THE BROADS ANNUAL WATER PLANT MONITORING
2014 – 2018

Broads Authority

The Broads Annual Water Plant Monitoring: 2014 – 2018

Draft report

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EXECUTIVE SUMMARY

The Broads Authority has surveyed the water plant communities supported by broads since 1983. The Broads Annual Water Plant Monitoring programme has provided information on the diversity of species and a measure of abundance. The programme has consistently surveyed key broads, such as Hickling Broad (a prime navigation site with high recreational value) and Cockshoot Broad (undergone restoration measures), providing long term datasets. Between 1983 and 2013, a transect-based technique was used for the monitoring programme. Due to limitations in the efficiency of the methodology with the improvements in water plants generally across the Broads, a new points sample based technique was developed and implemented. Point sample surveys have been conducted since 2014.

Based on each broad's area of open water, the ideal number of sample points was calculated and the location of the points selected based on a grid approach. The point sample allows for greater consistency between surveys and provides robust data for analysis of the long term datasets. At each broad surveyed, the sample point was located using GPS and two five metre hauls of a double-headed rake was undertaken (north and south). All water plant species gathered were recorded along with an abundance score in 10% increments (10% - low; 100% - high). A 1% score was given to samples with trace amounts of plants. The two scores were combined to provide an overall score for each sampling point.

The overall abundance of water plants (excluding macro-algae and duckweeds), abundance of Section 41 species and species richness (number of species) at each point was analysed to look at possible trends in the point sample surveys between 2014 and 2018. All data gathered from all broads combined, data from riverine broads and isolated broads was analysed by year using Kruskal-Wallis and Mann-Whitney tests. In addition, 17 individual broads with sufficient data were also analysed for trends over the five year period.

No statistically significant trends were recorded for all broads, riverine broads and isolated broads combined over the five year dataset. Of the 17 individual broads analysed, significant differences were revealed at ten broads; Alderfen Broad, Cockshoot Broad, Cromes Broad, Decoy Broad, Heigham Sound, Martham Broad North and South, Upton Great and Little Broads. Cockshoot and Decoy, along with Hickling and Rockland had general increasing trends for water plant abundance. The water plant abundance of Alderfen, Cromes, Upton Great and Little fluctuated with no consistent pattern between 2014 and 2018. Martham Broad North and Martham Broad South, along with Whitlingham Great Broad, exhibited five year trends which could be considered as decreasing. However, the scores for the Martham Broads remain high in comparison to other broads in the Broads Annual Water Plant Monitoring programme.

1 Introduction

1.1 Background information

The Broads Authority (the Authority hereafter) has monitored aquatic macrophytes (water plants hereafter) annually at numerous broads within its Executive Area since 1983. The water plant monitoring programme has provided data on species richness (number of species) and a measure of abundance of the water plants present in each of the broads surveyed. The surveys have created long-term datasets, provided vital information in monitoring the response of a number of broads to restoration measures such as suction dredging and / or biomanipulation and are contributing to scientific reviews of key broads (http://www.broads-authority.gov.uk/__data/assets/pdf_file/0006/549114/Broads-Lake-Review.pdf).

Following increased water plant growth across many of the broads, it was acknowledged that the transect methodology (employed until 2013), was difficult to implement in a robust and consistent manner required for analysis of long-term trends. Following consultation with Natural England, Environment Agency, Dr Nigel Wilby (University of Stirling) and other researchers, a point based survey methodology was developed. Between 2011 and 2013, the point sample survey was conducted alongside the transect surveys. The purposes of the concurrent surveys was to understand if the data gathered was directly comparable and would allow long-term trend analysis. Whilst research undertaken by Dr Nigel Wilby, revealed the data gathered by the two techniques was not directly comparable, the point based technique was adopted as the method for the Broads Annual Water Plant Monitoring programme (Monitoring programme hereafter).

1.2 Aims & objectives

The main objectives in the annual programme are to monitor key broads with long-term datasets, those that have undergone restoration measures or those that are known to be experiencing a change in their water plant community. Broads that have not received restoration efforts or are stable (with or without water plants) are monitored on a less frequent basis. When resources allow, the monitoring of sites not previously surveyed is an ongoing objective.

The general aim of the Monitoring programme is to monitor water plant growth and provide an assessment of the condition, or health, of the broads and waterways within the Broads. The Monitoring programme also provides an assessment of Section 41 species, true water plants 'of principal importance for the conservation of biodiversity in England' (The Natural Environment and Rural communities [NERC] Act 2006'.

Two types of surveys are undertaken as part of the Monitoring programme, point samples surveys to assess species diversity and provide a measure of abundance supported by a broad or stretch of river and hydroacoustic surveys, which uses sonar technology to estimate cover and volume of water plants along transects.

The purpose of this report is to present an assessment of the data gathered over five years of point sample surveys in broads between 2014 and 2018 to determine any significant trends. The standard reporting of the 2018 Monitoring programme is appended to this document.

The data gathered through the water plant and hydroacoustic surveys and presented within these reports are used to:

- Report the status of conservation priority species, e.g. certain stoneworts and Holly-leaved naiad (Section 41 species)
- Assess the condition of designated sites (SSSIs) and WFD waterbodies in partnership with NE and EA respectively.
- Assess the success of restoration measures such as catchment or in-lake projects by managers and research scientists as well as assessing long-term trends
- Assess the impact of and ability to cut water plants to allow the safe passage of boats

1.3 Report structure

To present the assessment of the point sample data gathered between 2014 and 2018 and the findings of the 2018 Monitoring programme, the report has been structured in the following way:

- **Introduction**. This provides general background information and aims of the Monitoring programme;
- **Methodology**. This details the design of the point sample surveys, its methodology and the broads surveyed and the subsequent analysis;
- **Results**. The presents the analysis of the data from the Monitoring programmes between 2014 and 2018;
- **Overview**; and
- **Appendices**. These include the point samples from the 2018 annual water plant survey and hydroacoustic survey reports.

2 Methodology

2.1 Survey design

The point sample survey was designed in consultation with Dr Nigel Wilby using Broad's species accumulation data. The data generated a relationship (y = 4.6242ln(x) + 17.149) between the area of the open water of a broad and the required number of points to be sampled (see Figure 1). Using ArcGIS, the area of open water of each broad to be surveyed was measured in hectares (ha) and the number of sample points calculated. Once the required number of points was calculated, a grid system was applied over an aerial image of the open water areas of each broad. Sample points were set equidistant from each other and the co-ordinates generated (see Figure 2). The maps and sample point co-ordinates were loaded onto a Samsung tablet for the survey teams to use.

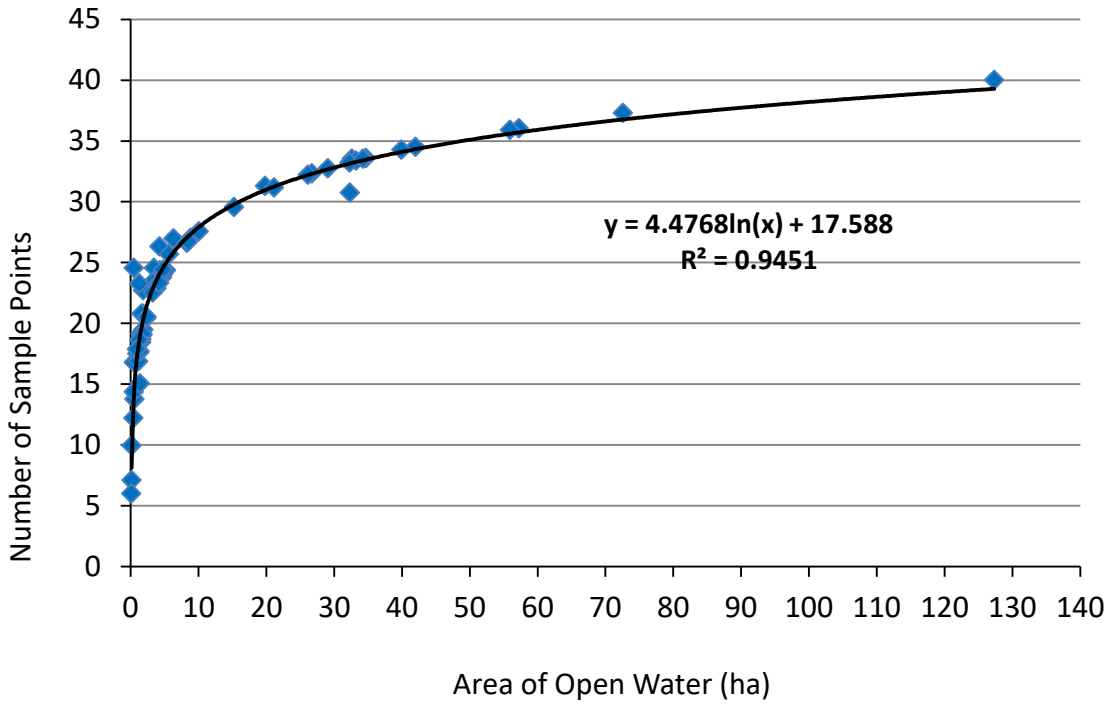

Figure 1. The relationship between the area of open water and the required number of points sampled.

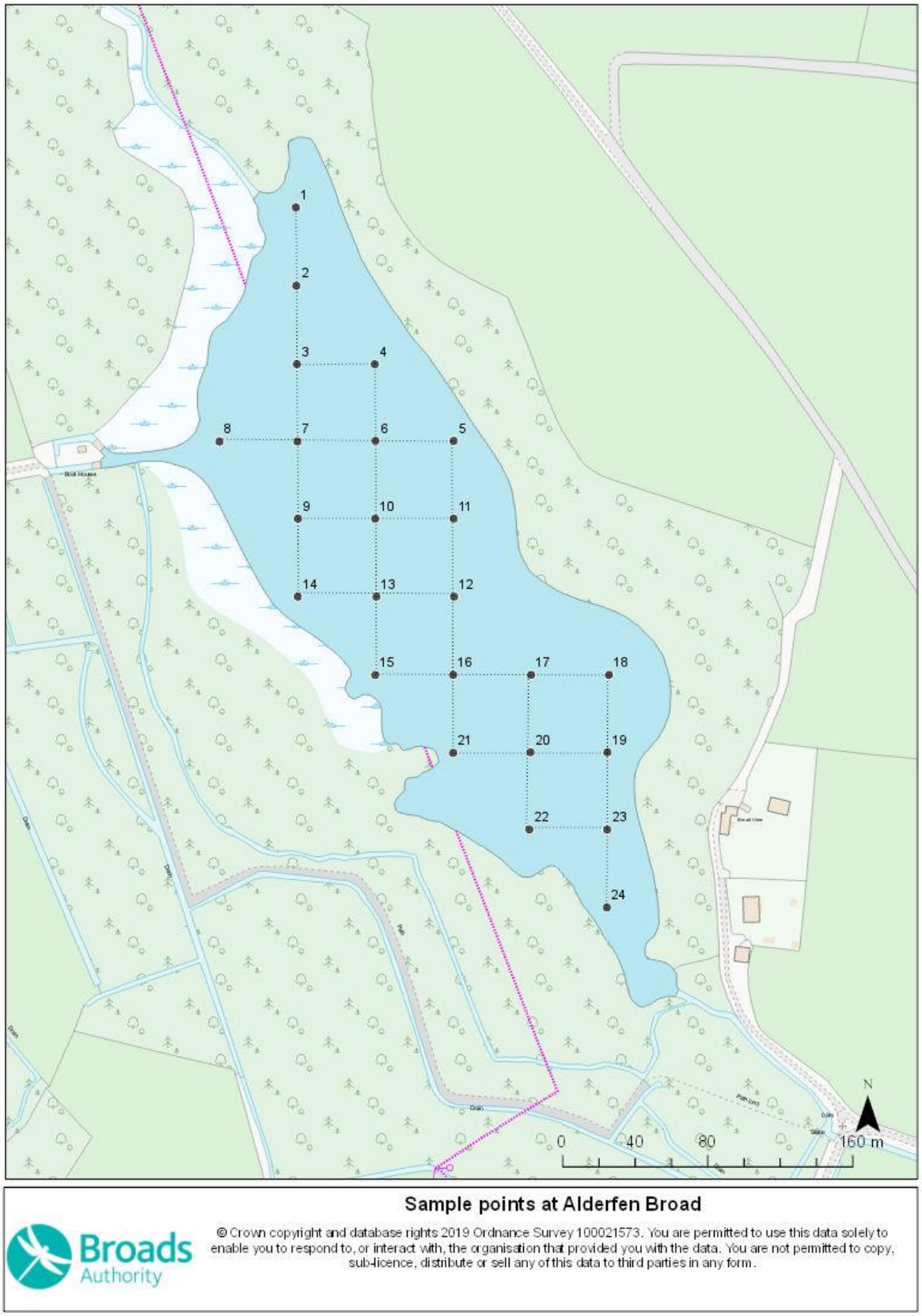

Figure 2. Map showing the sample points of Alderfen Broad.

The broads sampled in the Monitoring programmes between 2014 and 2018 are presented in Table 1. Surveys were conducted during the summer period, July to September.

2.2 Point sample survey technique

At each broad, the surveyors used the maps and grid references on the Samsung tablet and GPS to navigate by boat to each of the sample points. Once within 5 m of the plotted grid reference, mud weights were deployed to keep the boat in the correct location.

At each sample point, a double headed survey rake was thrown a distance of 5 m from the boat edge. The rake was left for 10 seconds to sink to the bottom after which the rake was pulled slowly and steadily back towards the boat. For points that were in known deeper water, additional rope was thrown to allow the rake to sink and rest on the bed of the lake at a distance of 5m from the edge of the boat.

On retrieval of the rake, the plants attached to the rake head were collected in a white survey tray. If necessary, plants were washed to remove excess sediment to aid identification. All the live plant material was identified to species level wherever possible. For example, some particularly difficult groups e.g. any non-fruiting starworts *Callitriche* sp. were only identified to genus level. Any unidentified plant specimens (or where identification was uncertain) were collected in plastic bags and labelled using the station number reference. These samples were then taken for subsequent observation using a high powered microscope, or sent for expert identification. Wherever possible, voucher specimens were pressed and dried using standard herbarium techniques.

To assign a level of abundance for each species, the total volume of live water plant material was scored based on the maximum trap-ability on the rake. Scores attributed to each species present range from 10% (low abundance) and 100% (the maximum trappable) in increments of 10%. For example, if the maximum plant volume was present on the rake, but split equally between two species then each species would be scored 50%. In addition, scores of 1% were given to trace and very small amounts of identifiable plant material.

The 'trap-ability' of a particular species on the rake, was taken into account the so that a score of 100% represents the maximum amount trappable on the rake. For example, a fine leaved species such as Unbranched bur-reed *Sparganium emersum* is not as 'trappable' on the rake as a more structured species such as Spiked water milfoil *Myriophyllum spicatum*. Surveyor experience and judgement is therefore important in scoring the less trappable species based on the likelihood of being retrieved in the rake and possibly other visual indications. The risk being that high abundances of less trappable species are routinely under-scored compared to more easily retrieved species. Other less trappable water plant families include duckweeds *Lemna* sp. and water lilies.

The maximum total of all species abundance scores on an individual rake sample cannot really be more than 100%, although ± 10% is considered acceptable to account for the varying trap-ability of different species.

Two rake throws, north and south, were undertaken at each sample point.

Table 1. **Sites surveyed as part of the Monitoring programme between 2014 and 2018 and individual broads used for statistical analysis. Broads are denoted as riverine (R) or isolated (I).**

Broad		2014	2015	2016	2017	2018	Analysis
Alderfen Broad	I	X	X	X	X	X	X
Bargate Broad	R	X			X		
Barnby Broad	I		X				
Barton Broad	R	X	X	X	X	X	X
Belaugh Broad	R				X		
Blackfleet broad	I			X			
Bridge Broad	R		X				
Buckenham Broad	I		X		X		
Burntfen Broad	I			X			
Calthorpe Broad	I	X					
Catfield Broad	I		X				
Cockshoot Broad	I	X	X	X	X	X	X
Cromes Broad	I	X	X	X	X	X	X
Decoy Broad	R	X		X		X	X
Hassingham Broad	I		X		X		
Heigham Sound	R	X	X	X	X	X	X
Hickling Broad	R	X	X	X	X	X	X
Horsey Mere	R	X	X	X	X	X	X
Hoveton Great Broad	R	X	X	X	X	X	X
Hoveton Little Broad	R	X			X		
Hudson's Bay	R		X			X	
Little Broad	I			X			
Martham Broad North	R	X	X	X	X	X	X
Martham Broad South	R	X	X	X	X	X	X
Mautby Decoy	R			X			
Norton's Broad	R			X			
Oulton Broad	R			X			
Pound End	R		X				
Ranworth Broad	R	X	X		X		
Reedham Water	I						
Rockland Broad	R	X	X	X	X	X	X
Round Water Broad	I			X			
Sotshole Broad	I			X			
Sprat's Water	I			X			
Strumpshaw broad	I		X			X	
Upton Broad	I	X	X	X	X	X	X
Upton Little Broad	I	X		X		X	
Wheatfen Broad & Channels	R		X			X	
Whitlingham Great Broad	I	X	X	X	X	X	X
Whitlingham Little Broad	I		X	X	X	X	X
Woolner's Carr	I			X			
Wroxham Broad	R	X	X	X	X	X	X

2.3 Data processing

For each sample point, an abundance score for each species was calculated, derived from the data from the north and south throws;

$$\frac{\text{(Score from north + Score from south)}}{2}$$

The abundance score for each species was then totalled to produce an abundance score for each sample point. An overall mean abundance for each species for the whole broad was then calculated by summing the scores from each sample point and dividing by the number of sample points. The overall mean abundance score for each species was then added together to give the overall total abundance score for the broad. Assuming maximum plant abundance on the site, the site abundance score should have a maximum of 100 (± 10%).

The water plants present in the surveys were also categorised into groups, such as stoneworts or macro-algae, and abundance scores were calculated for each group in each broad, as described above. The water plant groups and the species within them are presented in Appendix I.

The number of broads and the total points sampled in each Monitoring programme are presented in Table 2.

Table 2. The number of broads surveyed and the total number of points sampled each year of the monitoring programme.

Year	Number of broads	Number of points
2014	20	578
2015	25	634
2016	27	558
2017	21	589
2018	21	527

2.4 Statistical analysis

Non-parametric Kruskal-Wallis tests were used to establish any significant differences in water plant growth between the five years of point sample surveys. The analysis used each sample point, grouped by year. The total abundance of water plants (algae, mosses and species such as Common duckweed *Lemna minor* were omitted) and Section 41 species (see Appendix I) and species richness (number of species) at each point were used. Where there were significant differences, Mann-Whitney tests were used to establish which years were significantly different.

All the sample points from all broads were compiled for each year and were analysed for trends. Broads considered riverine and isolated (or connected through complex dyke systems) were also analysed separately by year. Individual broads sampled every year since 2014 and those broads sampled three times in alternative years (e.g. 2014, 2016 and 2018) were also analysed to establish any trends within them. In total, 16 broads were individually analysed. In addition, all broads surveyed in each year were combined and analysed.

3 Results

The results of the 2018 Monitoring programme and the hydroacoustic survey of Hickling are presented in Appendices II & III.

The mean abundance of water plants across all the broads surveyed combined showed that peak value was recorded in 2018 with a score of 28.2%, increasing from the lowest value of 20.0% in 2014 (Figure 3). The highest score for the Section 41 species was also recorded in 2018 (14.71%) increasing from the lowest score in 2016. The species richness per point increased slightly from 1.4% to 1.6 over the five year period. Kruskal-Wallis test revealed that none of the above factors were significantly different (Appendix IV).

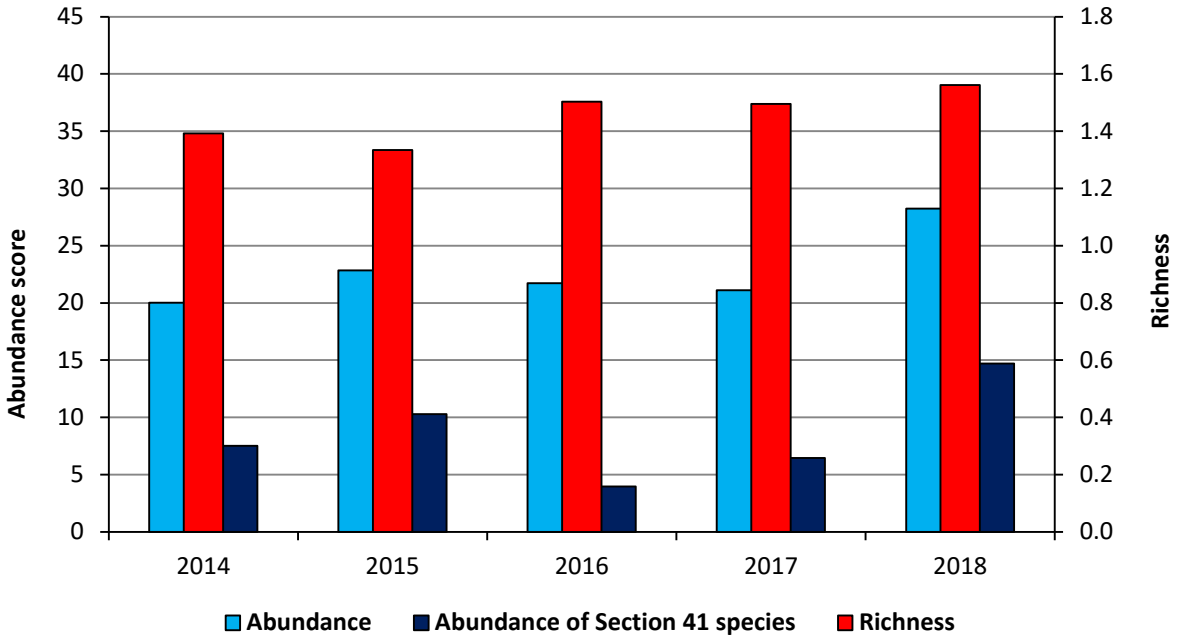

Figure 3. Mean overall abundance, abundance of Section 41 species and species richness (secondary axis) per point for all broads combined for each year.

Similar patterns were recorded in the riverine broads in comparison with all broads, with peak mean abundance scores and species richness recorded in 2018, with values of 22.0% and 1.7 respectively (Figure 4). In regard to the abundance of Section 41 species, although abundance decreased from the peak in 2015 (11.2) to the lowest score of 2.7 the following year, again the Kruskal-Wallis test did not reveal any significant differences between years.

The broads considered to be isolated did exhibit different patterns from the riverine broads, but again no significant trends were revealed using the Kruskal-Wallis tests. The mean species richness score per point peaked with 1.8 in 2014 and the poorest was in 2018 with 1.4 (Figure 5). Despite the declining pattern of species richness, the overall mean abundance increased from the lowest value in 2016 (25.6%) to reach a high of 40.1 in 2018. The abundance of Section 41 species mirrored the pattern for all species, decreasing in 2015 and 2016 from the initial mean score of 11.5% in 2014 and increasing in 2017 and reaching a peak (26.3%) in 2018.

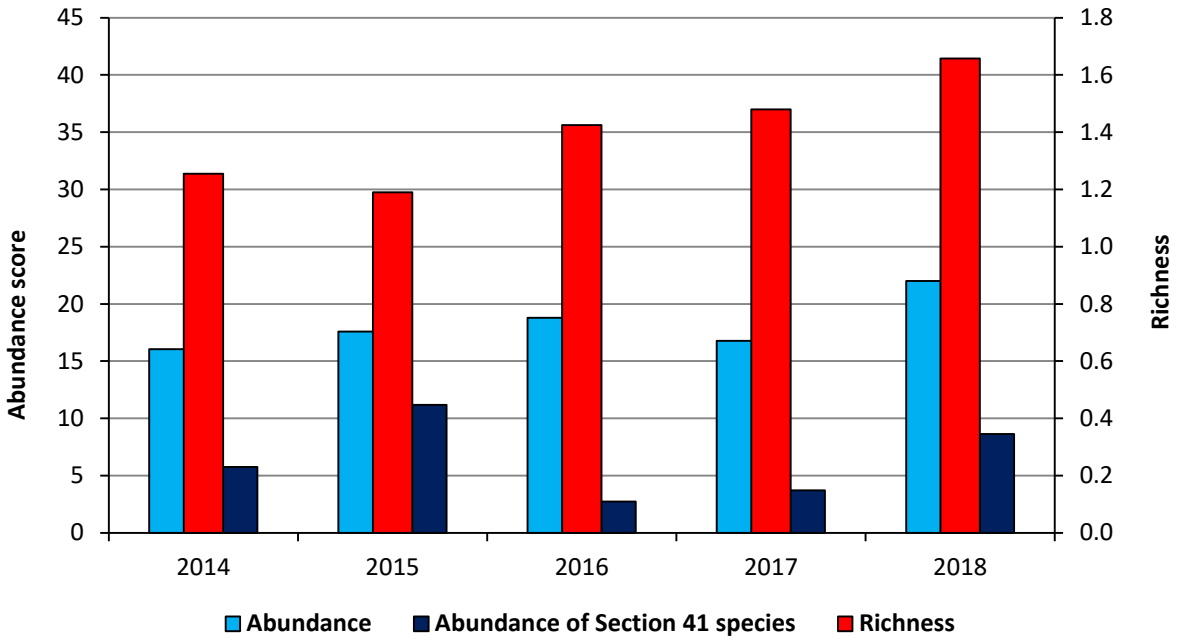

Figure 4. **Mean overall abundance, abundance of Section 41 species and species richness (secondary axis) per point for riverine broads combined for each year.**

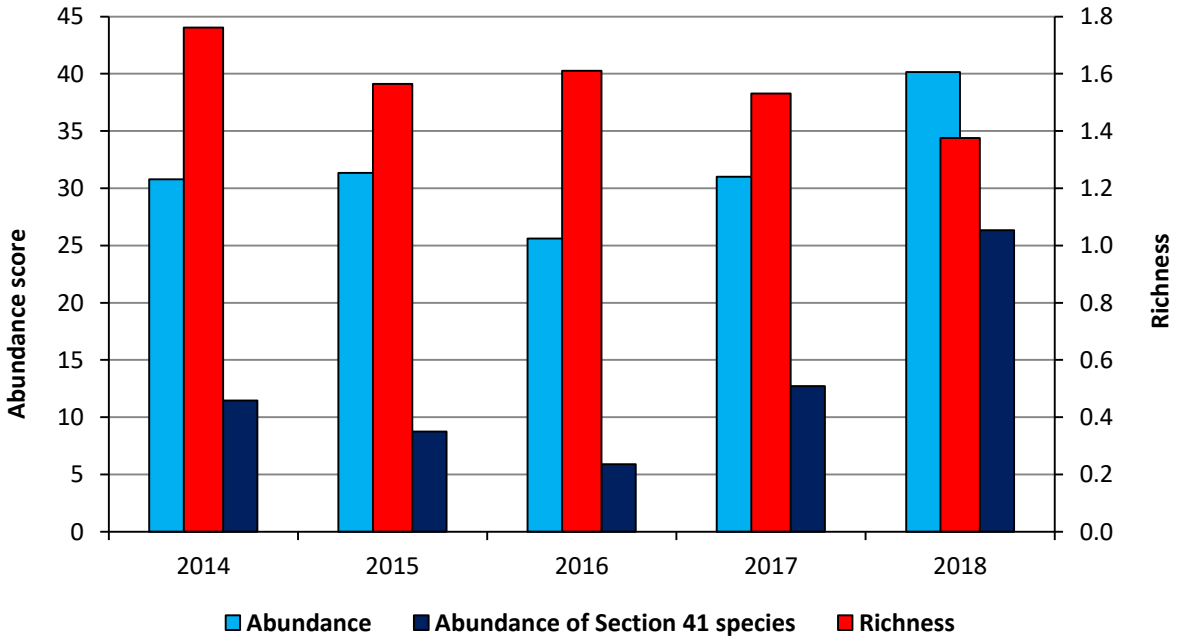

Figure 5. **Mean overall abundance, abundance of Section 41 species and species richness (secondary axis) per point for isolated broads combined for each year.**

The mean abundance scores for all species within the broads surveyed regularly in the Monitoring programme varied dramatically between broads (e.g. Barton Broad and Martham Broad North & South) and within the broads over the five year period (see Figure 6). Whilst broads with high abundance scores often had corresponding high species richness values, some broads such as Wroxham Broad generally had low abundance but good species richness (Figure 7).

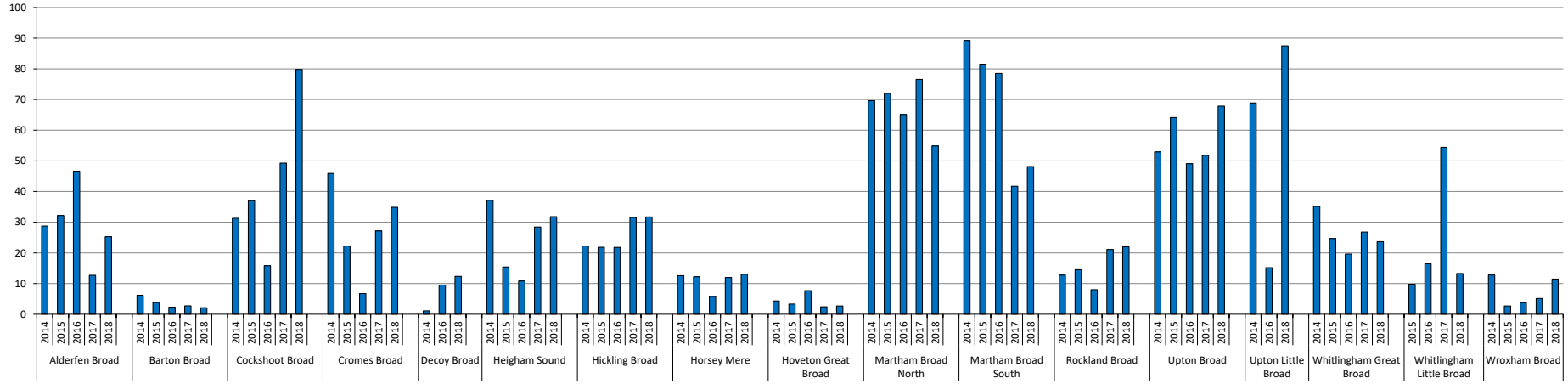

Figure 6. Mean overall abundance per point sampled in the key broads between 2014 and 2018.

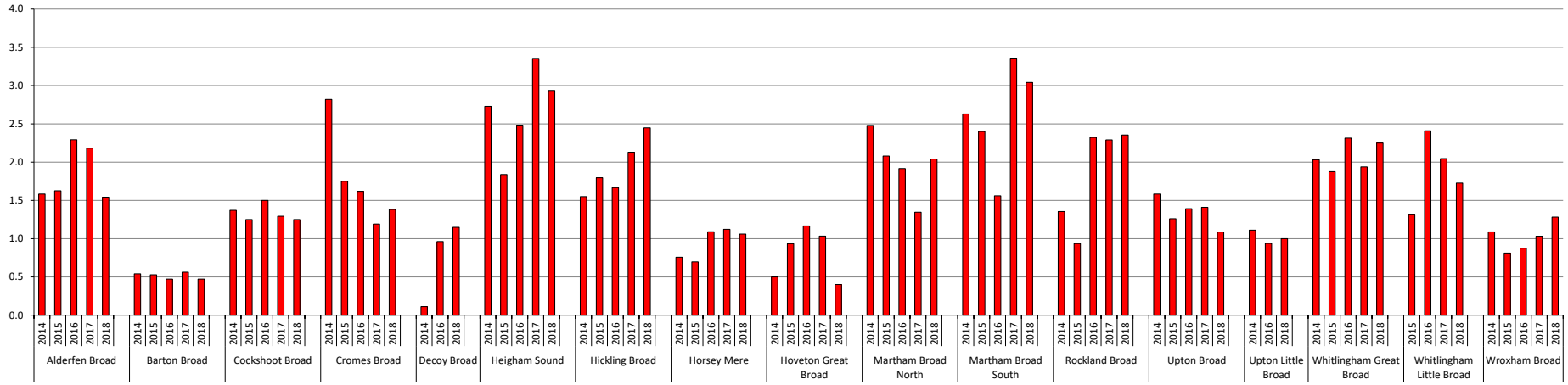

Figure 7. Mean species richness per point sampled in the key broads between 2014 and 2018.

Kruskal-Wallis tests conducted on overall abundance revealed significant differences in ten of the 17 individual broads tested (Table 3). Of the nine broads with data for the Section 41 species (Figures 8 & 9), significant differences were revealed at five (Table 4). In contrast, no significant differences between years were revealed by the analysis of species richness or the number of Section 41 species present (Appendix IV).

Table 3. Details of the significant differences for overall abundance between years at individual broads as revealed by Kruskal-Wallis tests.

Broad	n	H	df	p	Differences
Alderfen Broad	120	50.33	4	0.000	14<15,16 15<16 17<14,15,16,18 18<15,16
Cockshoot Broad	123	178.05	4	0.000	14<15,17,18 15<17,18 16<14,15,17,18 17<18
Cromes Broad	106	78.30	4	0.000	14>15,16,17,18 15<17,18 16<15,17,18 17<18
Decoy Broad	81	13.67	2	0.001	14<16,18 16<18
Heigham Sound	157	30.90	4	0.000	14>15,16,17,18 15<17,18 16<15,17,18 17<18
Martham Broad North	125	23.90	4	0.000	14<15,17 15>16,18 16>18 17>16,18
Martham Broad South	127	95.63	4	0.000	14>15,16,17,18 15>16,17,18 16>17,18 17<18
Upton Broad	116	24.80	4	0.000	14<15,18 15<18 16<17,18 17<15,18
Upton Little Broad	50	854.19	2	0.000	14<18 16<14,18
Whitlingham Little Broad	88	174.86	3	0.000	15<16,17,18 16<17 17>18

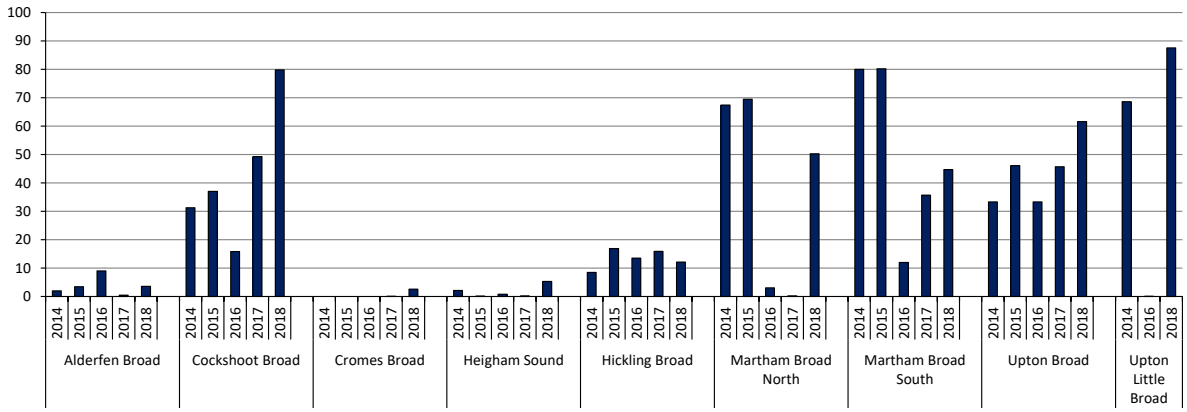

Figure 8. Mean abundance of Section 41 species per point sampled in relevant broads between 2014 and 2018.

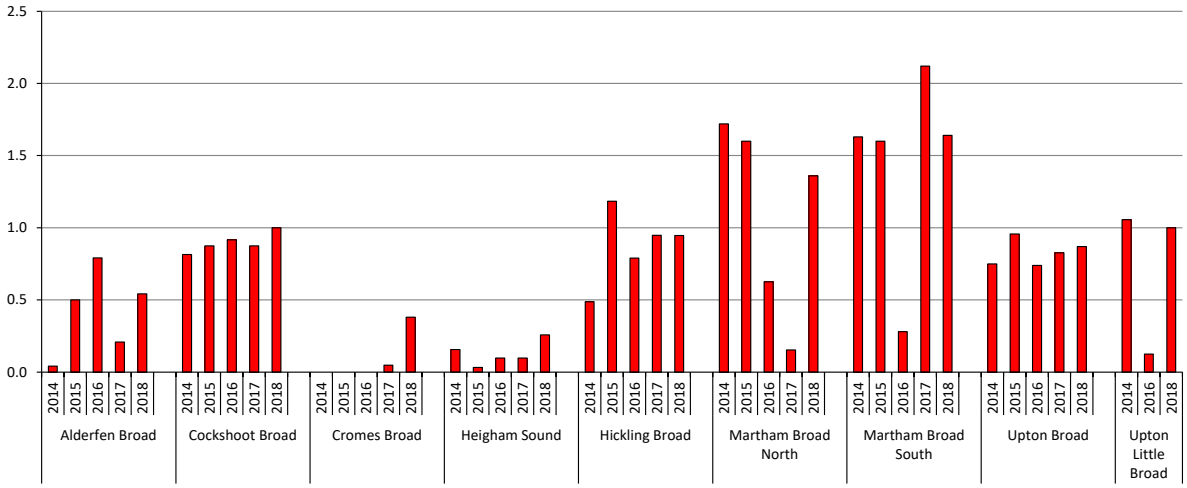

Figure 9. Mean number of Section 41 species present per point sampled in relevant broads between 2014 and 2018.

4 Overview

Combining all data from all the broads surveyed during the Monitoring programme between 2014 and 2018 did not produce any significant trends, for all water plant species and the Section 41 species. In general, the abundance scores were within 5%, but values increased in 2018. Similar patterns were recorded within the riverine and isolated broads combined, with peak values recorded in 2018 (see Figures 3 to 5). Given that 17 broads are regularly surveyed in the Monitoring programme, the observed trends are likely to be a function of climate, e.g. 2018 was a long hot summer promoting good growth, rather than the influence of sampling of new or rarely surveyed broads. Of the observed trends, it is of note that the abundance of water plants (including Section 41 species) was higher in the isolated broads than those directly connected to rivers. Individual broads are considered below, but this could be linked to some of these broads being isolated as part of restoration programmes, rather than the influence of navigation (and associated plant cutting requirements).

Table 4. Details of the significant differences for abundance of Section 41 species between years at individual broads as revealed by Kruskal-Wallis tests.

Broad	n	H	df	p	Differences
Cockshoot Broad	123	178.05	4	0.000	14<15,17,18 15<17,18 16<14,15,17,18 17<18
Martham Broad North	125	88.84	4	0.000	14<15 15>16,17,18 17<14,15,16,18
Martham Broad South	127	65.56	4	0.000	14>15,16,17,18 15>16,17,18 16<17,18 17<18
Upton Broad	116	10.47	4	0.033	14<15, 18 15<18 16<15,17,18 17<18
Upton Little Broad	50	321.25	2	0.000	16<14,18 18>14

Of the 17 individual broads surveyed, only three had general patterns of increasing water plant abundance over the monitoring period; Cockshoot, Decoy and Hickling. Of these, only Cockshoot had significant differences in water plant abundance. The overall abundance score increased by more than double from 31.3% to 79.8% in 2018 (Figure 6). The species richness per point remained stable (1.3 to 1.5) over this period of increased water plant abundance. It is worthy of note that seven species were initially present in 2014, but this reduced to just two species, Holly leaved naiad *Najas marina* and Rigid hornwort *Ceratophyllum demersum*, excluding Yellow water lily *Nuphar lutea*. The limited number of species present, yet the richness score per point reveals how water plants cover the broad in its entirety. Over the course of the last 10 years the main broad has improved from two small areas of Holly leaved naiad in the north-east and south-west (*pers. obs*.) to almost total coverage.

Although only three surveys have been completed at Decoy Broad using the point sample method (2014, 2016 and2018), a significant trend of increasing water plant abundance (albeit low) was recorded. In the 2014 survey, only yellow water lily was recorded, with water plants often associated with eutrophic lakes, Rigid hornwort and/or Canadian pondweed *Elodea Canadensis* becoming prominent (approximately recorded at 70% of sample points).

No significant trend was recorded at Hickling Broad, although water plant abundance increased in 2017 (31.6%) and 2018 (31.7%) from previous stable levels (21.8 to 22.2%) (Figure 6). The species richness per point over the five year monitoring period did increase (1.6 to 2.5 – Figure 7). This appears to represent increasing distribution of species across the broad as 12 water plant species were recorded in the 2015, 2017 and 2018 surveys. In regard to Section 41, Baltic stonewort *Chara baltica*, Intermediate stonewort *C. intermedia* and Holly leaved naiad are key components of the water plant community (Convergent stonewort *C. connivens* was present in trace amounts in 2015, 2016 and 2017), along with Spiked water milfoil *Myriophyllum spicatum*.

A number of broads had significant differences between the sample years, but had fluctuating patterns over the study period, including Alderfen, Cromes, Upton and Upton Little (Figure 6). Alderfen Broad is dominated by Rigid hornwort and the fluctuations are largely a result of the success of the support species. For example, only one additional species was recorded in 2018, Holly leaved naiad, compared with six in the peak year of 2016. Whilst stoneworts contribute to Alderfen's water plant community (principally the collective Fragile / Convergent *C. globularis* / *connivens* and Bristly *C. virgata*), Holly leaved naiad represents the Section 41 species at Alderfen (Figures 8 & 9).

Another broad with fluctuating overall abundances, Cromes, initially declined to its lowest point in 2016 before increasing again in the subsequent surveys (Figure 6). Interestingly, the greatest number of water plant species (12) was recorded in 2016. Rigid hornwort could be considered the dominant species within the broad, as it was ever-present in the surveys and its abundance decreased between 2014 and 2016 before increasing in 2017 and 2018. It is worthy of note that the abundance scores in the later surveys were far greater than in the initial surveys. As with Rigid hornwort, Canadian pondweed also decreased between 2014 and 2016, but was not recorded in the 2017 and 2018 surveys. The Section 41 species, Holly leaved naiad, in contrast was first recorded in 2017 and became the second most dominant species in regard to overall abundance in 2018.

The isolated Upton Broad has maintained clear water and historically is a key site for Holly leaved naiad within the Broads. The abundance of this nationally rare species has been consistently high throughout with greater cover recorded in the overall peak years, 2016 and 2018. No other species was recorded in all point sample surveys conducted, indeed the number of species present has decreased in recent years. However, small areas of good growth of Opposite stonewort *C. contraria* and also Bristly stonewort have become apparent and contributed to the increased overall abundance in 2018.

The fluctuation of overall abundance of water plants within Upton Little Broad is principally a function of the cover of the dominant species, Bristly stonewort. The low abundance in 2016 seemingly resulted in a greater diversity with Holly leaved naiad, Common and Intermediate stonewort also recorded, whereas in 2018 when Bristly stonewort (and the broad) recorded its highest value, no other water plant species was recorded.

The Martham Broads can be considered as key sites within the Monitoring programme, generally recording the highest overall abundance scores. The two broads connected by the River Thurne, have similar water plant communities dominated by stoneworts, with Bristly stonewort prevalent. Of the broads with significant differences in overall abundance, both Martham Broads are the only lakes with a general declining trend (Figure 6, Table 3). Similar trends would be expected given their connectivity, with only the 2017 point sample survey producing differing results. The northern broad recorded its highest overall abundance whereas Martham Broad South had its lowest overall abundance. Whilst the five year trend can be considered as declining, the mean overall water plant abundance still remains greater than most surveyed as part of the Monitoring programme. The pattern for the abundance of Section 41 species, differs from the overall, primarily due to the non-inclusion of Bristly stonewort. It is worthy of note that all five species are recorded in the Martham Broads.

Appendix I:
Common water plants in the Broads

Table 1. Details of Broads water plants.

Group	Scientific name	Common name	Section 41
Stoneworts	*Chara aspera*	Rough stonewort	
	C. baltica	Baltic stonewort	Y
	C. connivens	Convergent stonewort	Y
	C. contraria	Opposite stonewort	
	C. curta	Lesser bearded stonewort	
	C. globularis	Fragile stonewort	
	C. hispida	Bristly stonewort	
	C. intermedia	Intermediate stonewort	Y
	C. pedunculata	Hedgehog stonewort	
	C. virgata	Delicate stonewort	
	C. vulgaris	Common stonewort	
	Nitella flexilis	Starry stonewort	Y
	N. mucronata	Pointed stonewort	
	N. translucens	Translucent stonewort	
Vascular macrophytes	*Acorus calamus*	Sweet flag	
	Crassula helmsii	Australian swamp stonecrop	
	Callitriche sp.	Starwort sp.	
	Ceratophyllum demersum	Rigid hornwort	
	Elodea canadensis	Canadian waterweed	
	E. nuttallii	Nuttall's waterweed	
	Eleogiton fluitans	Floating club-rush	
	Glyceria maxima	Reed sweet grass	
	Hippuris vulgaris	Mare's tail	
	Myriophyllum spicatum	Spiked water milfoil	
	M. verticillatum	Whorled water milfoil	
	Najas marina	Holly-leaved naiad	Y
	Persicaria amphibia	Amphibious bistort	
	Potamogeton acutifolius	Sharp-leaved pondweed	
	P. berchtoldii	Small pondweed	
	P. crispus	Curled pondweed	
	P. friesii	Flat-stalked pondweed	
	P. lucens	Shining Pondweed	
	P. natans	Broad –leaved pondweed	
	P. obtusifolius	Blunt-leaved pondweed	
	P. pectinatus	Fennel-leaved pondweed	
	P. perfoliatus	Perfoliate pondweed	
	P. pusillus	Lesser pondweed	
	P. trichoides	Hair like pondweed	
	Potamogeton x Salicifolius	Willow-leaved pondweed	
	Ranunculus circinatus	Fan-leaved water crowfoot	
	Rorippa nasturtium-aquaticum	Water cress	
	Saggitaria sagittifolia	Arrowhead	
	Sparganium erectum	Branched bur-reed	
	S. emersum	Unbranched bur-reed	
	Stratiotes aloides	Water-soldier	
	Utricularia vulgaris	Greater bladderwort	
	Zannichellia palustris	Horned pondweed	

Free-floating or Round floating leaved macrophytes	*Hydrocharis morsus-ranae*	Frogbit	
	Lemna gibba	Inflated duckweed	
	L. minor	Common duckweed	
	L. minuta	Least duckweed	
	L. trisulca	Ivy-leaved duckweed	
	Nuphar lutea	Yellow water lily	
	Nymphaea alba	White water lily	
	Spirodela polyrhiza	Greater duckweed	
Macro-algae & Mosses	*Enteromorpha*		
	Fontinalis antipyretica	Common water moss	
	Hydrodictyon	Water net	
	Leptodictyum riparium	Stringy moss	
	Zygnematales	Filamentous algae	

Appendix II
2018 Annual Report

The Broads Annual Water Plant Monitoring Report 2018

Broads Authority
Yare House
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2018

EXECUTIVE SUMMARY

This report presents and discusses the findings from the annual water plant surveys carried out during 2018, which covered 20 waterbodies. This is a long running survey which began in 1977 by Michael J. Jackson & Peter Wright at the Nature Conservancy Council who developed the transect method within the Broads (Jackson, 1978). This method was used to complete surveys on a wide set of broads every year since 1983. In 2014, the methodology changed from a transect-based method, to a point based method which had been in development since 2011.

Key Results for 2018 can be summarised as:

- Heigham Sound recorded an increase in filamentous algae and stoneworts, particularly Baltic stonewort. Vascular macrophyte levels were similar to levels seen in 2017.
- Hickling was surveyed twice for the second year running, both of which showed better abundance scores than those obtained in 2017. The new earlier survey had increased species numbers than the later regular survey, however Holly-leaved naiad was not fully represented, as it has not grown sufficiently. Although the earlier survey showed increased species it had a lower abundance score that the later regular survey.
- Twenty species were recorded this year from Martham South, a much better year than 2017, although there was a big reduction in Holly-leaved naiad and pondweeds. Enteromorpha had reduced considerably and common water moss, an indicator of clean waters, increased.
- Conversely Martham North had a better representation of Holly-leaved naiad and pondweed. Bristly stonewort is still the main presence but not to the level seen in 2017. Filamentous algae still has a considerable presence on the eastern part of this broad.
- Stoneworts were not found in Alderfen broad this year; Rigid hornwort was the most abundant species again but not to the extent seen in previous years. Water net was also recorded which is a delicate algae and an indicator of clean eutrophic waters.
- Cockshoot broad continues to be highly productive for Holly-leaved naiad and have very clear water. The extensive mats of Holly-leaved naiad could be seen very clearly, even without a bathyscope.
- Upton Little has had a big increase in stoneworts since 2016 and seems to be an enclave for Bristly stonewort.
- Wroxham broad maintains its low levels of plant abundance, however it appears that its plant life is very slowly increasing.
- Strumpshaw broad when last surveyed in 2015 had very little apart from swathes of filamentous algae. Large amounts of filamentous algae were found again this year but not to the same extent, although the algae could have crashed earlier in the year. Whorled water milfoil was found amongst the reeds on the eastern side of the broad.
- Wheatfen had a good year with increases in the ‘free-floating or round floating leaved’ and ‘vascular macrophytes’ groups; this is mostly because of the quantity of duckweeds and Nuttall’s waterweed.
- Whitlingham Little was not as productive as last year, much of this was down to a big reduction in Nuttall’s waterweed and possibly a filamentous algae crash earlier in the year.

1. Aims & Objectives

The aim of the Broads annual survey programme is to monitor the water plant growth of the broads and waterways within the Broads. The resident water plants are used as an indicator, from which data is produced. These results can then be used over the longer term to assess the condition, or health, of the waterbody.

As such our objectives are to use different types of surveys to gain the best information, whilst covering as much of the Broads as possible during the growing season.

This report presents the Broads water plant survey which manually assesses the species abundance and diversity of the water plants within a selected number of Broads.

2. Introduction

The aim of the Broads annual survey in 2018 was to continue to monitor water plant growth within specified broads, using the point based method across all selected sites. The main objectives in the annual programme are to monitor key broads with long-term datasets, those that have had restoration measures put in place or those that are known to be experiencing a change in their water plant community. Where broads have historically been sampled around a particular date, the aim is to undertake repeat surveys as near as possible to the original date. Broads that have not received restoration efforts, or are stable and/or generally without plants are monitored on a less frequent basis. When resources allow, a rolling program of monitoring sites not previously surveyed is also an ongoing aim.

The summarised data for each surveyed broad is shown along with discussion and explanation of the data. Casual observations are included such as species noticed on or in the broad but not recovered in the actual survey. This is then followed by a graph depicting the plant groupings for the past five years of point based data

This year an additional section will be included in the discussion and explanation section. This discusses the presence of 'Section 41 species' within the survey results; these are water based macrophytes which are included in the list of 'species which are of principal importance for the conservation of biodiversity in England' under section 41 of The Natural Environment and Rural Communities (NERC) Act 2006. Our occurring 'Section 41' species are; Holly-leaved naiad and Baltic, convergent, intermediate, starry & potentially bearded stonewort.

2. Survey Methodology

2.1 Survey point selection

a. The area of open water of each broad to be surveyed was measured using GIS mapping.
b. The equation y = 4.6242ln(x) + 17.149 was used to calculate the ideal number of survey points, where y = the area of open water in a site. This relationship was generated by Dr Nigel Wilby, based on Broad's species accumulation data. Once this number was calculated, a grid system was applied and a set of points plotted on to the open water areas of each broad. Points were spaced equidistantly.

c. An aerial photograph of each broad was produced on which each of the numbered survey points was marked. Grid references for each numbered point were also included.

2.2 Field Method

a. In the field, surveyors used the grid references of each plotted point to identify the point's location. The boat was navigated to each point using a handheld GPS device. Once within 5 m of the plotted grid reference, mud weights were deployed to keep the boat in the correct location.

b. At each point, a 5m rake throw was completed to the north and to the south. Each sample (either north or south) was recorded separately, for subsequent analysis. Two samples at each point has been previously been found to be a suitable representative number.

c. On each rake throw, the rake was left for 10 seconds to sink to the bottom after which the rake was pulled slowly and steadily along the bed of the broad, back towards the boat. For points that were in deeper water, additional rope was thrown to allow the rake to sink and rest on the bed of the broad at a distance of 5m from the edge of the boat.

d. On retrieval of each rake, the plants attached to the rake head were collected in a white survey tray. If necessary, plants were washed to remove excess sediment to aid identification.

e. All the live plant material was identified to species level wherever possible. For example, some particularly difficult groups e.g. any non-fruiting starworts *Callitriche sp.*, were only identified to genus level.

f. Any plant specimens where identification in the field was uncertain were collected in plastic bags, labelled using the station number reference and the direction of the throw. These samples were then taken for subsequent observation using a high powered microscope, or sent for expert identification. Wherever possible, voucher specimens were pressed and dried using standard herbarium techniques.

g. To assign a level of abundance for each species, the total volume of live plant material, was ascribed a value, based on the maximum trap-ability on the rake. Therefore the maximum possible score would be given to a retrieved rake that couldn't possibly hold any more plant material. To make the scoring simpler in the field, the values ascribed to each species ranged between 1 and 10, with 10 being the maximum trappable. If the maximum plant volume was present on the rake, but split equally between two species for example, then each species would be scored 5. Scores of 0.1 were given to trace and very small amounts of identifiable plant material.

h. The score assigned to each species should take into account the trap-ability of that particular species on the rake, so that a score of 10 (91 to 100%) represents the maximum amount trappable on the rake. As such, a fine leaved species such as unbranched bur-reed would not be as trappable on the rake as a more structured species such as spiked water milfoil. The scoring for less trappable species then requires a little bit of surveyor experience and judgement to ascribe a suitable score that reflects the likelihood of being retrieved in the rake, and possibly other visual indications as to how much of the species is actually present. The risk being that high abundances of less trappable species are routinely under-scored compared to more easily retrieved species. Other less trappable water plant families include the duckweeds and water lilies.

i. The maximum total of all species abundance scores on an individual rake sample cannot really be more than 100%; plus or minus 10% is an acceptable tolerance to account for the varying trap-ability of different species.

2.3 Data processing

a. For each sample, species abundance scores can be totalled, to produce the total abundance score for each sample. Sum of all sample abundance scores produces the site total abundance. Assuming maximum plant abundance on the site, the site abundance score should have a maximum of 10 (± 10%).
b. For data comparison, the results have been calculated to show the species richness (number of species recorded) and the species abundance scores. Species abundance is calculated by summing all the abundance scores for a particular species at each site and dividing by the number of samples, which were surveyed for that site. Within each sites results table, the species abundances have been displayed in descending order so that the most abundant species in 2018 are listed at the top of each site table.

3. Results

3.1 Thurne Valley

The broads which are located in the Thurne valley are part of the reason that the Broads are designated as a Special Area of Conservation (SAC), containing two Annex I habitats. The two habitats are; Hard oligo-mesotrophic waters with benthic vegetation of stonewort species (3140), and Natural eutrophic lakes with Magnopotamion or Hydrocharition - type vegetation (3150).

These bodies of water are a sanctuary for vulnerable and rare species which are stated in the Joint Nature Conservation Committee (JNCC) Red Data Book, they include; three 'Vulnerable' species: Baltic stonewort, Convergent stonewort and Starry stonewort, and one 'rare' species: Intermediate stonewort (Stewart and Church, 1992). They also provide a safe haven for the rare Holly-leaved naiad, which is a UK Biodiversity Action Plan priority species (BAP), as well as more common vascular plants such as Spiked water milfoil and Mare's tail.

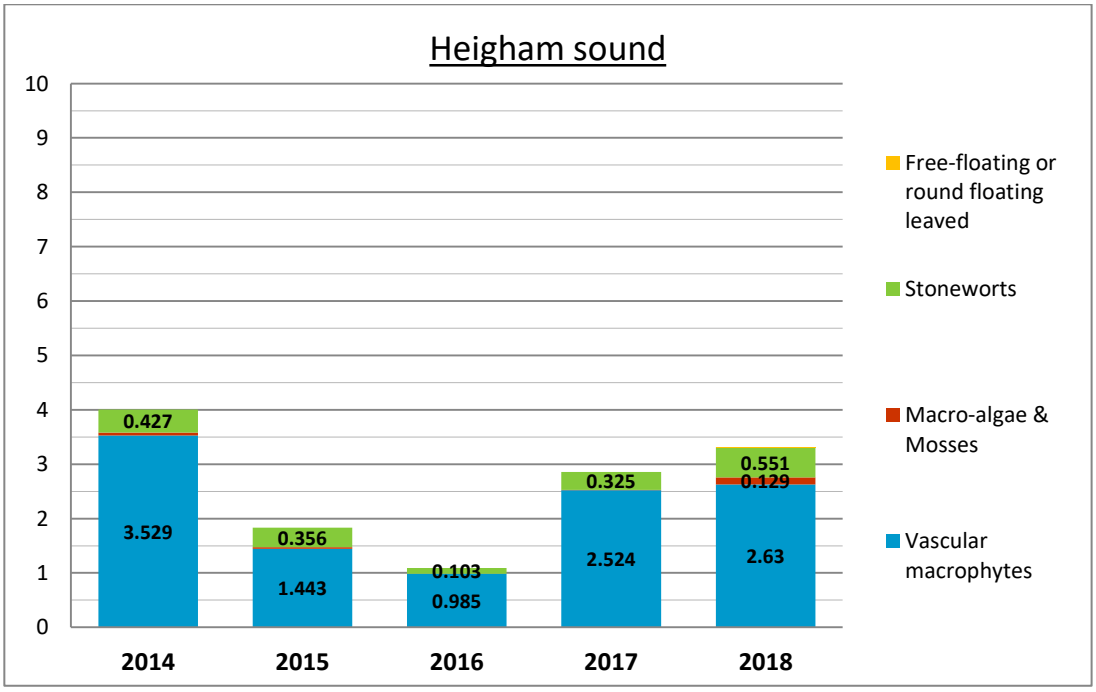
Two surveys were undertaken on Hickling broad, May & July, this was to assess the increased plant growth from spring to summer. The results of this can be seen in the Hickling section depicted by and extra column in the figure and an additional table.

Heigham Sound

Heigham Sound maintained its species richness from the previous year, while also having an increase in the total plant abundance.

Spiked water milfoil was the most abundant species, continuing its stable reputation. Baltic stonewort and Nuttall's waterweed were very productive and the former contributed to the increase in the 2018 Stonewort band depicted in the figure below. There was also an increase in filamentous algae. There were four points within the broad, all within the marked channel, where there was no trace of plants found.

Common Name	Scientific Name	Summary Abundance	Occurrences
Spiked water milfoil	*Myriophyllum spicatum*	0.834	35
Mare's tail	*Hippuris vulgaris*	0.629	20
Rigid hornwort	*Ceratophyllum demersum*	0.469	21
Baltic stonewort	*Chara baltica*	0.452	5
Fan-leaved water crowfoot	*Ranunculus circinatus*	0.260	7
Curled pondweed	*Potamogeton crispus*	0.171	15
Nuttall's waterweed	*Elodea nuttallii*	0.166	13
Filamentous algae	*Zygnematales*	0.129	5
Holly-leaved naiad	*Najas marina*	0.065	4
Translucent stonewort	*Nitella translucens*	0.065	2
Stonewort (*Chara*) species	*Chara sp.*	0.018	2
Fennel-leaved pondweed	*Potamogeton pectinatus*	0.018	2
Starwort species	*Callitriche sp.*	0.016	1
Fragile stonewort	*Chara globularis*	0.016	1
Whorled water milfoil	*Myriophyllum verticillatum*	0.002	1
Ivy-leaved duckweed	*Lemna trisulca*	0.002	1
Yellow water lily	*Nuphar lutea*	0.002	1
Total number of species recorded		**17**	**Total samples taken 62**



Section 41 species: Baltic stonewort and Holly- leaved naiad both had a good year increasing their abundance and range.

Hickling

The supplementary survey in May this year shows that Spiked water milfoil was more prolific earlier in the season in comparison to the supplementary survey in June last year. Fennel-leaved pondweed also had a very good spring. In addition more species were recorded this spring than last.

May			
Common Name	**Scientific Name**	**Summary Abundance**	**Occurrences**
Spiked water milfoil	*Myriophyllum spicatum*	1.041	60
Intermediate stonewort	*Chara intermedia*	0.481	29
Baltic stonewort	*Chara baltica*	0.403	22
Fennel-leaved pondweed	*Potamogeton pectinatus*	0.264	26
Hedgehog stonewort	*Chara pedunculata*	0.090	2
Holly-leaved naiad	*Najas marina*	0.085	12
Rough stonewort	*Chara aspera*	0.077	4
Common stonewort	*Chara vulgaris*	0.040	4
Fragile/convergent stonewort	*Chara globularis/connivens*	0.032	7
Curled pondweed	*Potamogeton crispus*	0.017	4
Opposite stonewort	*Chara contraria*	0.015	3
Bristly stonewort	*Chara hispida*	0.013	1
Mare's tail	*Hippuris vulgaris*	0.013	1
Flat-stalked pondweed	*Potamogeton friesii*	0.004	3
Stonewort (*Chara*) species	*Chara sp.*	0.003	2
Pondweed species	*Potamogeton sp.*	0.003	2
Canadian waterweed	*Elodea canadensis*	0.001	1
Rigid hornwort	*Ceratophyllum demersum*	0.001	1
Total number of species recorded		**18**	**Total samples taken 78**

The principal survey shows that total plant abundance is better this year than last, with Spiked water milfoil continuing to be the most dominant species in Hickling broad. Fennel-leaved pondweed and Baltic stonewort vie for third place, the stonewort obtaining this status in spring and the pondweed in summer.

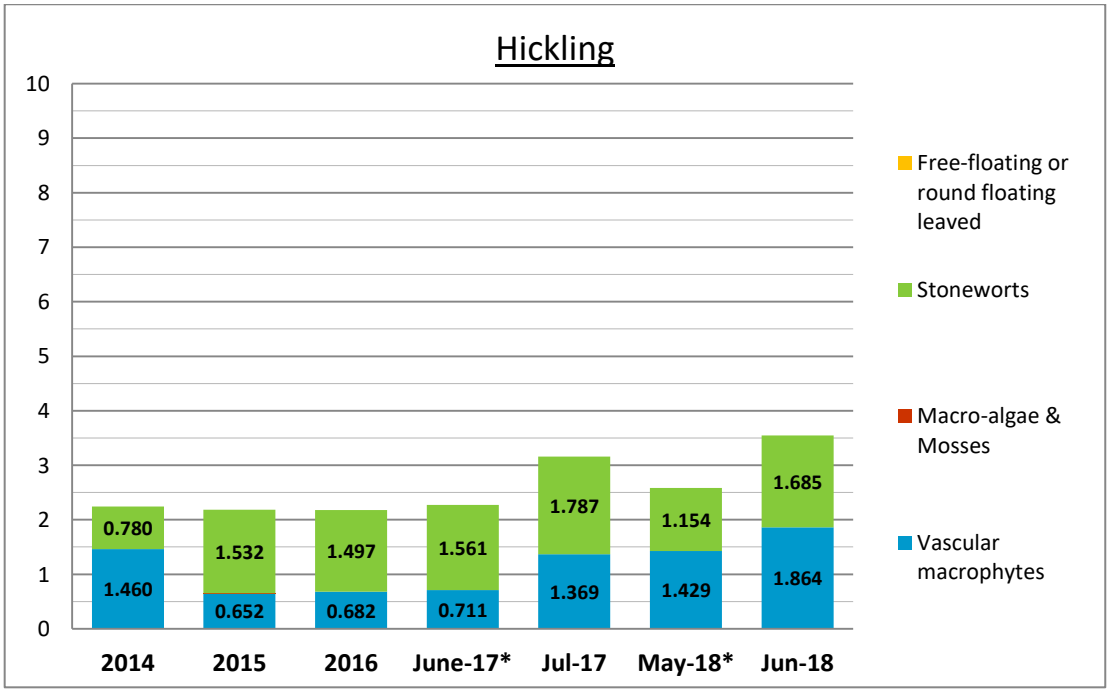
Hedgehog stonewort which is a distinctive feature in the northeast corner of Hickling close to the Wildlife Trust staithe, has reduced by about 71% which was quite obvious during the survey. It was noticed that this particular stonewort has, over the past couple of years, been recorded in higher numbers in the earlier May survey.

Conversely Holly-leaved naiad had a good year, increasing its presence in the broad by over 79%. This macrophyte was not as apparent in the supplementary survey, the reason being is that this species is for the most part an annual and has not grown significantly at the time of this springtime survey.

Unfortunately the number of species found in May did not continue to the main survey in July, with a reduction in species richness although overall abundance did increase.

July			
Common Name	Scientific Name	Summary Abundance	Occurrences
Spiked water milfoil	*Myriophyllum spicatum*	1.281	62
Intermediate stonewort	*Chara intermedia*	0.658	29
Fennel-leaved pondweed	*Potamogeton pectinatus*	0.386	26
Baltic stonewort	*Chara baltica*	0.372	14
Holly-leaved naiad	*Najas marina*	0.156	14
Bristly stonewort	*Chara hispida*	0.051	2
Hedgehog stonewort	*Chara pedunculata*	0.051	2
Common stonewort	*Chara vulgaris*	0.051	3
Curled pondweed	*Potamogeton crispus*	0.040	4
Rough stonewort	*Chara aspera*	0.026	2
Delicate stonewort	*Chara virgata*	0.013	1
Fragile/convergent stonewort	*Chara globularis/connivens*	0.003	2
Stonewort (*Chara*) species	*Chara sp.*	0.001	1
Pondweed species	*Potamogeton sp.*	0.001	1
Total number of species recorded		14	Total samples taken 78

Section 41 species: Holly-leaved naiad showed an increase from 2017 but a decrease from 2016. Intermediate stonewort appears to fluctuate bi-annually, Baltic stonewort is consistent, Convergent stonewort is bundled with Fragile stonewort due to the difficult of telling them apart, and showed a decrease.

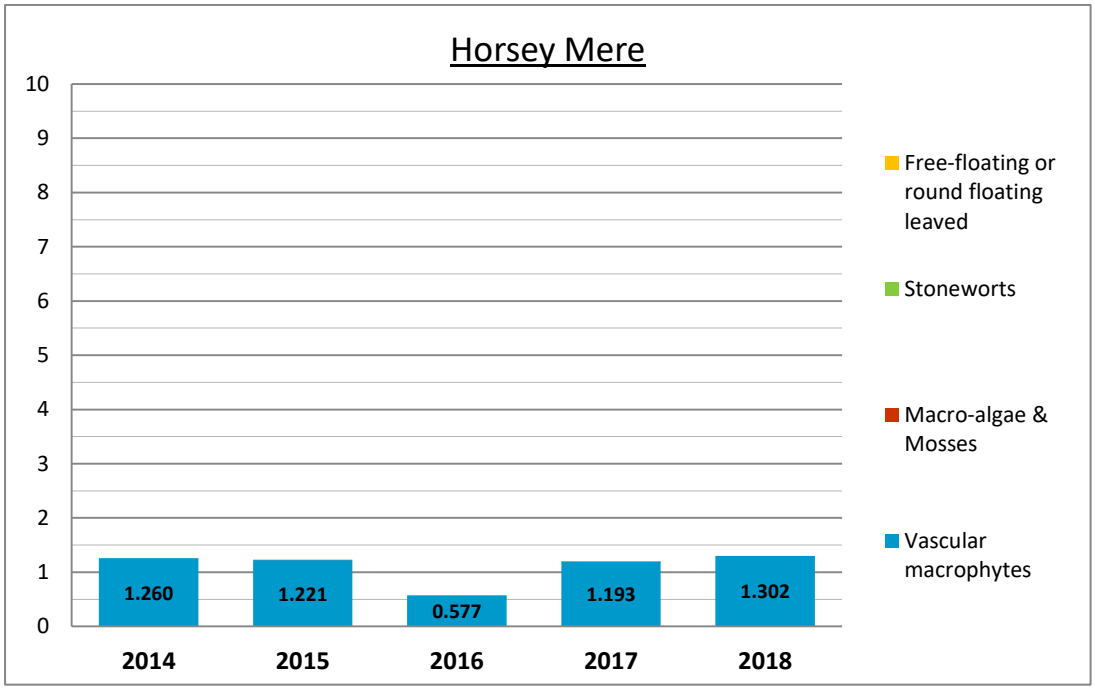


Horsey Mere

Spiked water milfoil has been pipped to the post to the title of most abundant species on this broad by Mare's tail; the title however is somewhat symbolic as there is very little plant growth in this broad.

Common Name	Scientific Name	Summary Abundance	Occurrences
Mare's tail	*Hippuris vulgaris*	0.652	18
Spiked water milfoil	*Myriophyllum spicatum*	0.648	36
Rigid hornwort	*Ceratophyllum demersum*	0.002	1
Total number of species recorded		**3**	**Total samples taken 66**

The majority of the plants are at the reed fringes and in the alcove bays which offer a modicum of shelter from turbid waters flowing from Waxham New Cut. Species richness has reduced; three species were recorded compared to last year's seven, admittedly most of those lost species were found in very small quantities



Martham North

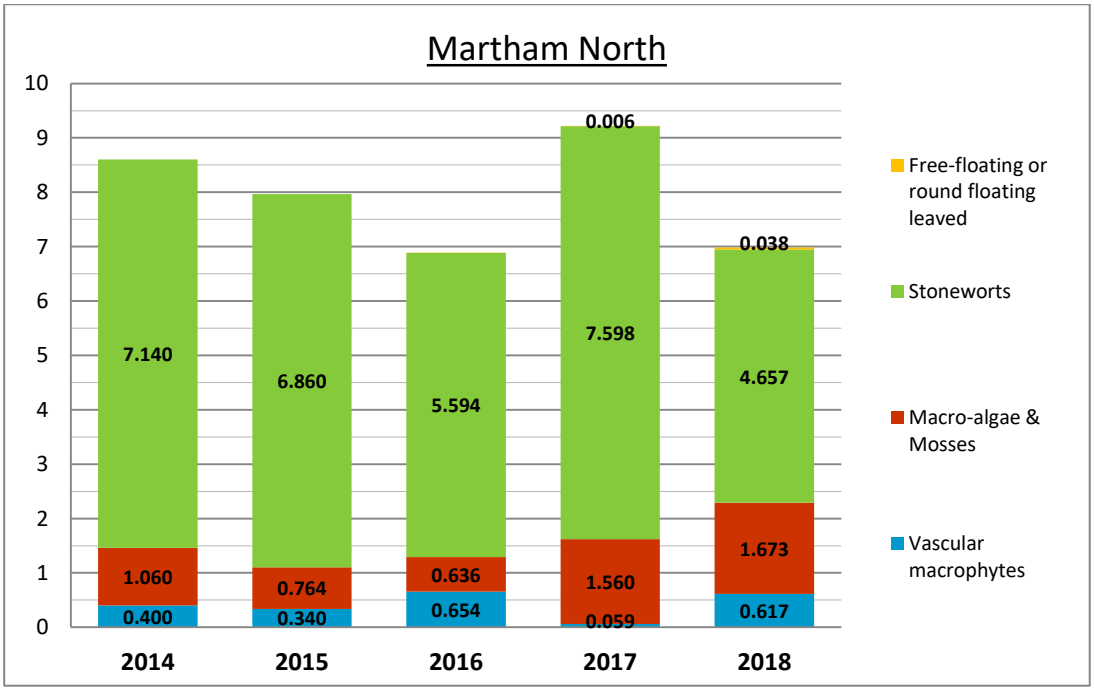
Martham North is one of the most plant abundant broads in the system with excellent species richness. Five of these species are the nationally rare stoneworts, the bulk of which is comprised of Bristly stonewort.

2017 was an excellent year for Bristly stonewort with an abundance score over two thirds higher than it was last year, however this appeared to come at a cost of reduced species richness, an

absence of the rare Starry stonewort, a reduction in vascular macrophytes and an increase in filamentous algae.

Common Name	Scientific Name	Summary Abundance	Occurrences
Bristly stonewort	*Chara hispida*	4.519	40
Filamentous algae	*Zygnematales*	1.673	14
Fennel-leaved pondweed	*Potamogeton pectinatus*	0.269	10
Holly-leaved naiad	*Najas marina*	0.252	11
Long-stalked pondweed	*Potamogeton praelongus*	0.077	4
Baltic stonewort	*Chara baltica*	0.060	4
Intermediate stonewort	*Chara intermedia*	0.038	1
Ivy-leaved duckweed	*Lemna trisulca*	0.038	1
Common stonewort	*Chara vulgaris*	0.021	2
Mare's tail	*Hippuris vulgaris*	0.019	1
Smooth stonewort	*Nitella flexilis*	0.019	1
Total number of species recorded		**11**	**Total samples taken 52**

This year species richness of Bristly stonewort has returned to a level recorded previously, as has quantities of vascular macrophytes (albeit in a different combination). Filamentous algae has increased since last year, particularly on the southern part of the broad where it boarders the river Thurne, conversely stoneworts has been decreasing within this same band



Observations: Excellent water clarity with stoneworts touching the surface of the water.

Section 41 species: Holly-leaved naiad has returned to a level seen in 2014; Intermediate stonewort is still located here at two locations. Starry stonewort has decreased over the past four years and was not found this year. Convergent/fragile stonewort was not found this year.

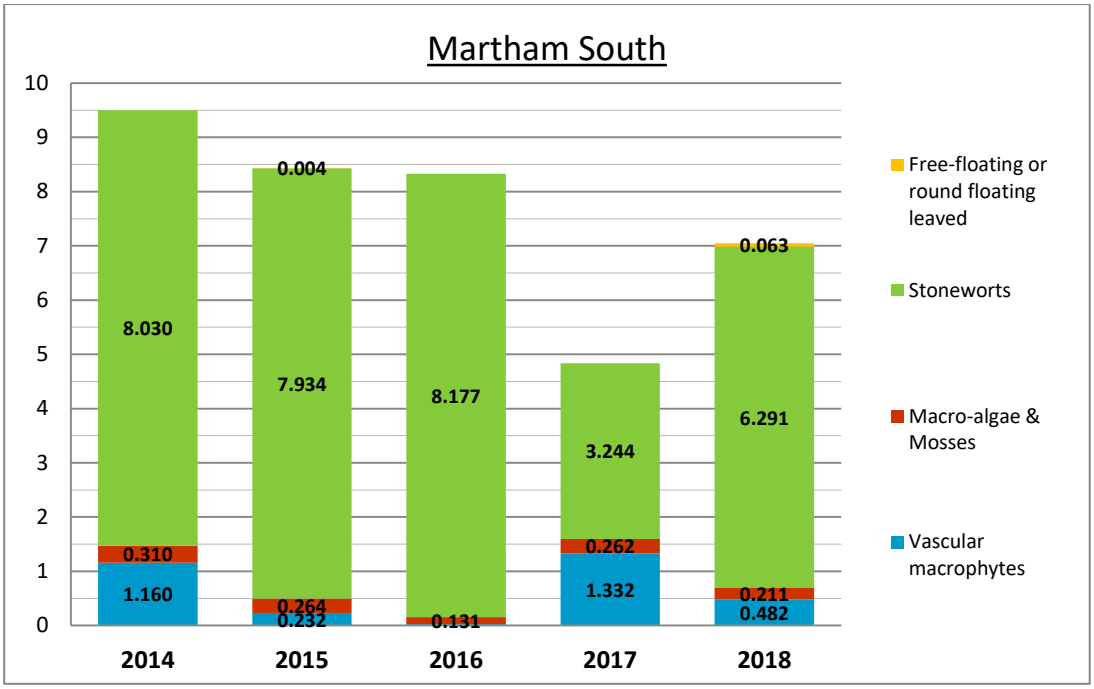
Martham South

This year Martham South was found to be the most species rich broad with a total number of twenty species found.

Common Name	Scientific Name	Summary Abundance	Occurrences
Bristly stonewort	*Chara hispida*	3.944	40
Intermediate stonewort	*Chara intermedia*	1.817	31
Holly-leaved naiad	*Najas marina*	0.292	14
Starry stonewort	*Nitellopsis obtusa*	0.229	3
Baltic stonewort	*Chara baltica*	0.190	10
Filamentous algae	*Zygnematales*	0.167	5
Fennel-leaved pondweed	*Potamogeton pectinatus*	0.083	3
Hedgehog stonewort	*Chara pedunculata*	0.063	3
Ivy-leaved duckweed	*Lemna trisulca*	0.063	3
Canadian waterweed	*Elodea canadensis*	0.042	2
Common water moss	*Fontinalis antipyretica*	0.042	2
Fragile/convergent stonewort	*Chara globularis/connivens*	0.023	2
Rough stonewort	*Chara aspera*	0.021	1
Spiked water milfoil	*Myriophyllum spicatum*	0.021	1
Lesser pondweed	*Potamogeton pusillus*	0.021	1
Pondweed species	*Potamogeton sp.*	0.021	1
Stonewort (Chara) species	*Chara sp.*	0.002	1
Enteromorpha	*Enteromorpha*	0.002	1
Starwort sp.	*Callitriche sp.*	0.002	2
Fragile stonewort	*Chara globularis*	0.002	1
Total number of species recorded		**20**	**Total samples taken 48**

Stoneworts are the most dominant species type, with Bristly stonewort supplying the bulk of that, much like Martham North. Conversely to its sister broad, Martham South had a more productive year for stoneworts than last, with an increase of over 90%. The vascular macrophyte group decreased by over 170%; most of that was down to a large reduction in Holly-leaved naiad and Fennel-leaved pondweed, 180% and 372% respectively. The macro-algae and mosses group stayed quite constant, but within the group Enteromorpha declined considerably with Common water moss almost taking its position. Unlike Enteromorpha and Filamentous algae, Common water moss is not an indicator of nutrient enrichment.

Section 41 species: Starry stonewort which is found principally in the Martham broads declined by 48% and is significantly reduced from the quantity found in 2014 when it was the second most abundant species on the broad. Baltic stonewort, as mentioned is the most abundant species in the broad, but has had better years; Intermediate stonewort is now the second most abundant species but this has had fluctuated greatly in previous years. Holly-leaved naiad has declined since last year and the combined Convergent/ Fragile stonewort was still present in small quantities at two locations.



3.2 Ant Valley

In the Ant Valley, Alderfen, Cromes and Barton Broads were some of the first broads surveyed in 1983 and have been regularly surveyed since. These water bodies have been subject to extensive restoration effort over the last 25 years, and all have experienced improved water quality.

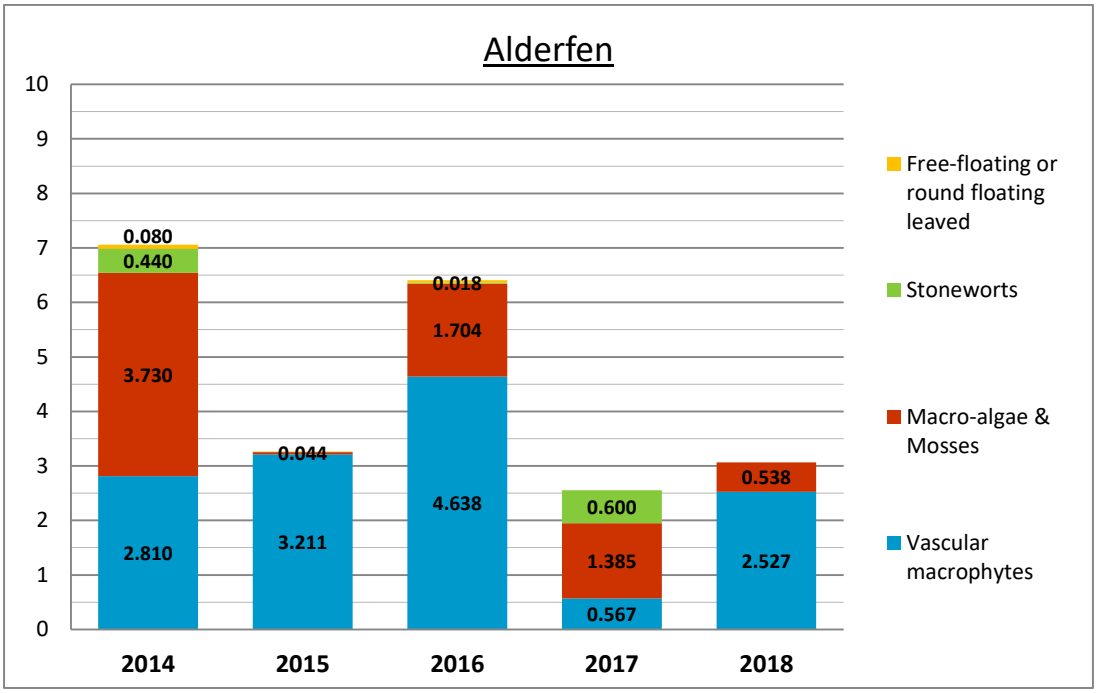
Alderfen

Rigid hornwort and Holly-leaved naiad have returned from a big decline last year, 86% and 95% respectively, but they have not returned to same quantities seen before 2017. Rigid hornwort has returned to be the most abundant species on the broad. The amount of filamentous algae has decreased by 66%, however it is still quite abundant. Unfortunately stoneworts were not found on the broad this year.

Common Name	Scientific Name	Summary Abundance	Occurrences
Rigid hornwort	*Ceratophyllum demersum*	2.169	45
Filamentous algae	*Zygnematales*	0.469	35
Holly-leaved naiad	*Najas marina*	0.358	18
Water net	*Hydrodictyon sp.*	0.069	6
Total number of species recorded		**4**	**Total samples taken 48**

Hydrodictyon is a green algae with colonies forming a mesh structure; this gives it the common name of water net; it likes clean eutrophic waters.

Section 41 species: Holly-leaved naiad has returned to the relatively consistent level found in 2014 and 2015 after the boom and bust of 2016 and 2017 respectively.

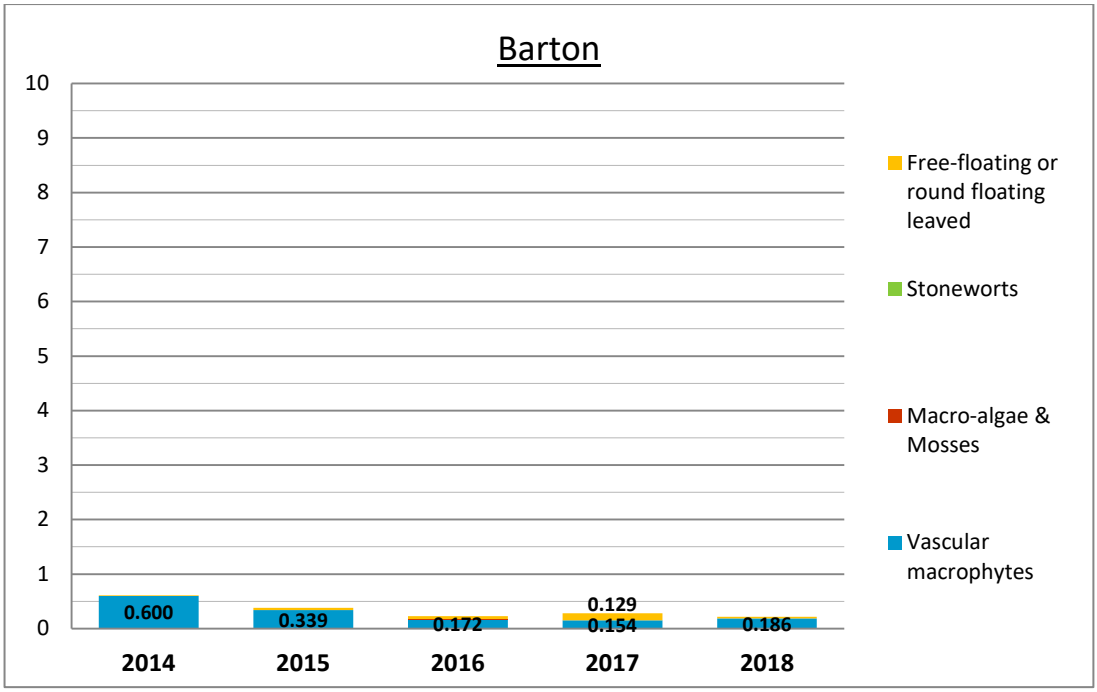


Barton

The usual low abundance levels were found on Barton broad, with Fennel-leaved pondweed being the most common species. There was a very slight decrease in the total abundance and White water lily was not found or observed by the recorders this year.

Common Name	Scientific Name	Summary Abundance	Occurrences
Fennel-leaved pondweed	*Potamogeton pectinatus*	0.100	9
Yellow water lily	*Nuphar lutea*	0.057	5
Nuttall's waterweed	*Elodea nuttallii*	0.029	3
Rigid hornwort	*Ceratophyllum demersum*	0.028	2
Total number of species recorded		**4**	**Total samples taken 72**

Observations: An informal investigation of the plants within the four fish barriers located on the southern half of Barton is conducted each year. The two which are in the Turkey broad area of Barton have a similar plant community and abundance to the main broad. The one at the entrance to the Neatishead Arm is a little better, whereas the final one within the Arm has quite abundant plant growth. Fennel-leaved pondweed and Rigid hornwort were found here along with Common bladderwort which was not recovered in the survey of the main broad.



Cromes Broad

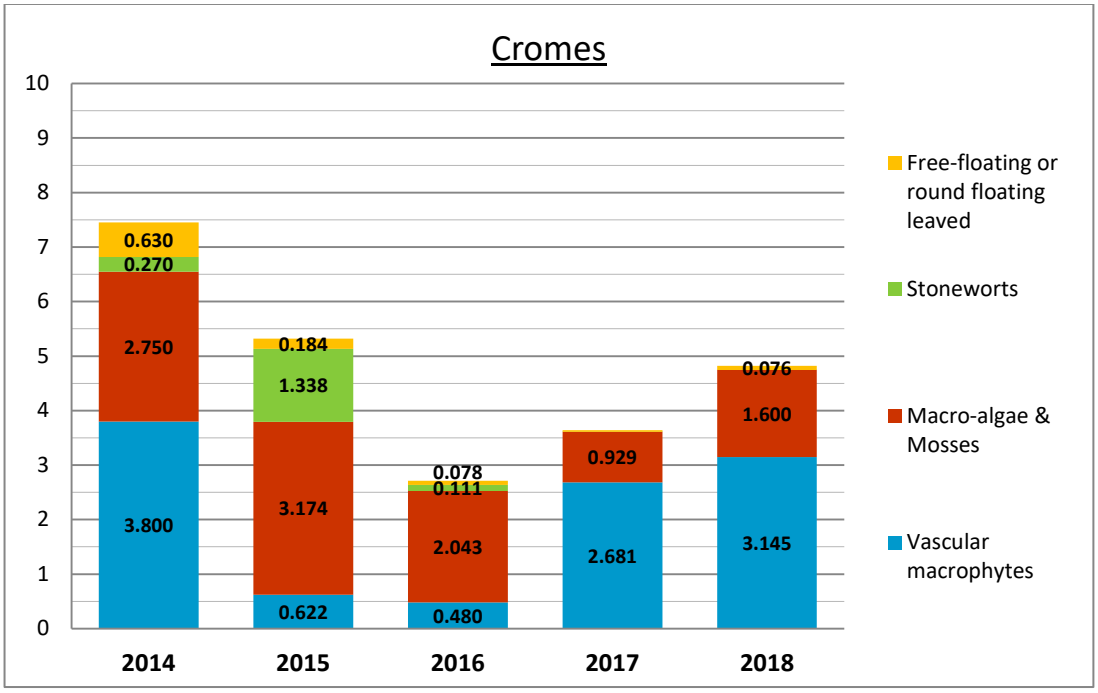
Rigid hornwort continues to do well with an increased abundance score and being found at more locations. Holly-leaved naiad, Water soldier and White water lily have also increased, all of which are indicators of good water quality. In addition, the number of species found here has increased by three; Frogbit, Yellow water lily and Enteromorpha. Admittedly Enteromorpha has been observed in previous years and is, in abundance, an indicator of nutrient enrichment.

Common Name	Scientific Name	Summary Abundance	Occurrences
Rigid hornwort	*Ceratophyllum demersum*	2.929	21
Filamentous algae	*Zygnematales*	1.526	27
Holly-leaved Naiad	*Najas marina*	0.262	10
Water-soldier	*Stratiotes aloides*	0.119	2
Greater bladderwort	*Utricularia vulgaris*	0.095	3
White water lily	*Nymphaea alba*	0.074	3
Enteromorpha	*Enteromorpha*	0.074	4
Fragile/convergent stonewort	*Chara globularis/connivens*	0.002	1
Frogbit	*Hydrocharis morsus-ranae*	0.002	1
Yellow water lily	*Nuphar lutea*	0.002	1
Total number of species recorded		**10**	**Total samples taken 42**

On the graph below it can be seen that vascular plant levels are almost at a level found in 2014. Filamentous algae had a productive year whereas Common bladderwort, a species particularly associated with this broad had a poor year, declining in both abundance and locations.

Unfortunately, stoneworts and floating plants such as duckweeds and lilies are underrepresented.

Section 41 species: Holly leaved naiad appears to be doing well and spreading. Convergent/Fragile stonewort was only found in very small quantities at one location.



3.3 Bure Valley

This is a valley of contrasts, it contains broads which have minimal plant abundance such as Wroxham, Ranworth and Hoveton Great, and then on the contrary there are broads like Cockshoot and Upton Great which are refuges for the rare Holly-leaved naiad which grows there in abundance. Being isolated from the river appears to be a contributing factor.

In addition to the traditional broads surveyed annually, Cockshoot, Hoveton Great, Upton Great and Wroxham, the 2018 survey programme included Decoy broad and Upton Little, which are on different survey timescales.

Cockshoot

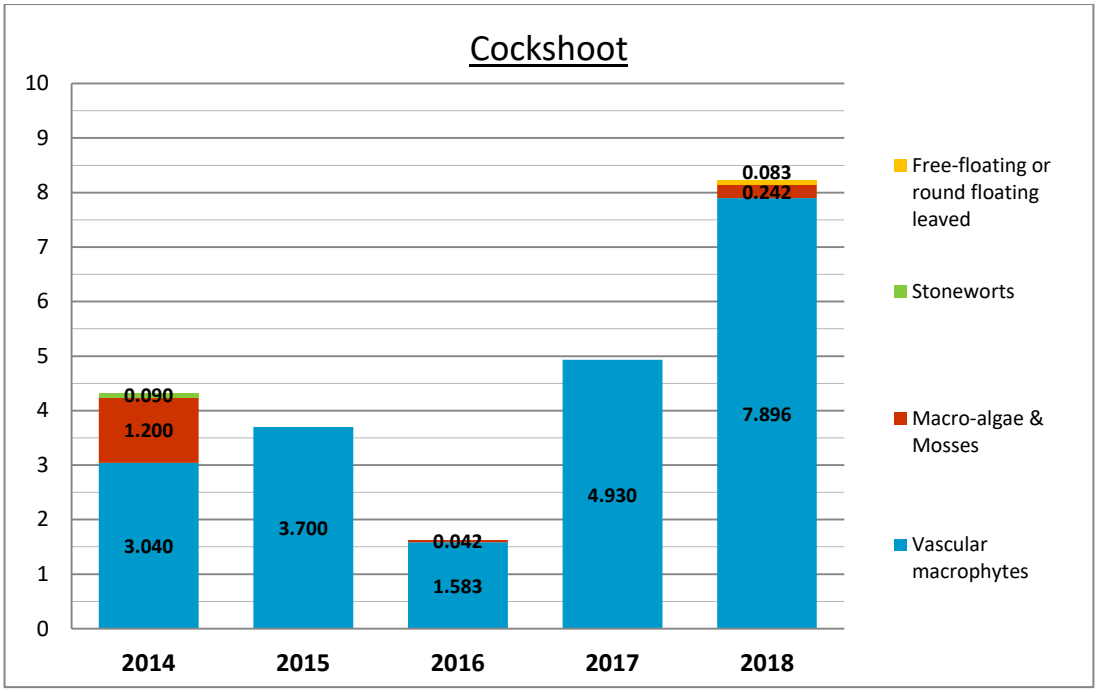
Holly-leaved naiad continues to dominate this broad; it has increased in its abundance and presence. The water clarity here is excellent and the naiad can easily be seen when traversing the broad.

Common Name	Scientific Name	Summary Abundance	Occurrences
Holly-leaved naiad	*Najas marina*	7.542	45
Rigid hornwort	*Ceratophyllum demersum*	0.354	7
Filamentous algae	*Zygnematales*	0.196	13
Yellow water lily	*Nuphar lutea*	0.083	1
Enteromorpha	*Enteromorpha*	0.046	4
Total number of species recorded		**5**	**Total samples taken 48**

The locations where rigid hornwort has been found have decreased; although its density in these locales increased resulting in the increased summary abundance score. Yellow water lily was recorded in one of the bays on the eastern side of the broad. Filamentous algae has increased slightly and along with the new addition of Enteromorpha is something to keep track of in future surveys.

Observations: Frogbit was seen in the entrance to Cockshoot Dyke and both water lilies were seen along with Frogbit in the dyke itself. The survey rake was deployed here to get a further impression of the dyke; it recovered evidence of large quantities of dead filamentous algae which had sunk to the dyke bed.

Section 41 species: Holly-leaved naiad is present almost as a monoculture in this broad.



Decoy Broad

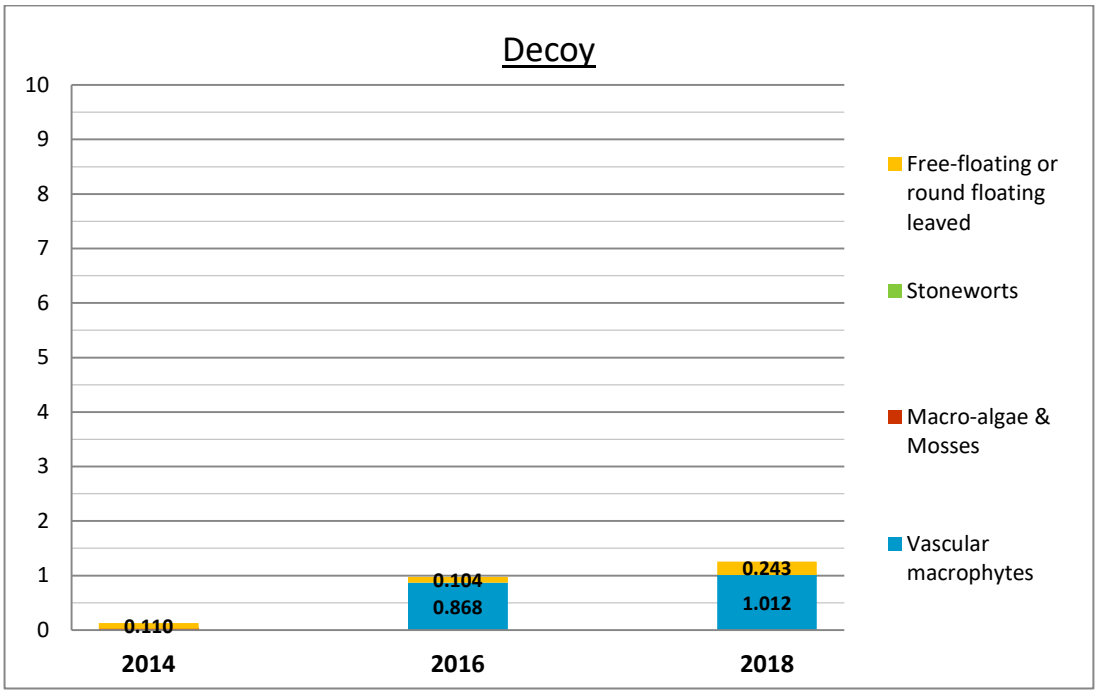
This year's results from Decoy broad are consistent to the previous survey in 2016, however there are differences when abundance scores and occurrences are compared between years.

Common Name	Scientific Name	Summary Abundance	Occurrences
Rigid hornwort	*Ceratophyllum demersum*	32	0.748
Yellow water lily	*Nuphar lutea*	9	0.243
Nuttall's waterweed	*Elodea nuttallii*	8	0.206
Starwort species	*Callitriche sp.*	2	0.020
Unbranched bur-reed	*Sparganium emersum*	1	0.019
Fennel-leaved pondweed	*Potamogeton pectinatus*	1	0.019
Total number of species recorded		**6**	**Total samples taken 54**

Rigid hornwort, which is the most common species, has slightly declined this year but has increased its presence appearing at four more locations. Nuttall's waterweed has increased in abundance and occurrences, with six more locations. Yellow water lily has stayed consistent at its nine locations but it did have a more productive year.

Unbranched bur-reed and Fennel-leaved pondweed appear to be consistent at their location and richness and a starwort species was recorded this year.

Section 41 species: Holly-leaved naiad was not found this year.



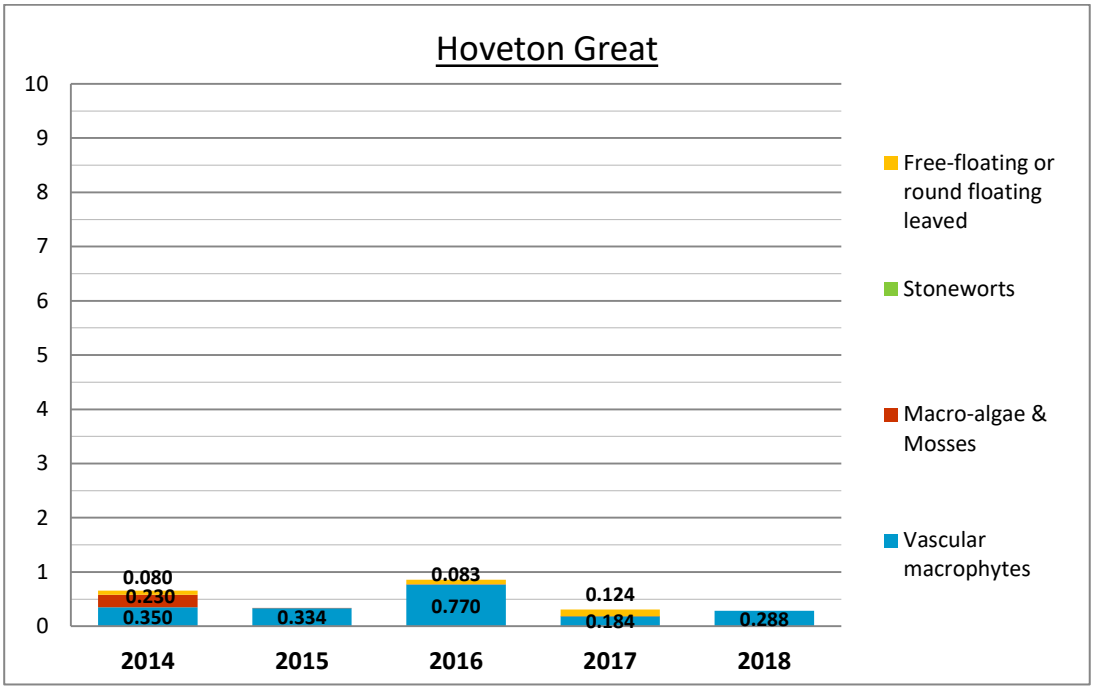
Hoveton Great

Total abundance values are similar to those recorded in 2017. Interestingly it appears that Fennel-leaved pondweed has somewhat benefited from the more disturbed conditions associated with lake restoration works. Rigid hornwort decreased considerably once work began, and levels for 2017 and 2018 are similar but much lower than in 2016. The similar score indicates that it is staying stable but although abundance levels remain similar, the number of hornwort locations has reduced with thicker growth therein.

Common Name	Scientific Name	Summary Abundance	Occurrences
Rigid hornwort	*Ceratophyllum demersum*	0.145	9
Fennel-leaved pondweed	*Potamogeton pectinatus*	0.143	7
Total number of species recorded		**2**	**Total samples taken 56**

Neither yellow water lily nor filamentous algae were recorded in the survey this year.

Observations: The number of survey points on the broad has reduced with the creation of much needed areas of potential reedbed, which is a Priority Habitat listed and described in the UK Biodiversity Action Plan. It has reduced from sixty points in 2016 to fifty-six in 2018.



Upton Great

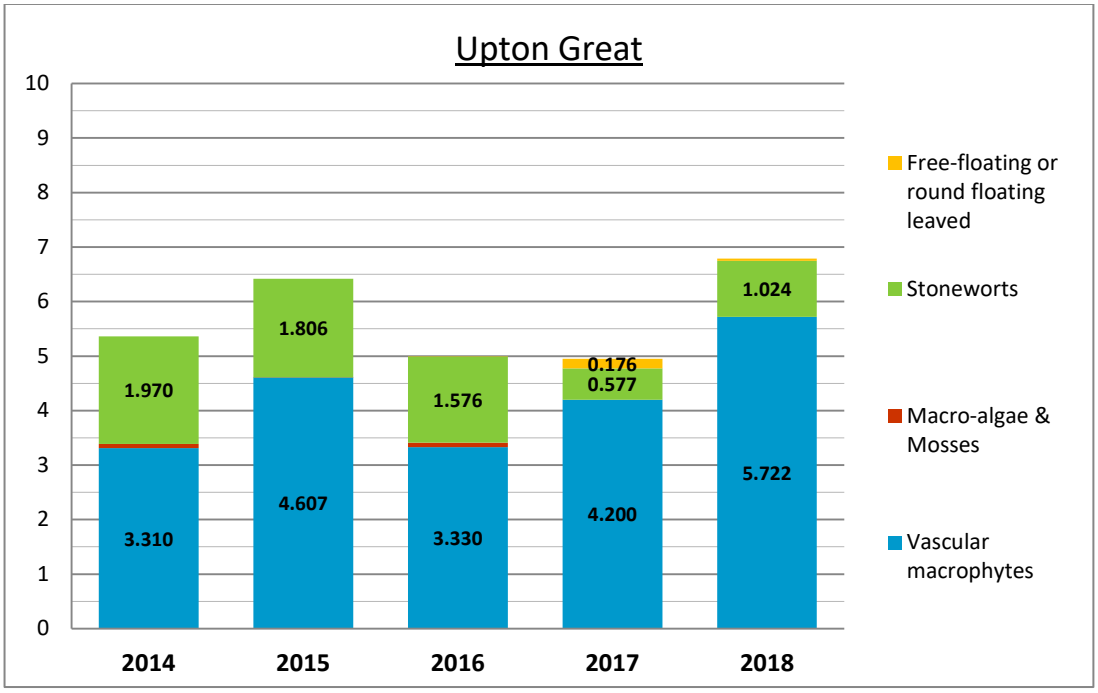
Upton Great is another refuge for the rare Holly-leaved naiad; this year it has increased its presence, occurring at two new points and being found in good quantities. Bristly stonewort appears to be increasing in the broad and Opposite stonewort has returned following a drop in abundance in 2017.

Common Name	Scientific Name	Summary Abundance	Occurrences
Holly-leaved naiad	*Najas marina*	5.722	32
Opposite stonewort	*Chara contraria*	0.587	5
Bristly stonewort	*Chara hispida*	0.435	2
Ivy-leaved duckweed	*Lemna trisulca*	0.043	1
Intermediate stonewort	*Chara intermedia*	0.002	1
Total number of species recorded		**5**	**Total samples taken 46**

Despite these species increasing in abundance, overall species richness has decreased to five compared to nine species found in 2016 and 2017. Species richness has decreased in the past (reduced to four in 2015) in conjunction with a boost in abundance.

Observations: This broad is unusual as there are different bands that stretch across it. The first is a strange sediment band which is quite barren of plant life and begins in the north-west side of the broad and continues all along the southerly side and then stops just before the south easterly corner. Above that there is a thick band of Holly-leaved naiad which cuts horizontally across the broad. Above the Holly-leaved naiad band up to the northern shore is comprised of stoneworts, the composition of which is changeable.

Section 41 species: Holly-leaved naiad and Bristly stonewort are present here and discussed in the above text. Intermediate stonewort was found at a single point in a very small quantity this year.



Upton Little

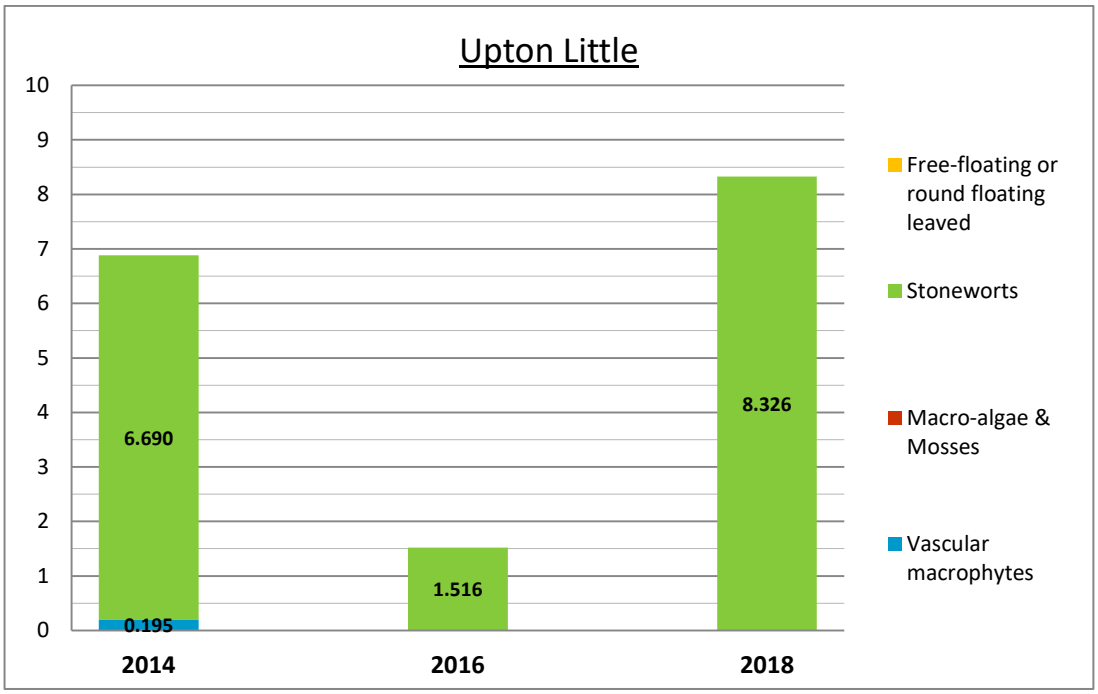
Since this was last surveyed in 2016, it appears that Bristly stonewort has increased its abundance by 467% and increased its range by 10 points. Common stonewort has also increased but nowhere near to the same degree; abundance has gone up by 44% and it has gained three points. Species richness has decreased, from five to two species.

Common Name	Scientific Name	Summary Abundance	Occurrences
Bristly stonewort	*Chara hispida*	8.235	31
Common stonewort	*Chara vulgaris*	0.091	4
Total number of species recorded		**2**	**Total samples taken 34**

Incidentally, in 2016 there were 7 locations where no plants were recorded whereas in 2018 there was only one.

Observations: Small globular green balls were found at a few of the locations within the broad; it is that this is Jelly algae and actually a globular form of cyanobacteria in the genus Nostoc.

Section 41 species: Previously in 2016, Holly-leaved naiad and Intermediate stonewort were found at single locations within the broad. None were found this year.

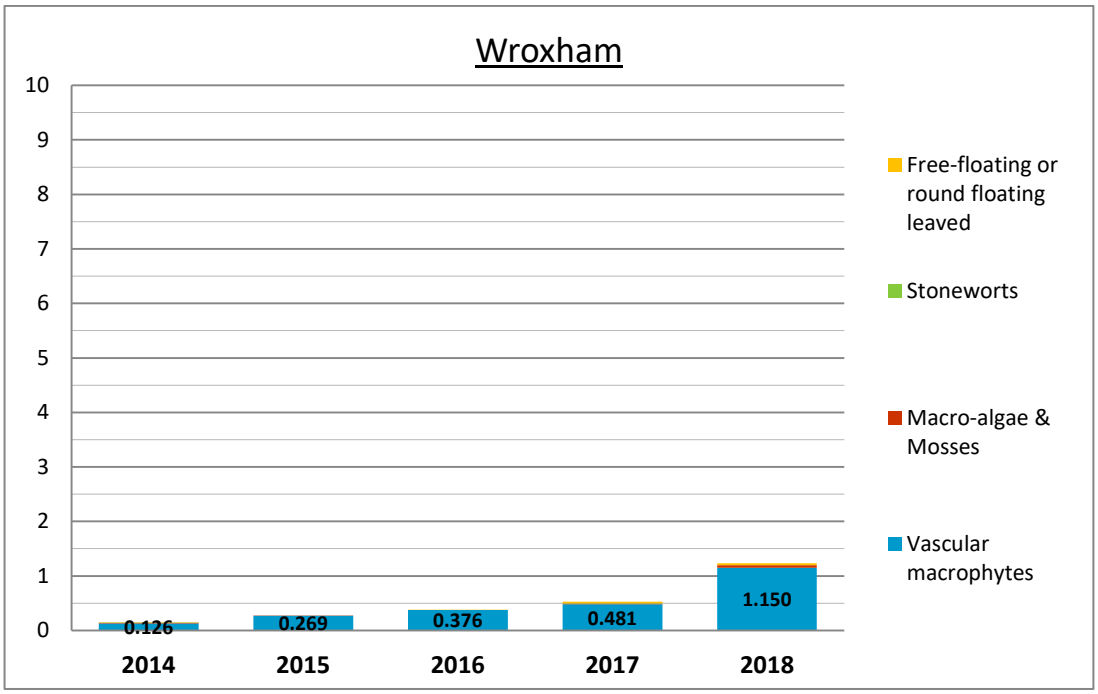


Wroxham

A comparatively good year for Wroxham broad, with an increase in the total summary abundance by 133%. The bulk of this increase comes from Rigid hornwort and Fennel-leaved pondweed with an increase of 62% and 370% respectively. The naturalised Nuttall's waterweed also had a good year, as did filamentous algae, but not in large quantities.

Common Name	Scientific Name	Summary Abundance	Occurrences
Rigid hornwort	*Ceratophyllum demersum*	0.623	29
Fennel-leaved pondweed	*Potamogeton pectinatus*	0.419	19
Nuttall's waterweed	*Elodea nuttallii*	0.074	10
Filamentous algae	*Zygnematales*	0.050	4
Yellow water lily	*Nuphar lutea*	0.032	1
Fan-leaved water crowfoot	*Ranunculus circinatus*	0.018	2
Spiked water milfoil	*Myriophyllum spicatum*	0.016	1
Total number of species recorded		**7**	**Total samples taken 62**

Fan-leaved water crowfoot and Spiked water milfoil were found this year albeit in small quantities



3.4 Yare Valley

The majority of the broads within the Yare Valley are isolated from the main river, with only Bargate, Rockland and Wheatfen having a direct hydrological connection. The Yare valley survey also includes two water bodies which are not a true 'broad' or 'decoy', a manmade lake created from flooded peat diggings or a lake created for wildfowl shooting respectively. Whitlingham Great and Little are created from gravel extraction and are quite young compared to other 'broads'. Rockland and both Whitlingham broads are surveyed every year. Strumpshaw and Wheatfen were also surveyed this year but are not on the annual timetable.

Rockland

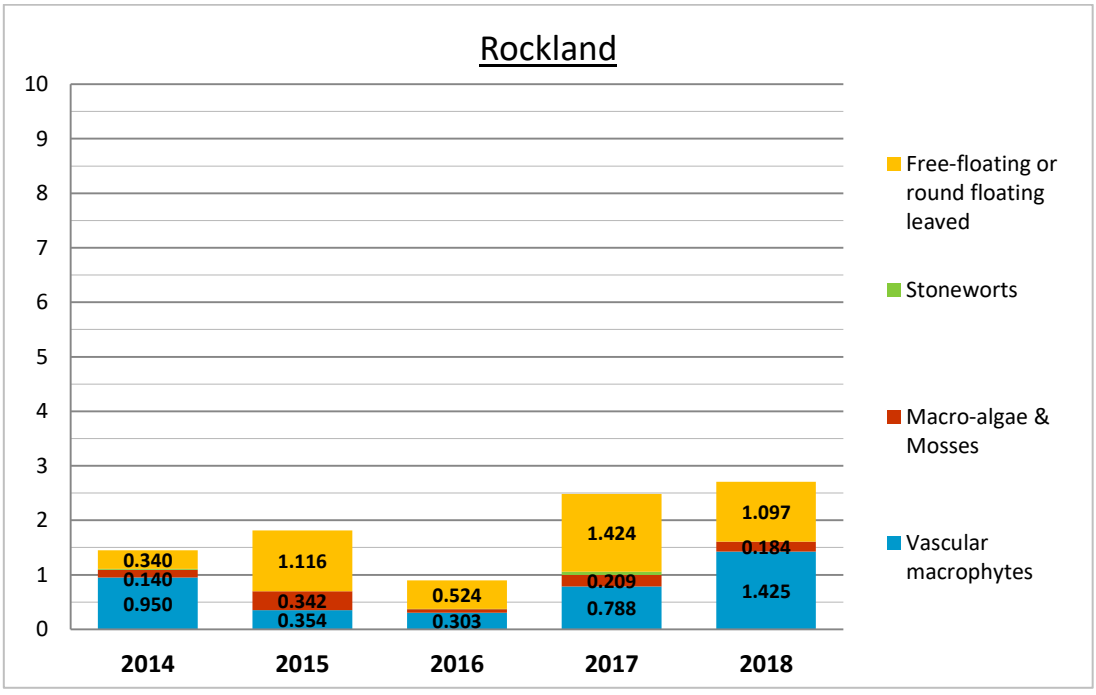
Rockland broad is known for its swathes of yellow water lilies and this year was no exception. There was a slight reduction but they were still very well represented within the shallow bays. Rigid hornwort maintained its position as the second most abundant species. Unbranched bur-reed was recorded on the survey; it is a species that appears to be more typical to flowing waters like rivers, however the tidal flow of Rockland and Wheatfen appear to suit as it is one of the most prolific species.

This year small amounts of three different pondweeds were identified on the survey, lesser, long-stalked and the regular Fennel-leaved pondweed. Whorled water milfoil had a good year as well with increased summary abundance and locations.

Usually a Nitella stonewort species is found in the broad, however no stoneworts were found this year.

Section 41 species: Holly-leaved naiad was not found this year

Common Name	Scientific Name	Summary Abundance	Occurrences
Yellow water lily	*Nuphar lutea*	1.097	26
Spiked water milfoil	*Myriophyllum spicatum*	0.489	31
Rigid hornwort	*Ceratophyllum demersum*	0.324	15
Common water moss	*Fontinalis antipyretica*	0.261	18
Unbranched bur-reed	*Sparganium emersum*	0.163	10
Nuttall's waterweed	*Elodea nuttallii*	0.131	8
Filamentous algae	*Zygnematales*	0.053	5
Fan-leaved water crowfoot	*Ranunculus circinatus*	0.048	3
Starwort sp.	*Callitriche sp*	0.037	5
Intermediate water-starwort	*Callitriche stagnalis*	0.035	4
Holly-leaved naiad	*Najas marina*	0.034	3
Stonewort (*Nitella*) species	*Nitella sp.*	0.016	1
Lesser pondweed	*Potamogeton pusillus*	0.016	1
Long-stalked Pondweed	*Potamogeton praelongus*	0.002	1
Total number of species recorded		**14**	**Total samples taken 62**

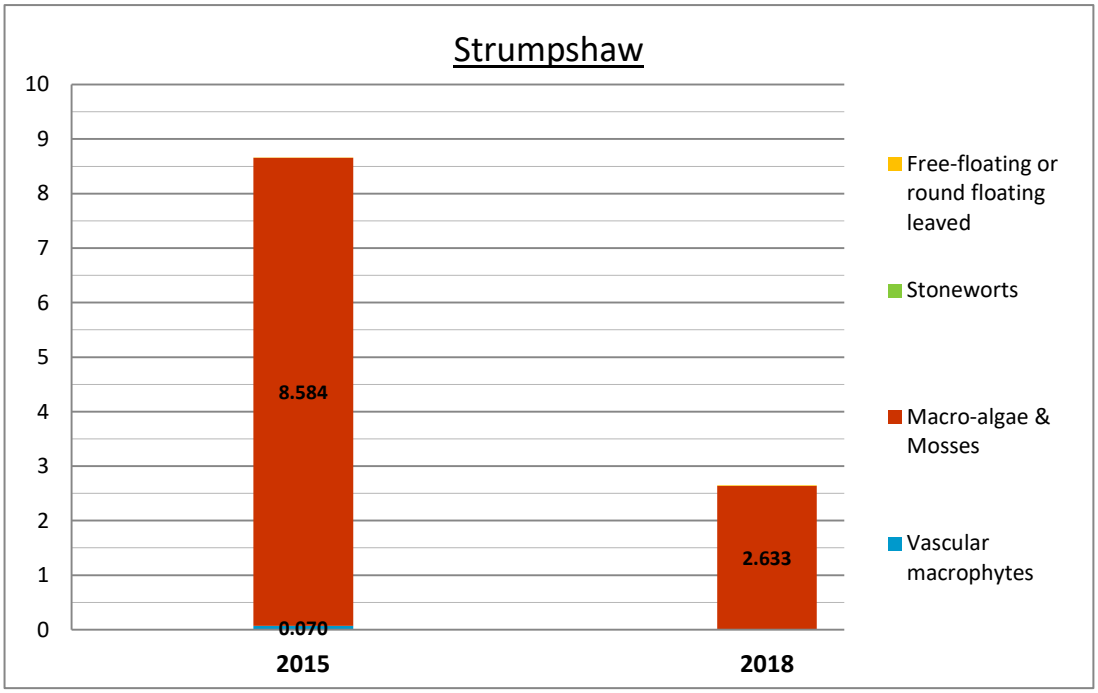


Strumpshaw

Strumpshaw is still dominated by filamentous algae although not to the same extent as seen in 2015 when there were thick blankets across the broad.

Common Name	Scientific Name	Summary Abundance	Occurrences
Filamentous algae	*Zygnematales*	2.633	27
Ivy-leaved duckweed	*Lemna trisulca*	0.01	3
Whorled water milfoil	*Myriophyllum verticillatum*	0.003	1
Total number of species recorded			**Total samples taken 30**

Although there is less filamentous algae, species richness has not increased and in fact it has reduced. Holly-leaved naiad, Rigid hornwort and Inflated duckweed were absent from the survey this year. One instance of Whorled water milfoil was found on eastern side of the broad behind the island.



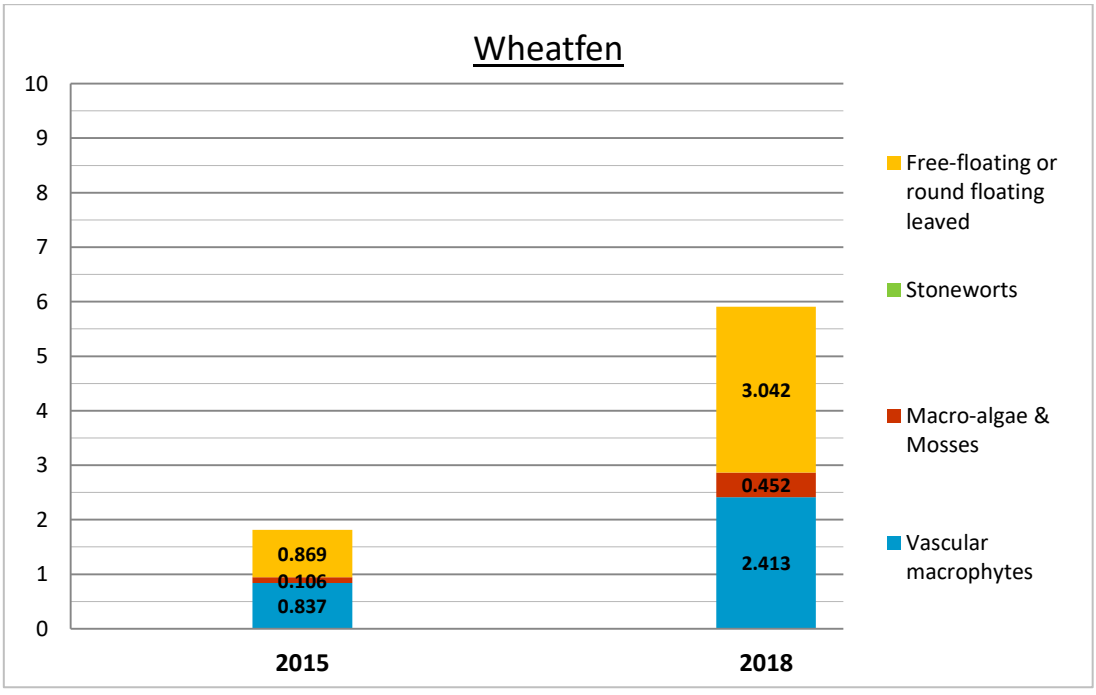
Wheatfen

In the three years since this broad was last surveyed there has been a substantial increase in the total summary abundance score, which can be seen in the figure below. The substance of this increase has been in the free-floating or round-floating leaved, and vascular macrophyte groups. These duckweeds formed thick blankets in the sheltered pools of this broad.

The increase in the vascular macrophyte group appears to be down to Nuttall's waterweed which has increased by over 900%. Filamentous algae also increased, by over 300%.

Species which did not occur in the survey last time include; Whorled water milfoil, Greater duckweed, Arrowhead and Rigid hornwort. Horned pondweed and Common water moss were not recorded this time.

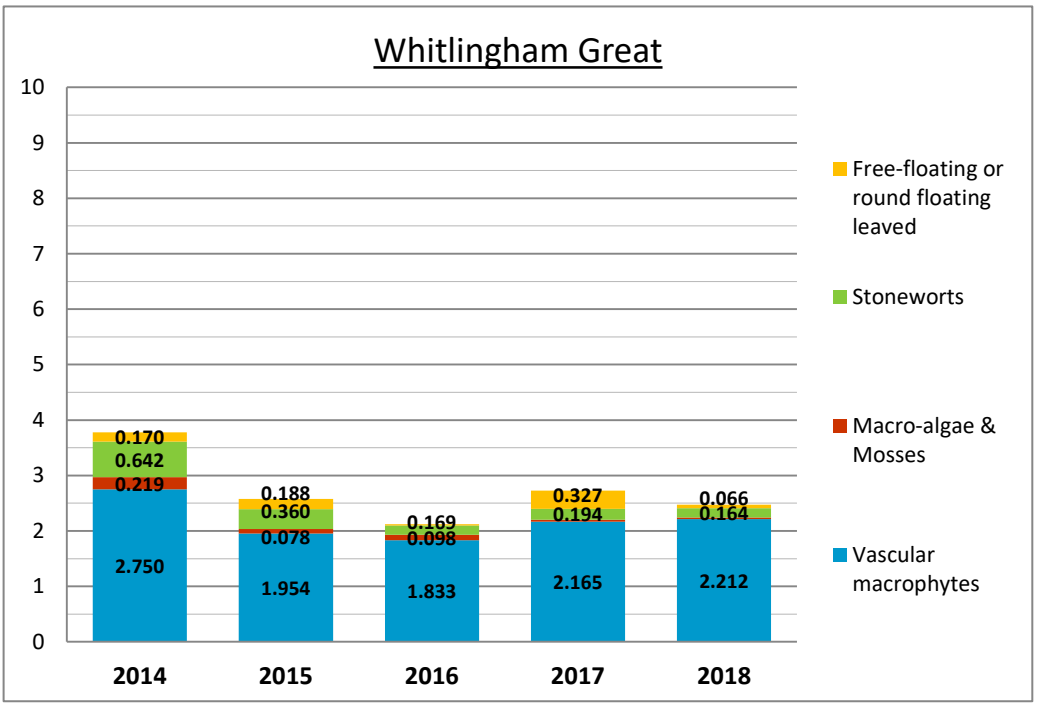
Common Name	Scientific Name	Summary Abundance	Occurrences
Yellow water lily	*Nuphar lutea*	1.111	21
Nuttall's waterweed	*Elodea nuttallii*	1.108	26
Common duckweed	*Lemna minor*	0.863	27
Inflated duckweed	*Lemna gibba*	0.747	21
Filamentous algae	*Zygnematales*	0.426	12
Starwort species	*Callitriche sp.*	0.379	17
Unbranched bur-reed	*Sparganium emersum*	0.371	11
Whorled water milfoil	*Myriophyllum verticillatum*	0.342	5
Greater duckweed	*Spirodela polyrhiza*	0.242	9
Ivy-leaved duckweed	*Lemna trisulca*	0.079	3
Frogbit	*Hydrocharis morsus-ranae*	0.079	2
Amphibious bistort	*Persicaria amphibia*	0.053	1
Enteromorpha	*Enteromorpha*	0.026	1
Spiked water milfoil	*Myriophyllum spicatum*	0.026	1
Fan-leaved water crowfoot	*Ranunculus circinatus*	0.026	1
Arrowhead	*Saggitaria sagittifolia*	0.026	1
Rigid hornwort	*Ceratophyllum demersum*	0.003	1
Total number of species recorded		**17**	**Total samples taken 38**



Whitlingham Great

For the most part, Whitlingham Great has stayed consistent with the previous year; everything apart from the free-floating or round-leaved group has changed very little, although the composition of the main groups has altered.

Common Name	Scientific Name	Summary Abundance	Occurrences
Nuttall's waterweed	*Elodea nuttallii*	1.085	40
Flat-stalked pondweed	*Potamogeton friesii*	0.735	36
Lesser pondweed	*Potamogeton pusillus*	0.274	12
Common stonewort	*Chara vulgaris*	0.129	4
Ivy-leaved duckweed	*Lemna trisulca*	0.066	5
Rigid hornwort	*Ceratophyllum demersum*	0.066	5
Filamentous algae	*Zygnematales*	0.032	2
Curled pondweed	*Potamogeton crispus*	0.032	2
Smooth stonewort	*Nitella flexilis*	0.032	2
Fan-leaved water-crowfoot	*Ranunculus circinatus*	0.016	1
Delicate stonewort	*Chara virgata*	0.003	2
Canadian waterweed	*Elodea canadensis*	0.002	1
Hair-like pondweed	*Potamogeton trichoides*	0.002	1
Total number of species recorded		**13**	**Total samples taken 62**



Nuttall's waterweed is now the most abundant species on the broad, beating Flat-stalked pondweed. Lesser pondweed which was not recovered last year was found this year in decent quantities and numerous locations. Very small amounts of hair-like pondweed and Smooth stonewort were also acquired on the survey.

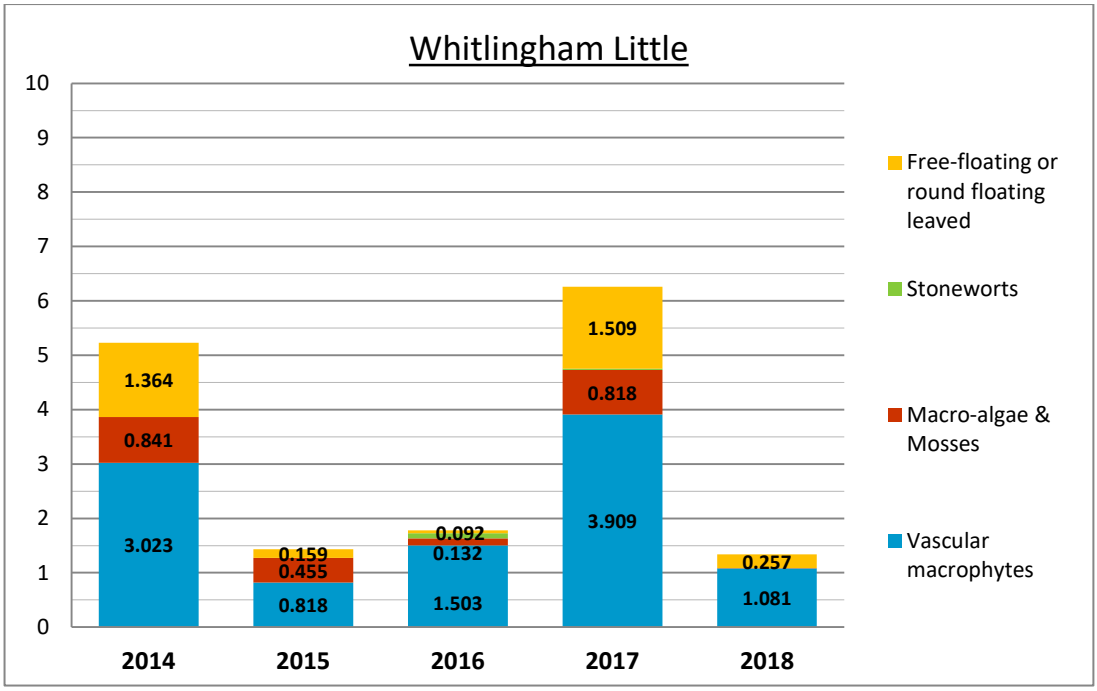
Flat-stalked pondweed decreased by 36%, although it still remains higher than it was in 2014 to 2016. Ivy-leaved duckweed also had a noticeable decrease, nearly 80%, and Common stonewort had a slight decrease, about 32%.

Observations: Water levels were quite low due to the hot conditions and the abstraction of water for agricultural use; the stoneworts in the conservation area north of the island had patches of bleaching.

Whitlingham Little

There was a big reduction in plant growth this year, with a reduction of 79% in total summary abundance. The bulk of this decrease was caused by Nuttall's waterweed which declined by 84% and was found at fewer locations. Conversely Rigid hornwort and Fennel-leaved pondweed were found at more locations and increased by 103% and 75% respectively, although not in the quantities needed to fill the void left by Nuttall's waterweed. At the time of the survey, very little filamentous algae was found on the broad, on paper it is a reduction of over 99%, however this could be due to the algae crashing before the survey, as dead filamentous algae was recovered on the survey rake.

Common Name	Scientific Name	Summary Abundance	Occurrences
Nuttall's waterweed	*Elodea nuttallii*	0.570	20
Rigid hornwort	*Ceratophyllum demersum*	0.352	18
Ivy-leaved duckweed	*Lemna trisulca*	0.248	16
Fennel-leaved pondweed	*Potamogeton pectinatus*	0.159	4
Common duckweed	*Lemna minor*	0.009	4
Filamentous algae	*Zygnematales*	0.002	1
Total number of species recorded		**6**	**Total samples taken 44**



Observations: Jelly alga was found attached to the stems of plants near the centre of the broad. It can be found at the bottom of lakes and is a photosynthesizing bacterium capable of fixing nitrogen and may have a symbiotic relationship with hornwort which it was attached to. Amphibious bistort (Persicaria amphibia) was spotted at a location in the southern half of the broad.

3.5 Waveney Valley

There are six broads along the Waveney valley which are within the Broads Authority executive area, these are; Barnby, Spratt's Water, Woolner's Carr, Round Water, Flixton Decoy and Oulton Broad. The surveying of these broads has been focused on monitoring the progress of the broads following restoration programmes.

None of these broads were scheduled to be surveyed this year.

Acknowledgements

The Broads Authority, Jonathon Cook and Gavin Devaney would like to thank all those individuals and organisations who assisted during the 2018 survey season by providing their time, boats, identification skills or permissions.

Many thanks must be expressed to the landowners who kindly granted permission to access the privately owned & managed broads: Norfolk Wildlife Trust, Natural England, Blofeld Estate, RSPB Strumpshaw, the Horsey Estate and the National Trust.

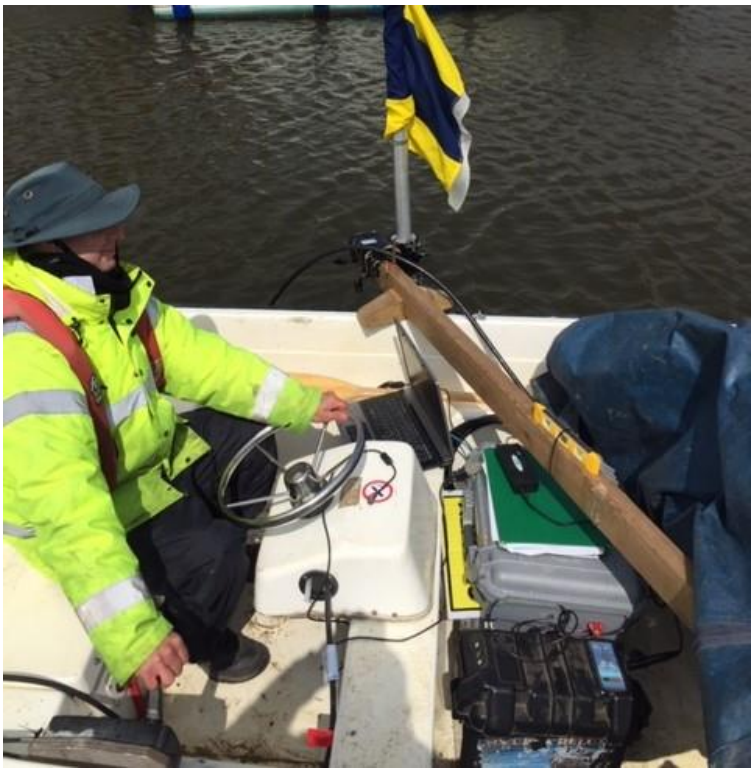
Many thanks to those individuals who facilitated access to the broads this year; John Blackburn, Stephen Watts, Adam Pimble, Kevin Hart, Claire Brooks, Robin Buxton, Steve Prowse, Rick Southwood, Amy Prendergast, Jon Clarke, Richard Starling, Siobhán Rowe & Norwich Canoe Club, Mike Roper & Whitlingham OEC, Will Fitch & The Ted Ellis Trust, John Hopes, Simon Partridge and Chris Tubby from How Hill Trust, Tim Strudwick, Elaine Green, Alex Hendry, Graeme Hewitt, Chris Morphew, Jon Hopes & Christon Iliffe.

Most of all many thanks all those who gave up their time to collect and assist with analysing the water plant and hydroacoustic data; Max Hand, Jonathon Cook, Hannah Southon, Vicky Short, Mark Tomlinson, Beth Williams, Lucy Wright, Lawrence Smith, David Norton, Robert Bellow, Marie-Pierre Tighe, Rachel Stewart, Shaun Taylor, Wyn Purdy, Kath Warner, Elaine Green, Amy Radcliffe, Chris Glasel, Oliver Howlett, Laura Milner and Erica Murray.

A special thanks to Vicky Short for all the GIS work involved.

Appendix III
Hydroacoustic Report

HYDROACOUSTIC SURVEYS OF HICKLING BROAD
Annual Report 2018



Equipment in the survey vessel *Mark Tomlinson*

Hydroacoustic Surveys of Hickling Broad

Draft Annual Report 2018

Mark Tomlinson
Jonathan Cook
Vicky Short
Sue Stephenson

Origination

Version	Author	Date	Detail	Approved by
1.1	MT	05/12/18	Initial Draft	SS
1.2	MT	11/01/19	Final Draft incorporating comments	SS

Distribution

Name	Role	Organisation	For sign-off, information, or comment
Sue Stephenson	E&D Supervisor	BA	Comment & sign off
Dan Hoare	Head of CME	BA	Comment
Andrea Kelly	Senior Ecologist	BA	Comment
Rob Rogers	Director of Operations	BA	Comment

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January 2019

1 Background Information

1.1 Hickling Broad

Hickling Broad (Figure 1) is the largest body of water within the Norfolk & Suffolk Broads, comprising 128 hectares (ha) of open water. The broad has an average depth of 1 metre (m), and the bed is mostly comprised of soft mud with a layer of fluidised sediment on top. Hickling Broad contains species and habitats of high conservation importance, and is also a key navigation waterbody within the Broads executive area.

Figure 1. Aerial image of Hickling Broad from 2014 overlain with OS mapping.

During the spring and summer the vigorous growth of water plants can impede the movement of boats within the broad. As the navigation authority, the Broads Authority (BA hereafter) is obliged to maintain navigable access within the Broads Executive Area. Therefore, the BA has assent to routinely cut submerged macrophytes (water plants hereafter) within the marked channels to enable boat access to continue. At Hickling Broad, the current water depth is below recommended guidelines in parts of the broad (1.3 m at MLW, Sediment Management Strategy, 2007) and water plant growth from the bed during summer months can further reduce accessibility for boats. For Hickling Broad, these recommended guidelines are assessed with consideration to the presence of protected water plant communities. Given the good water plant growth in Hickling Broad and the importance of the broad to navigation and recreation in the Broads, the main channel has undergone management in the form of dredging during the winter months and water plant cutting in the summer.

Hickling Broad is monitored by the BA to assess the condition and status of the water plant community and provide useful information to inform management decisions. Two complimentary survey techniques are conducted at Hickling Broad. Hydroacoustic surveys provide a measure of the height, cover and volume of water plants across the broad. Standard water plant surveys identify the species present at 39 sampling points and provide a score of their abundance. Two water plant surveys are conducted early (May) and mid-season (July). The purpose of this report is to present the findings of the hydroacoustic surveys of Hickling Broad.

1.2 Hydroacoustic surveys

Hydroacoustic surveys have been conducted annually at Hickling Broad since 2012 (Table 1). In 2016, the survey design was updated to incorporate the water plant survey points (see below), with the frequency of surveys also increased (Table 1). In 2017, an additional 18 transects, running parallel to the main transects were conducted in the June, August and October surveys, to increase the coverage of the western section of the broad. The increased survey effort was in response to the expansion of water plants in 2016 with the aim of monitoring the growth of plants over the growing season.

Table 1. Details hydroacoustic survey conducted at Hickling Broad.

Year	Survey date	No. of transects	Distance surveyed (m)
2012			
2013	October	14	4,746
2014		26	8,120
2015	August	18	6,585
2016	June	19	12,468
	October	19	10,565
2017	May	19	12,204
	June	37	21,238
	August	37	22,148
	October	37	22,673

In addition to the survey of the main broad, hydroacoustic surveys have been utilised to monitor the experimental charophyte cutting project conducted in Hickling Broad (see BA 2017).

2 Methodology

Hydroacoustic survey equipment, utilising sonar technology, is commonly used for detection, assessment, and monitoring of underwater physical and biological objects. Boat-mounted hydro-acoustic equipment can be utilised to detect the depth of a water body (bathymetry), as well as the presence or absence, distribution and size of underwater plants.

Such survey equipment measures the range to an object and its relative size by producing a pulse of sound and measuring the time it takes for an echo to return from the object and the amplitude of the returned echo. The range is calculated as a function of the speed of sound and the time it takes for the echo to return.

2.1 Survey design and programme

In 2018, the survey design reverted to the 19 transects (A to S) first surveyed in 2016. The total length of the programmed transects is 12,600 m. The survey consisted of ten transects on an east – west axis and nine on a north – south axis (Figure 2). These parallel transects are 177 m apart and the location where transects intersect correspond to the sample points for the standard water plant survey.

Three surveys were programmed for 2018, in May, August and October. The programme was devised following the assessment of previous hydroacoustic surveys (see 1.2 above). The results suggested that August surveys capture the peak growth of water plants and October best represented the end of the season. The May survey was originally planned for April, but the extension of winter conditions into March 2018 was thought likely to delay the early season plant growth. The survey programme also allowed comparison with previous surveys undertaken

2.2 Survey methodology

The hydroacoustic surveys were conducted by navigating a survey boat along the transects (see Figure 2), maintaining a constant speed approaching 5 miles per hour (mph). The equipment used in this survey included a BioSonics DT-X, single beam (10°), 420 KHz transducer, with an on-board control unit and operating laptop. All data recorded was geo-referenced through connection to an external GPS receiver. This allowed subsequent quantitative analysis of the data using Sonar5-Pro post-processing software, developed specifically with a vegetation analysis component (see below).

The surveys were conducted by trained BA staff with assistances of volunteers on 14th and 15th May, 20th and 21st August and 15th and 16th October 2018. Table 2 presents the total length of transects surveyed in each of the surveys conducted in 2018.

Table 2. Sampling details of the hydroacoustic monitoring of Hickling Broad.

Survey	Dates	Number of transects	Distance surveyed (m)
May	14th & 15th May 2018	19	11,944
August	20th & 21st August 2018	18	11,762
October	15th & 16th October 2018	19	11,976

2.3 Data analysis

Using the Sonar5-Pro software, the sediment surface of each transect file was identified, as well as the less intense return derived from the upper surface of the water plants. Transects were divided into 1 m sections to improve the data analysis.

All features taller than 15 cm above the inferred sediment surface were recorded as water plants during data processing in order to reduce the likelihood of recording false positive results. This level was selected by adjusting the heights at 1 cm increments between 5 and 15 cm for a single transect containing minimal plant growth in the data analysis of the 2016 monitoring. The 15 cm threshold was then used for all surveys for consistency.

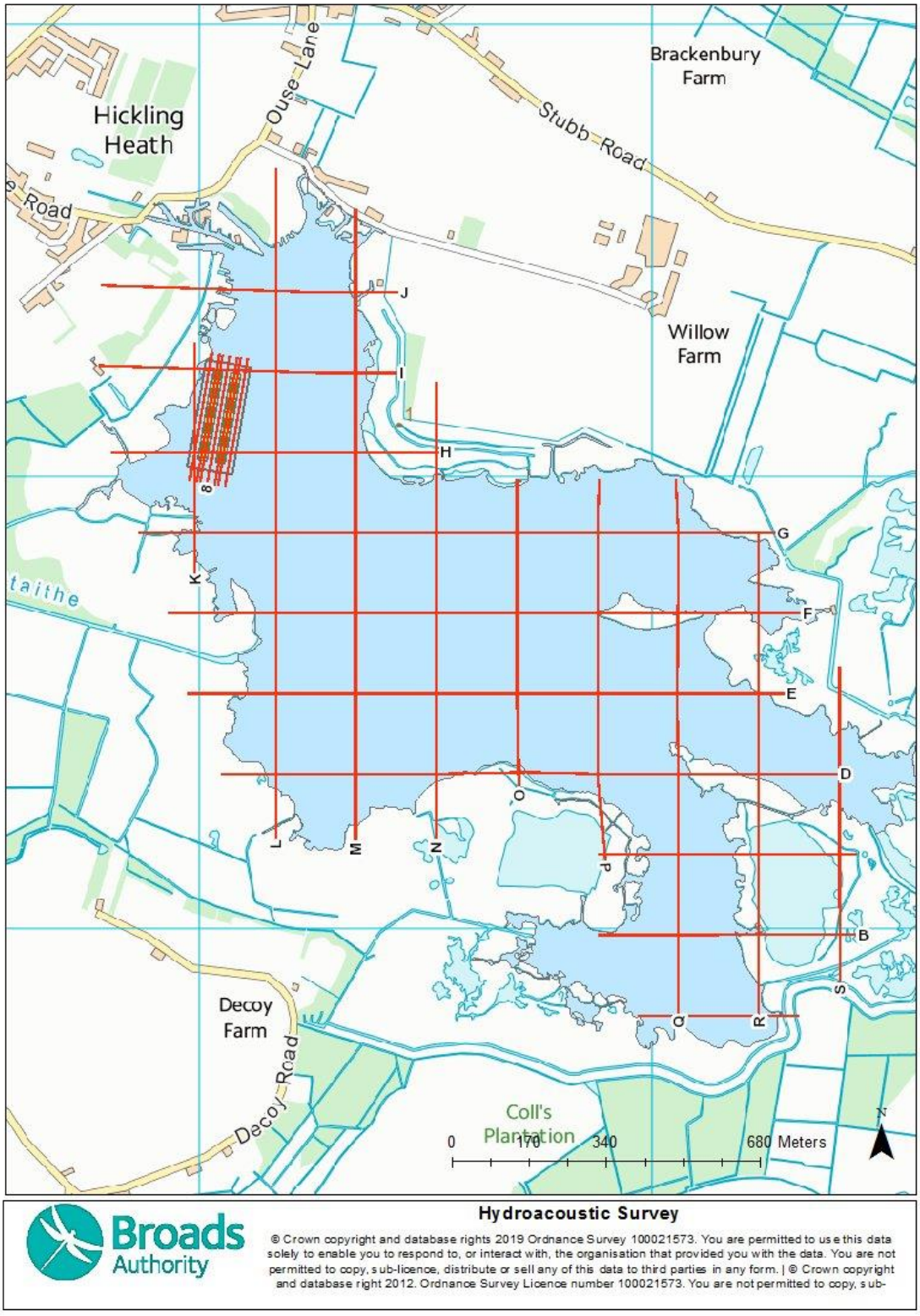

Figure 2. Location of the 19 hydroacoustic survey transects covering Hickling Broad.

The derived results from the processing of the hydroacoustic data were then used to calculate plant height, mean area of lake bed covered by water plants (PAI) and mean percent volume of the water

column inhabited by water plants (PVI). All water depth data was corrected for variation through reference to local water level datums. Overall means were calculated for each survey for the entire broad and the individual transects (A to S).

3 Results & Overview

The results of the three surveys of Hickling Broad are presented in Table 3.

Table 3. Results of the hydroacoustic surveys of Hickling Broad in 2018.

	May	August	October
Maximum water depth (m)	1.83	1.65	1.94
Mean water depth (m)	1.15	1.19	1.48
Maximum water plant height (m)	0.90	0.91	0.97
Mean water plant height (m)	0.43	0.35	0.30
PAI (%)	46.48	57.17	55.95
PVI (%)	18.99	18.11	13.59

In May, water plants reached a maximum height of 90 cm (Transect O), with a mean height of 43 cm overall. Nine transects had plants that reached a maximum height of 80 cm and nine transects had mean heights of at least 40 cm. Transect E (see Figure 2) had the greatest mean cover of water plants with 70%, with the shortest transect (S) containing the lowest cover at just 1%. Overall PVI was estimated at 19%, with values ranging from 0.3% (S) to 34% (E), with a further four transects containing a mean of over 20%.

The maximum plant height recorded in August was 91 cm, with just five transects containing water plants in excess of 80 cm in height. The mean heights ranged from 25 to 41 cm, with only two transects with a mean of at least 40 cm in height. Overall, mean cover was estimated at 57%, with a range of values from 12 (S) to 80% (G) and 12 transects containing a minimum of 50% cover. The mean PVI ranged from just 4 (S) to 27% (B), resulting in an overall mean of 18%. In total, six transects contained PVI minimum values of 20%.

The maximum height of the water plants in Hickling Broad increased to 97 cm in October, with ten transects containing plants greater than 90 cm in height. The mean height of water plants by transect ranged from 22 (B) to 41 (O) cm, resulting in an overall mean of 30 cm for the broad as a whole. Cover of plants ranged from 24 (S) to 73% (O) which resulted in an overall mean of 56% across the entire broad. The mean PVI values by transect ranged from 7 (S) to 21% (O), with an overall mean of 14%.

The three surveys do reveal interesting patterns of water plant growth over the summer and autumn. The western area of Hickling Broad consistently contained greater cover throughout the study period (see the dominance of red and orange values in Figure 3). For example the north-south transects K, L, M and N had a minimum mean cover of 40% in the May survey, with N and O increasing over the study period. Cover in L decreases, however this is a function of the northern section of the transect running through the marked channel and thus cut for navigation reasons. The dredging of the channel is also reflected in L with the second lowest PVI in August and October.

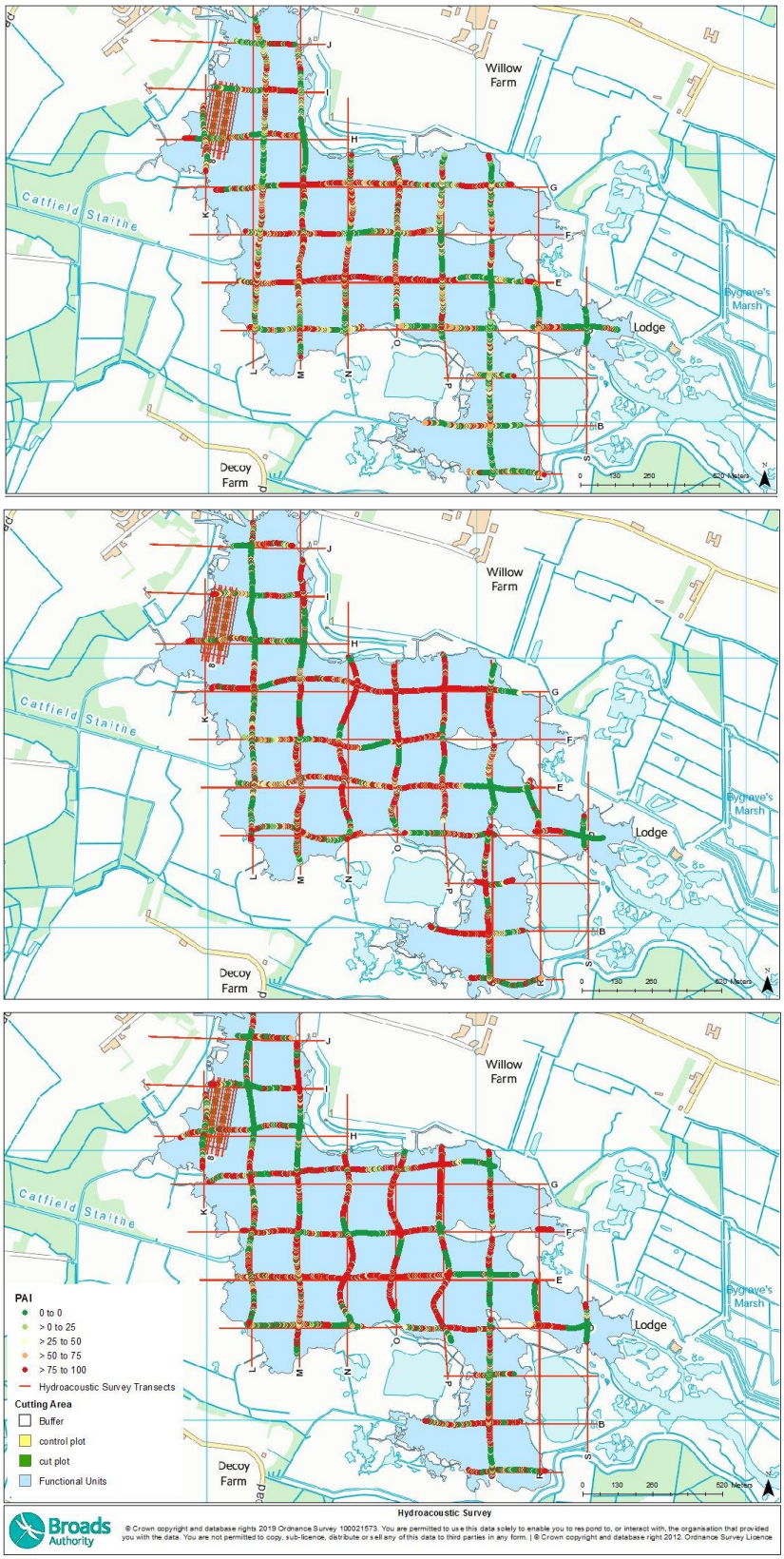

Figure 3. Map detailing the cover of water plants within Hickling Broad as revealed by the hydroacoustic survey in May, August and October 2018.

The east-west transects which cover the western section E to J also maintained good cover with E, F and G maintaining cover of at least 60%throughout the study period. In contrast, the eastern and southern transect, A, B, C, Q, R and S have relatively poor cover in spring (1 to 38%) but increased over the summer (12 to 73% in August).

These patterns of water plant growth correspond with the findings of the annual water plant surveys of Hickling Broad (see Table 4). Whilst the key species are the same in the eastern and western areas of the broad, the abundance scores were relatively constant between May and August in the west whereas the abundance scores generally increased in the east.

Table 4. Abundance scores of key species in the eastern (n=15) and western (n=16) areas of Hickling Broad as revealed by the water plant surveys of May and August 2018.

Common name	Scientific name	East		West	
		May	August	May	August
Baltic stonewort	*Chara baltica*	0.6	0.5	0.5	0.5
Intermediate stonewort	*C. intermedia*	0.4	1.1	0.7	0.5
Spiked water milfoil	*Myriophyllum spicatum*	0.6	1.0	1.3	1.2
Holly-leaved naiad	*Najas marina*	0.2	0.2	0.0	0.2
Fennel-leaved pondweed	*Potamogeton pectinatus*	0.3	0.6	0.3	0.3

Figures 4 and 5 present the water plant growth patterns over the growing seasons consistently sampled between 2016 and 2018. The data for plant height doesn't reveal clear patterns of growth, although the mean height will be influenced by the cutting of plants within the marked navigational channel. Nevertheless, with the exception of the maximum height of 2.19 m recorded in August 2018, the maximum height of water plants generally remained within 23 cm over the course of a single growing season. Likewise, the mean height of the water plants remained within 15 cm during each growing season (Table 5; Figure 4).

Table 5. Results of the hydroacoustic surveys conducted at Hickling Broad between 2012 and 2017.

Year	Survey date	Max. plant height (m)	Mean plant height (m)	PAI (%)	PVI (%)
2012					
2013	October	0.89	0.18	24.40	7.15
2014		0.97	0.28	52.09	16.19
2015	August	1.04	0.24	33.13	15.52
2016	June	1.11	0.31	17.44	5.48
	October	0.91	0.41	23.97	10.54
2017	May	0.80	0.41	28.73	12.77
	June	0.89	0.34	51.64	19.36
	August	2.19	0.47	65.69	27.66
	October	1.03	0.39	65.55	27.14

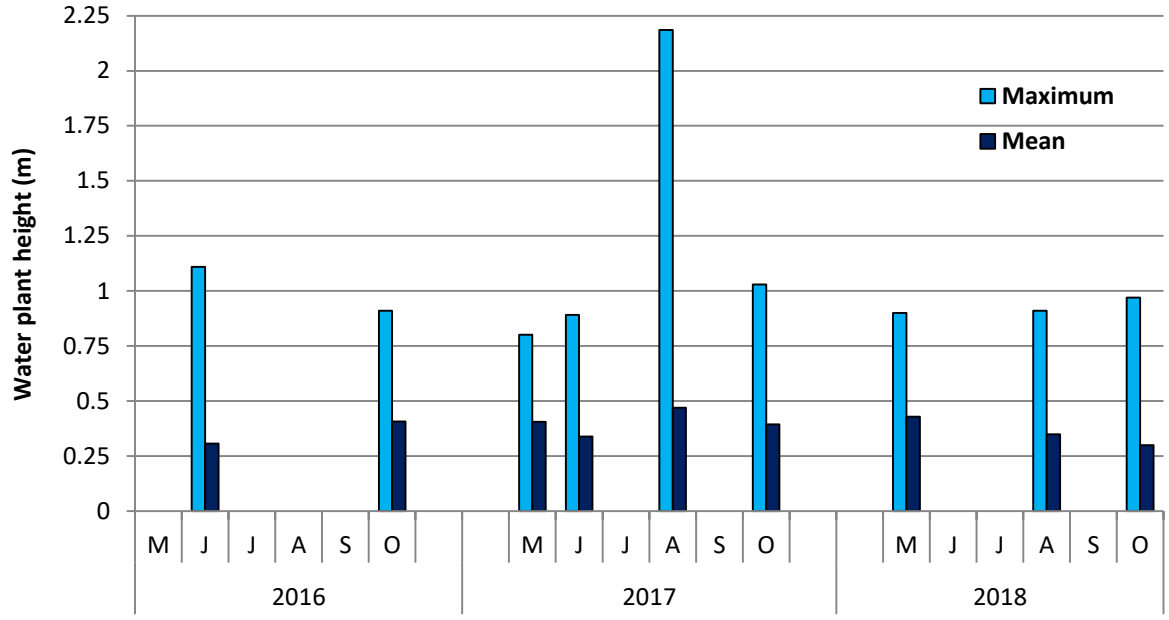

Figure 4. Details of water plant growth over a single growing season (May to October) as revealed by hydroacoustic surveys of Hickling Broad, 2016 to 2018.

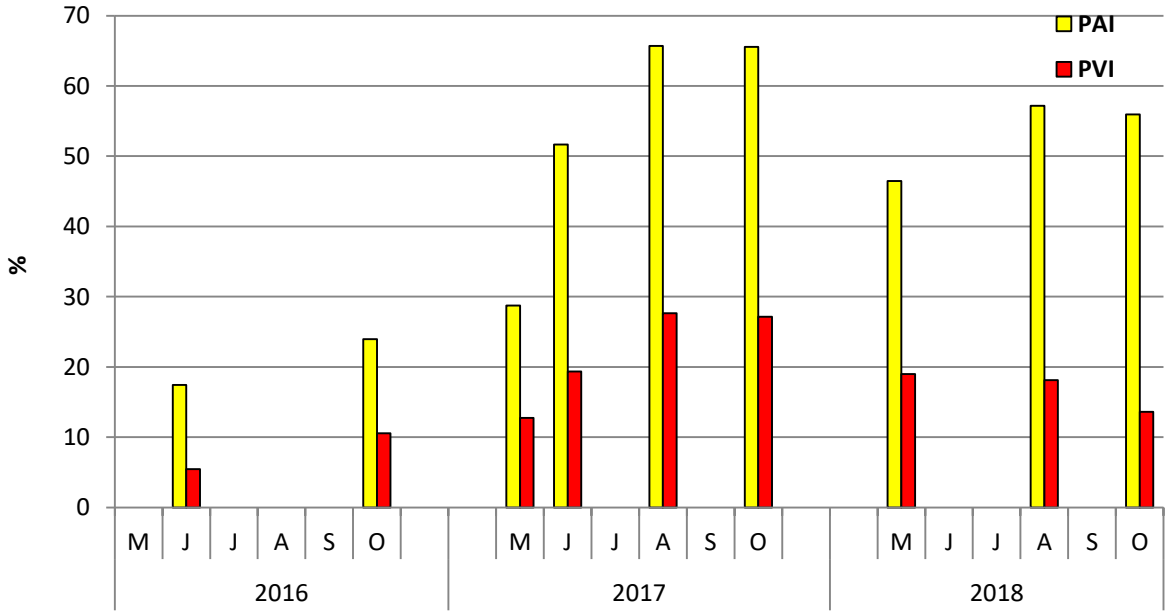

Figure 5. Details of the cover and volume of water plants in Hickling Broad as revealed by hydroacoustic surveys, 2016 to 2018.

Whilst data has not been gathered each month of the growing season, the conducted surveys indicate that the cover of water plants within Hickling Broad increase from spring levels, reaching a peak in August (Table 5; Figure 5). Cover reduces with natural 'die back' of plants in October but levels appear to remain high. Given the similar patterns observed in 2017 and 2018, cover is unlikely to have exceeded 30% in August 2016. Also worthy of note is that despite the higher cover of water plants in the May survey of 2018 compared to 2017, subsequent cover was lower than 2017 despite the ideal conditions for growth, i.e. the hot dry summer weather experienced in 2018. In general,

the volume of water plants followed a similar pattern, although the PVI values are calculated based on the water depth at the time of the survey and do not account for the tidal nature of the broad. Given the range of water levels experienced at Hickling Broad, typical range of between 0.1 and 0.69 mAOD (https://www.gaugemap.co.uk/#!Detail/1561/1706) this can influence the observed patterns.

4 Conclusions & Recommendations

- Peak cover of water plants in 2018 was recorded in August with a mean value of 57%. Both the greatest values for mean height and volume of water plants were recorded in May at 43 cm and 19% respectively;
- The cover of plants was consistent in the western area of Hickling Broad, with the increased overall cover from May to August linked to the growth within the eastern section;
- The hydroacoustic surveys of Hickling Broad (2016-2018) reveal that water plant growth and cover was greatest in 2017, followed by 2018;
- The survey programme conducted in 2018 provided good water plant data to present growth patterns over the growing season and should be repeated in 2019. Should resources allow the intermediate months should be considered for survey; and
- Coupled with the standard water plant point surveys, hydroacoustic surveys are a useful monitoring tool for the broads.

Appendix IV
Details of Statistical Analysis

Table 1. Details of the Kruskal- Wallis tests for all broads combined, riverine broads combined, isolated broads combined and individual broads for overall abundance, species richness, Section 41 species abundance and Section 41 species richness between sampling years.

Category	Broad	n	H	df	p
Overall abundance	All broads	2886	0.03	4	ns
	Riverine broads	1896	0.03	4	ns
	Isolated broads	995	0.27	4	ns
	Alderfen Broad	120	50.33	4	0.000
	Barton Broad	181	0.16	4	ns
	Cockshoot Broad	123	178.05	4	0.000
	Cromes Broad	106	78.30	4	0.000
	Decoy Broad	81	13.67	2	0.001
	Heigham Sound	157	30.90	4	0.000
	Hickling Broad	195	1.37	4	ns
	Horsey Mere	165	2.10	4	ns
	Hoveton Great Broad	150	0.88	4	ns
	Martham Broad North	125	23.90	4	0.000
	Martham Broad South	127	95.63	4	0.000
	Rockland Broad	155	8.45	4	ns
	Upton Broad	116	24.80	4	0.000
	Upton Little Broad	50	854.19	2	0.000
	Whitlingham Great Broad	160	7.89	4	ns
	Whitlingham Little Broad	88	174.86	3	0.000
	Wroxham Broad	162	3.67	4	ns
Species richness	All broads	2886	<0.01	4	ns
	Riverine broads	1896	<0.01	4	ns
	Isolated broads	995	<0.01	4	ns
	Alderfen Broad	120	<0.01	4	ns
	Barton Broad	181	<0.01	4	NS
	Cockshoot Broad	123	<0.01	4	ns
	Cromes Broad	106	0.01	4	ns
	Decoy Broad	81	0.03	2	ns
	Heigham Sound	157	0.02	4	ns
	Hickling Broad	195	<0.01	4	ns
	Horsey Mere	165	<0.01	4	ns
	Hoveton Great Broad	150	<0.01	4	ns
	Martham Broad North	125	<0.01	4	ns
	Martham Broad South	127	0.02	4	ns
	Rockland Broad	155	0.03	4	ns
	Upton Broad	116	<0.01	4	ns
	Upton Little Broad	50	<0.01	2	ns
	Whitlingham Great Broad	160	<0.01	4	ns
	Whitlingham Little Broad	88	0.02	3	ns
	Wroxham Broad	162	<0.01	4	ns
Section 41 abundance	All broads	2886	0.05	4	ns
	Riverine broads	1896	<0.01	4	ns
	Isolated broads	995	<0.01	4	ns

	Alderfen Broad	120	1.02	4	ns
	Cockshoot Broad	123	178.05	4	0.00
	Cromes Broad	106	0.12	4	ns
	Decoy Broad	81	13.67	2	0.001
	Heigham Sound	157	0.28	4	ns
	Hickling Broad	195	0.55	4	ns
	Martham Broad North	125	88.74	4	0.000
	Martham Broad South	127	63.61	4	0.000
	Upton Broad	116	39.77	4	0.000
	Upton Little Broad	50	321.25	2	0.000
Section 41 Richness	All broads	2886	<0.01	4	ns
	Riverine broads	1896	<0.01	4	ns
	Isolated broads	995	<0.01	4	ns
	Alderfen Broad	120	<0.01	4	ns
	Cockshoot Broad	123	<0.01	4	ns
	Cromes Broad	106	<0.01	4	ns
	Decoy Broad	81	0.03	2	ns
	Heigham Sound	157	<0.01	4	ns
	Hickling Broad	195	<0.01	4	ns
	Martham Broad North	125	0.04	4	ns
	Martham Broad South	127	0.04	4	ns
	Upton Broad	116	<0.01	4	ns
	Upton Little Broad	50	0.04	2	ns