aug-09
SMAISD1	622592	161349	16-Jul-09
SMAISD2	622651	161417	16-Jul-09
SMAISD3	622724	161768	16-Jul-09
SMAISD4	622615	161762	16-Jul-09
SMAISD5	622213	161796	16-Jul-09
SMAISD6	623060	162718	16-Jul-09
SMAISD7	623393	162842	16-Jul-09
SMAISD8	623169	162487	16-Jul-09
SMAISO1	622340	161253	16-Jul-09
SMAISO2	622301	161565	16-Jul-09
SMAISO3	622237	161664	16-Jul-09
SMAISO4	623138	162535	16-Jul-09
SMAISO5	623257	162504	16-Jul-09
SMAISO6	623552	162761	28-Jul-09
SMAISO7	623393	162438	16-Jul-09
SMAISO8	623411	162316	16-Jul-09
SMMAC01	622286	161274	27-Jul-09
SMMAC02	622233	161358	27-Jul-09
SMMAC03	623718	162386	28-Jul-09
HBAISD1A	642856	321316	31-Jul-09
HBAISD2	642910	321290	21-Jul-09
HBAISD3	643080	321090	21-Jul-09
HBAISD4	643320	321320	21-Jul-09

HBAISD5	643420	321020	21-Jul-09
HBAISD6	643570	321120	21-Jul-09
HBAISD7	643890	321340	21-Jul-09
HBAISD8	643980	321650	21-Jul-09
HBAISO1	642873	321342	21-Jul-09
HBAISO2A	643356	321284	31-Jul-09
HBAISO3A	643278	321218	31-Jul-09
HBAISO4	643230	321120	21-Jul-09
HBAISO5A	643279	321022	31-Jul-09
HBAISO6	643400	321130	21-Jul-09
HBAISO7	643720	321220	21-Jul-09
HBAISO8	643710	321500	21-Jul-09