EXPERIMENTAL CUTTING OF STONEWORT IN HICKLING BROAD, 2017-2019

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Broads Authority
Yare House
62-64 Thorpe Road
Norwich NR1 1RY

Experimental Cutting of Stonewort in Hickling Broad, 2017-2019
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Abigail Leach
Jonathan Cook
Vicky Short
Sue Stephenson
Dan Hoare

Origination

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1. Introduction

1.1 Background

Hickling Broad is the largest broad within the Norfolk and Suffolk Broads system, with approximately 120 hectares of open water. Recent Broads Authority hydrographic surveys show a water depth outside the marked channel of less than 1.2 m at mean low water level. The bed of the broad is mostly comprised of soft mud overlain with a layer of fluidised sediment. Hickling Broad contains species and habitats of high conservation importance, including several rare and important species of charophyte, or stonewort (Barker et al., 2008). Hickling Broad is also an important recreational and race sailing waterbody, popular with a broad spectrum of water user groups. However, plant growth outside of the marked channel can impede sailing vessels, and improvements in water quality have led to increases in water plant growth which can exacerbate this issue. This then creates a challenge for year-round access for all craft to the whole of the broad, without compromising the biodiversity, or breaching the legislation designed to protect it.

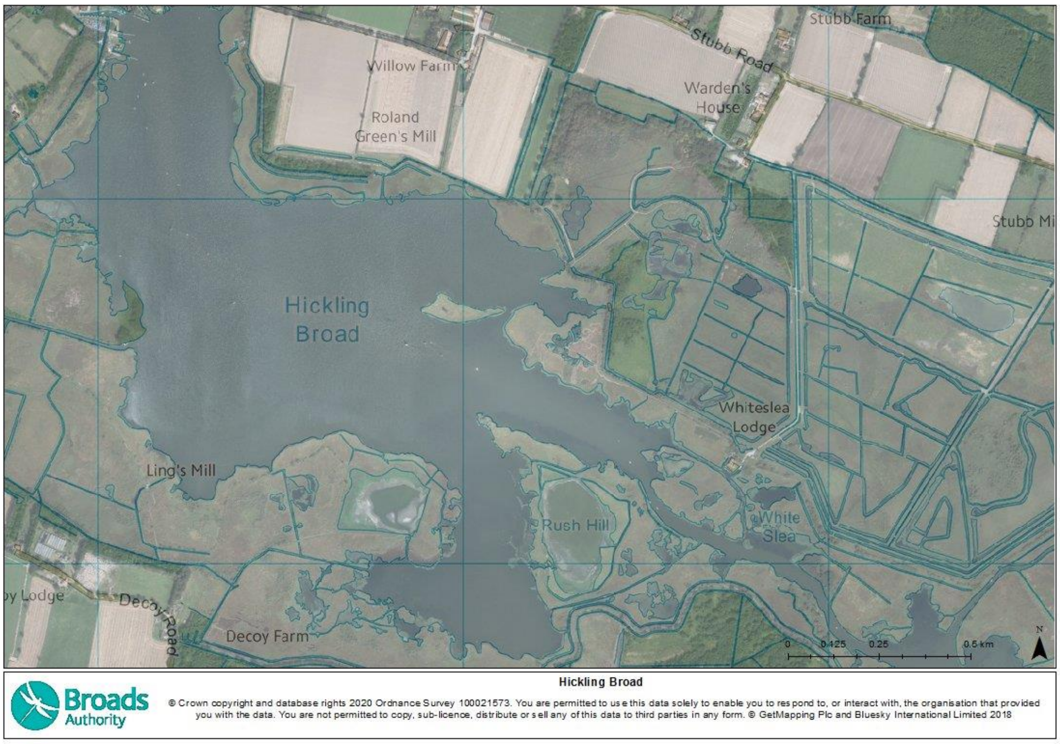

Figure 1: Map of Hickling Broad

The Broads Authority has a duty to maintain the navigation area for the purposes of navigation to such standard as appears to it to be reasonably required; and to take such steps to improve and develop it as it thinks fit. Vigorous plant growth in recent years has therefore presented a number of challenges around managing navigational access on a site dominated by a protected water plant community (Jackson et al., 2001).

The water plant growth in Hickling Broad has been managed within the marked channel through a programme of dredging projects and routine water plant cutting in the growing season (Table 1). Outside of the marked channel, dense growth of water plant near to the water surface has implications for boat handling and safety; sailing boats with deeper keels (typically drawing 90 cm) may become impeded by the plants. Not only sailing boats but windsurfers, canoers, paddleboarders and anglers also utilise a much greater proportion of the open water of the broad, compared with motor vessels which largely stay within the marked channel.

Table 1: History of Broads Authority water plant management across Hickling Broad (1994 - 2017)

Period	Description
1994 - 1998	A cutting and monitoring programme for Spiked water-millfoil (*Myriophyllum spicatum*) and pondweeds (*Potamogeton* species) which covered approximately a third of the open water area of the broad
1998	An experimental 50 x 50 m plot of Intermedia stonewort (*Chara intermedia*) cut and monitored.
1999	Trial plots of Intermediate stonewort cutting extended (38 ha).
2000 - 2006	Trial of Intermediate stonewort cutting suspended due to lack of growth.
2016 onwards	Annual cut of all plants within the marked channel when certain criteria are met was initiated as water plant abundance increased.
2017	Criteria met for experimental charophyte cut in small plots. One cut was carried out and then monitored for three seasons (this report)
2017-2019	Cutting of non-Chara species outside of the main channel in a limited strip either side of the marked channel

In most years prior to 2020, there has been limited plant growth in the central area of the broad, and within the marked channel; probably as a consequence of lower water clarity and poorer light conditions at the sediment surface in this deeper part of the broad. This central area is likely to be subject to greater sediment disturbance by motorboat traffic as well as wind generated wave action. These forces act on the mobile, unconsolidated sediment that tends to focus in the centre of the waterbody, and therefore creating poorer water quality conditions. Increased plant growth in recent years however, extending out from the broad margins and towards the marked channel, has resulted in significant impacts on water user groups who access areas outside the marked channel. Between 2017 and 2019, low water levels exacerbated the issue, with water plants being brought closer to the water surface.

In 2017 abundant plant growth, in conjunction with unresolved issues for recreational users of the broad, gave rise to a proposal for an experimental water plant cut, outside of the marked channel. This trial was developed in consultation with Natural England (NE), Environment Agency (EA) and the landowner, Norfolk Wildlife Trust (NWT), brought together under the Hickling Broad Enhancement Project. Given the uncertainty and limited international scientific literature around the impacts of cutting stonewort, the proposal included a specific trial of cutting stonewort in Hickling Broad.

1.2 Aims and Objectives

The trial was built upon a significant body of earlier research into stonewort growth in Hickling Broad (Harris, 2000; Jackson, Georgiou & Crooks, 2001). The purpose of this trial was to provide a better understanding of the impact of repeat cutting on the height, density and overall integrity of the stonewort bed; the stonewort species composition within the bed; and to generate robust data to inform discussions around the future management of water plants.

To focus the data gathering and statistical analysis, it was hypothesised that, in comparison to control areas, cutting would result in a:

a) reduction in overall plant height,

b) reduction in overall plant cover,

c) decrease in charophyte prevalence within the plant community.

The aim of this report is to summarise the findings of the three years of water plant monitoring conducted after cutting and produce recommendations for the future management of the water plant communities in Hickling Broad.

1.3 Project constraints

1.3.1 Cutting and collecting water plants

Routine cutting and collecting of water plants across the Broads is carried out with Berky type-6520 water plant harvesters; a work vessel with adjustable cutting bar height, reciprocating blades and integral conveyor belt system to collect the cut material. In terms of planning specific cutting operations, the geo-positioning of this type of vessel is highly influenced by wind; the overall limitations in manoeuvrability of a long vessel with a submerged and heavy cutter head attachment; and the absence of permanent marks by which to accurately locate in an open water environment. Typically, this type of vessel operates best in straight lines, with the ability to raise and lower the cutter head. Given these constraints, the size, shape and location of the cut areas needed to be as simple and repeatable as possible, without demanding complicated locating by the operator.

1.3.2 Criteria for permission for cutting stoneworts

There are legal restrictions, as regulated by Natural England, on activities and developments that might affect a designated site such as Hickling Broad. Central to the project was the set of ecological criteria and thresholds, established in consultation with the Hickling Broad Enhancement Project board, which had to be achieved before any cutting could take place. These criteria were:-

- Water plants were causing problems reported by water users,
- "favourable condition" (as defined within the Conservation Regulations 2010) for stoneworts was being achieved within the open water unit of the Hickling Broad SSSI. This was specifically defined for this SSSI unit by Natural England as characteristic Chara species present at >60% of plant survey sample points in the Broads Authority's June plant survey,
- A dense stonewort bed covered the study area,
- Plant growth reached within 60 cm of the water surface (at mean low water (MLW)).

2. Methodology

2.1 Experimental Design

Hydroacoustic and rake based water plant survey methods routinely used in Hickling Broad were reviewed and considered when developing this project's experimental design (see Broads Annual Water Plant Survey Report 2016 (broads-authority.gov.uk). In 2016, hydroacoustic surveys identified a dense stonewort bed in the north western section of Hickling Broad. A central 2.4ha (100 x 240m) study area was designated across this area, this was then apportioned into discrete 'cut', 'non-cut' and 'control' plots. Ten cut and ten non-cut plots of 20x20m in size, were alternated in two parallel rows, giving a 'checkerboard' effect. Twenty adjacent 20x20m plots were treated as the control (see Figure 2).

2.2 Stonewort Cutting

In early summer 2017, the criteria for permission to cut stonewort were met. The experimental cut was undertaken on 26th July 2017. This mid-season cutting date was chosen to minimise the impact of cutting on the ability of the plants to over-winter successfully. Before cutting began, mean water level was obtained from Environment Agency water level telemetry data and referenced to gauge boards on the broad. This level was then used to set the cutter bar to the appropriate depth of 40cm above the bed. The Environmental Operating Procedure 1: Water Plant Cutting governed the cutting methodology and outlined operational safeguards for this experiment. The ten cut plots were mapped to generate GPS coordinates and provide clear operational instructions for the harvester operator. Hydroacoustic survey was conducted to gather the "before cutting" data. The water plants removed from each cut plot were sampled, with species identified, relative composition of the plant community estimated and wet weight measured.

Over 2018 and 2019 the ecological criteria (see Appendix 1) were not met that would permit repeat annual cutting, and the project was limited thereafter to monitoring only. The project concluded at the end of growing season in 2019.

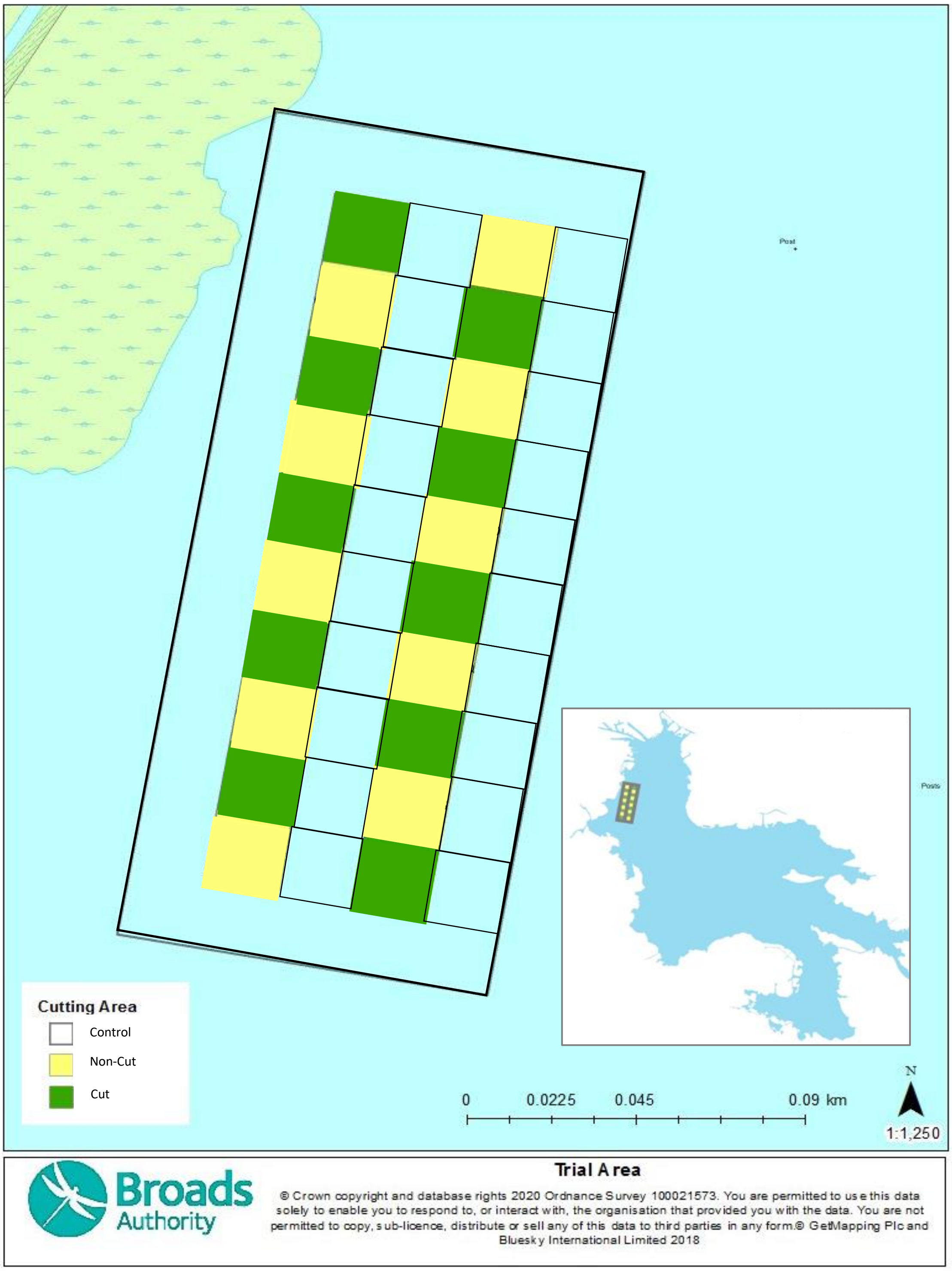

Figure 2: Checkerboard trial cut layout with control (light blue), non-cut (yellow) and cut plots (green) detailed

2.3 Monitoring

2.3.1 Hydroacoustic Surveys

Once the first water plant cutting had been completed, repeat hydroacoustic monitoring was undertaken, to quantify overall plant height, area covered and volume.

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.

The hydroacoustic surveys were conducted by navigating a survey boat along set transects across the study area, maintaining a constant speed. The equipment used in the surveys 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. The survey dates are presented in Table 2.

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 1m sections to enable identification of the cut areas within the data and exclude any uncut areas on the boundaries of the Cut plots or where patches of plants had been missed by the cutter.

All features taller than 9 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 during the processing of the initial May survey. The outputs (frequency distribution) for cover (5% increments) at the different heights were assessed, with 9 cm the lowest value considered to produce a normal distribution pattern. The 9 cm threshold was then used for all surveys for consistency.

The derived results from the processing of the hydroacoustic data were then used to calculate water plant height, percentage cover (PAI) and percentage volume of plants within the water column (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 study area, the ten cut treatment plots (combined), the ten non-cut treatment plots and the control transects using geographic information system (GIS) software (ArcGIS).

Table 2: Details of the cutting and monitoring programme conducted from 2017-2019

Date	Activity	Purpose
2017		
25 July	Hydroacoustic survey	Pre-cut survey
27 July	Water plant cutting	Reduce growing plants height and volume
23 August	Hydroacoustic survey	First post-cut monitoring survey
26 September	Hydroacoustic survey	Second post-cut monitoring survey
17 October	Species ID survey	Species identification and abundance
24 October	Hydroacoustic survey	Final post-cut monitoring survey
2018		
14 May	Hydroacoustic survey	Survey to establish status of potential cutting
15 July	Species ID survey	Species identification and abundance
16 July	Hydroacoustic survey	Survey to establish status of potential cutting
20 August	Hydroacoustic survey	Monitoring survey
24 August	Species ID survey	Species identification and abundance
15 October	Hydroacoustic survey	Monitoring survey
2019		
1 May	Hydroacoustic survey	Monitoring survey
27 June	Species ID survey	Species identification and abundance
2 July	Hydroacoustic survey	Monitoring survey
22 August	Species ID survey	Species identification and abundance
11 October	Species ID survey	Species identification and abundance
14 October	Hydroacoustic survey	Monitoring survey

2.3.2 Species Identification Surveys

Two rake survey throws were undertaken within each cut plot to identify species present and quantify the relative abundance of each species. The methodology to generate the species abundance values, was as per the annual Broads water plant survey Broads Annual Water Plant Monitoring Report 2019.pdf (www.broads-authority.gov.uk). The dates of the species identification surveys are presented in Table 2.

Replicate species survey were carried out in the control areas in 2019. To provide the background and context to the water plant community across the wider broad, data on species present and their relative abundance was utilised from the routine annual water plant surveys.

2.4 Statistical Analysis

All statistical analysis of data across all three years of the trial was undertaken in R v. 4.2.2. The data did not follow a normal distribution and data transformation failed to produce a suitably normally distributed dataset. Consequently, Mann-Witney U tests were used to identify any statistically significant differences between the different plot types plots.

3. Results & Discussion

3.1 Consolidation of Treatment Plots

The cutting trial was originally undertaken based on a checkerboard design that allowed for 'non-cut', 'cut' and 'control' plots. On investigation of the data, it was found that there was little difference between the non-cut and cut plots over each trial month.

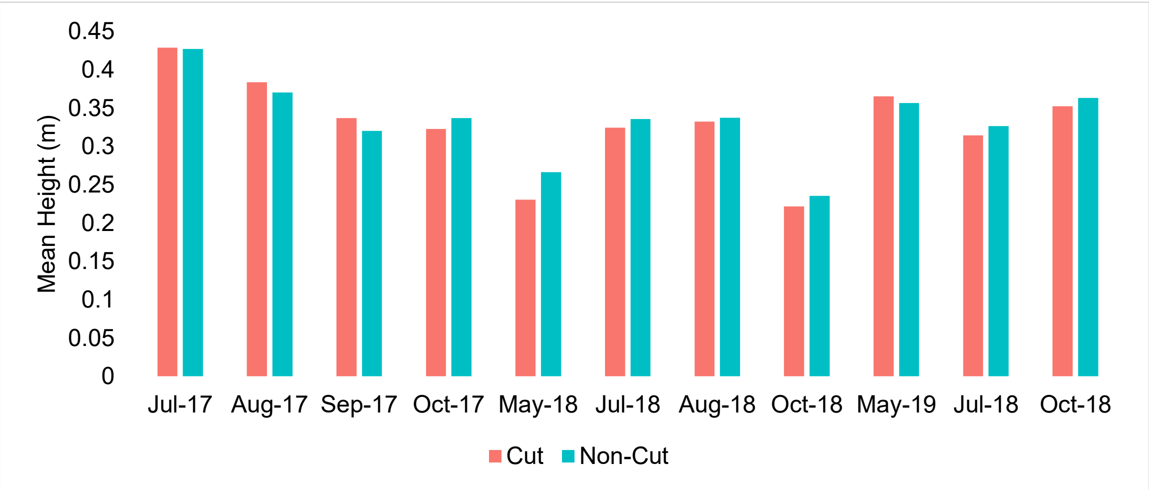

Figure 3: Average plant height between 'cut' and 'non-cut' treatment plots over the trial period.

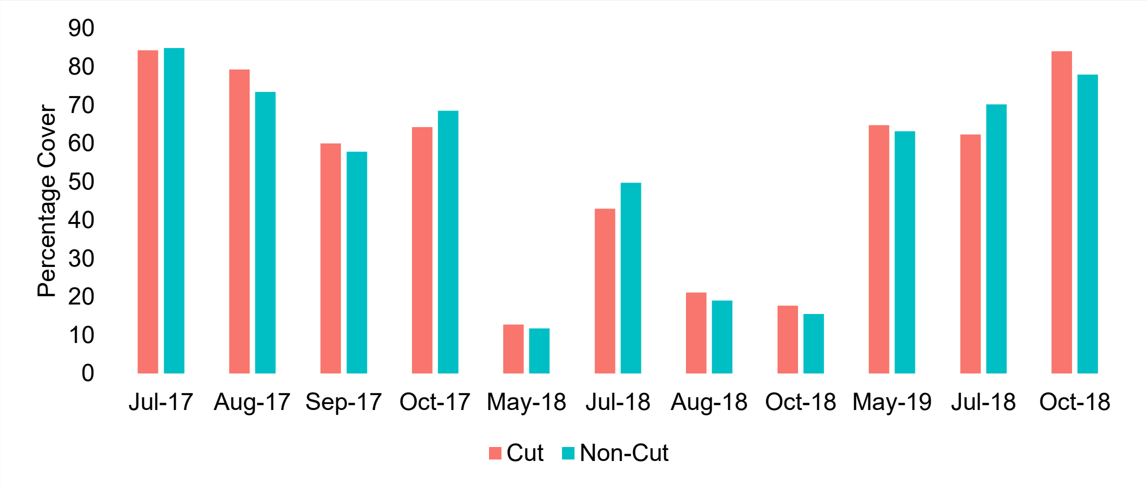

Figure 4: Average percentage cover between 'cut' and 'non-cut' treatment plots over the trial period.

Mann-Whitney U tests identified no statistically significant difference in mean plant height and percentage cover between cut and non-cut plots through 2017 and 2019. A statistically significant difference was identified in mean height between the cut and non-cut plots from August to October 2017 (Table 3). In 2018, no statistically significant differences were observed in percentage cover across the cut and non-cut plots. In July 2019 a statistically significant difference was observed between the cut and non-cut plots *(W = 68984, P <0.001).* However, this was not seen in any of the other trial months in 2019 (Table 3)

Table 3: Mann-Whitney U values (W) for mean plant height and percentage cover across the Non-Cut and Cut plots over each trial month.

	Mean Height (av.)		Percentage Cover (av.)	
Month	**W**	**Significance**	**W**	**Significance**
Jul-17	502318	0.5123	492110	0.8678
Aug-17	477076	0.7672	450072	<0.05*
Sep-17	296797	0.05432	296449	<0.05*
Oct-17	351968	0.08166	363686	<0.001*
May-18	5064.5	0.08926	4049.5	0.2891
Jul-18	47529	0.3154	49069	0.08319
Aug-18	9607	0.6579	8674.5	0.3321
Oct-18	4495	0.3215	4635	0.5199
May-19	68582	0.4349	36580	0.3904

	Mean Height (av.)		Percentage Cover (av.)	
Jul-19	63014	0.249	68984	<0.001*
Oct-19	34306	<0.05*	65019	0.534

Given the lack of statistically significant differences between the non-cut and cut plots outside of the summer and autumn months of 2017, it was decided to combine the two separate plots into one 'treatment' block. Non-cut and cut plots thereafter formed the combined treatment area to be compared against the control. This also had the advantage of equalising the number of treatment plots (20) to the number of control plots (20), which helped to meet the assumptions in the subsequent statistical testing.

3.2 Plant Height

In the initial pre-cut survey, mean plant height in the treatment blocks was found to be 3 cm lower than in the control blocks prior to cutting in 2017. This height difference was statistically significant (*W = 2082409, P<0.001*, see Table 4). Following cutting, the treatment blocks were still significantly shorter than the control in August and September 2017, but the difference between the treatment and control increased to approximately 7-8 cm. By October this statistically significant difference in height was no longer observed (See Figure 5). No difference between the treatment and control plots was observed through the spring and summer of 2018. A small difference was found in October 2018 (*W = 28363, P <0.05).* In 2019, no statistically significant difference was observed between the control and treatment plots in May or October. A statistically significant difference between the plots was found in July 2019 (*W = 258626, P <0.001)*, however it was found that this occurred because of higher plant growth in the treatment plots compared to the control plots.

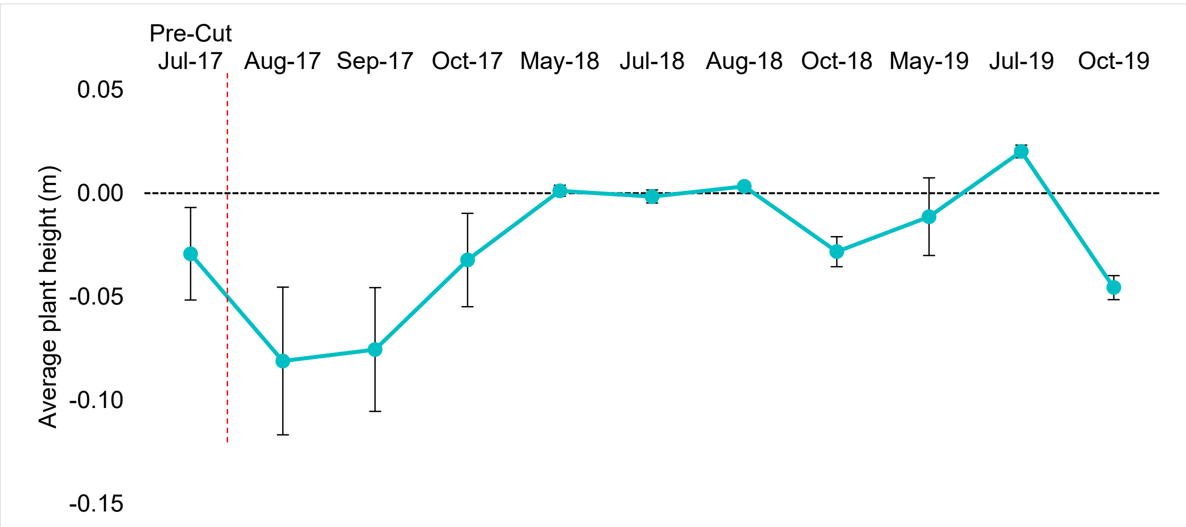

Figure 5: Line graph illustrating the variation in average plant height between treatment and control blocks across all trial months. Red dashed vertical line indicates the point of the cut. Error bars reflect the standard deviation of each point.

Table 4: Mann-Whitney U values (W) and associated significance levels for plant height. * indicates statistically significant results.

Year	Month	W	Significance
2017	July	2082409	< 0.001*
	August	1638887	< 0.001*
	September	1578917	< 0.001*
	October	1530538	2.79
2018	May	23672	0.08
	July	182170	0.85
	August	55576	0.43
	October	28363	< 0.05*
2019	May	288015	6.04
	July	258626	< 0.001*
	October	357286	4.93

With the height data bulked for each calendar year, average plant height was lower in the treatment plots in 2017 by around 14 cm compared to control. This equates to about a 12% difference in height. In 2018 and 2019 there was little observable difference in height between treatment and control (see Figure 6). 2019, the treatment plots were only 3% lower in height compared to control, but not to any statistically significant level.

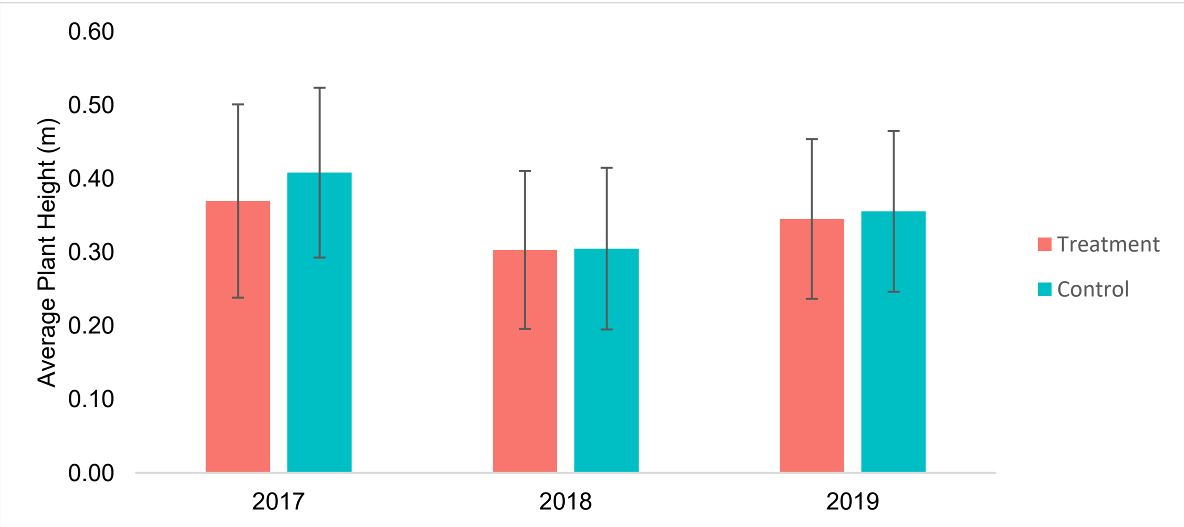

Figure 6: Bar graph illustrating average plant height between treatment and control blocks across the period of the cutting trial.

3.3 Plant Cover

From the individual surveys, significant differences in percentage cover between the control and treatment plots was observed throughout much of the study. For two years after the cutting, the treatment plots had significantly lower percentage cover of plants compared to control (see Figure 7 and Table 5). The reduced cover of plants was greatest in the late summer of 2017 and 2018. By May 2019, the continued pattern of reduced percentage cover of plants was no longer apparent in the treatment plots.

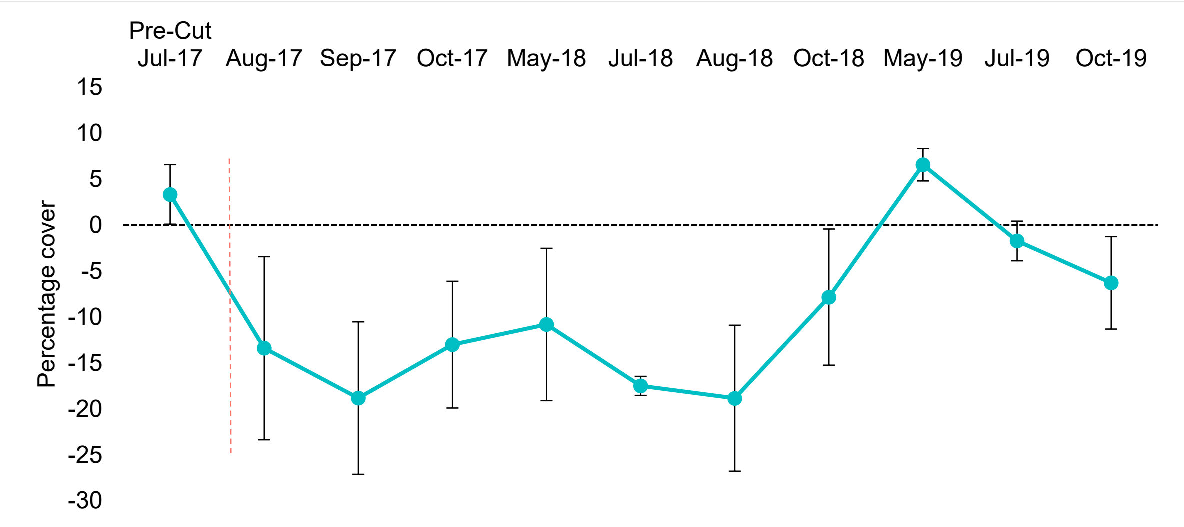

Figure 7: Line graph illustrating the difference in average percentage cover in the treatment plots (blue line) compared to control (black zero line). (red dashed line indicates when cutting occurred)

Table 5: Mann-Whitney U values (W) and associated significance levels for percentage cover. * indicates statistically significant results.

Year	Month	W	Significance
2017	July	1588858	<0.05*
	August	1445819	<0.001*
	September	1824486	<0.001*
	October	1985436	<0.001*
2018	May	329739	1.93
	July	360876	<0.001*
	August	349376	<0.001*
	October	286523	<0.001*
2019	May	286572	6.55

Year	Month	W	Significance
	July	357329	0.05*
	October	388726	1.982

With the percentage cover data bulked for each calendar year, the 2017 treatment plots had approximately 17% less plant cover compared to control. This had increased to 36% less cover in 2018. Note the lower red bars in Figure 8 for 2017 and 2018. However, by 2019 the plant cover was very similar between treatment and control with very similar variance for each.

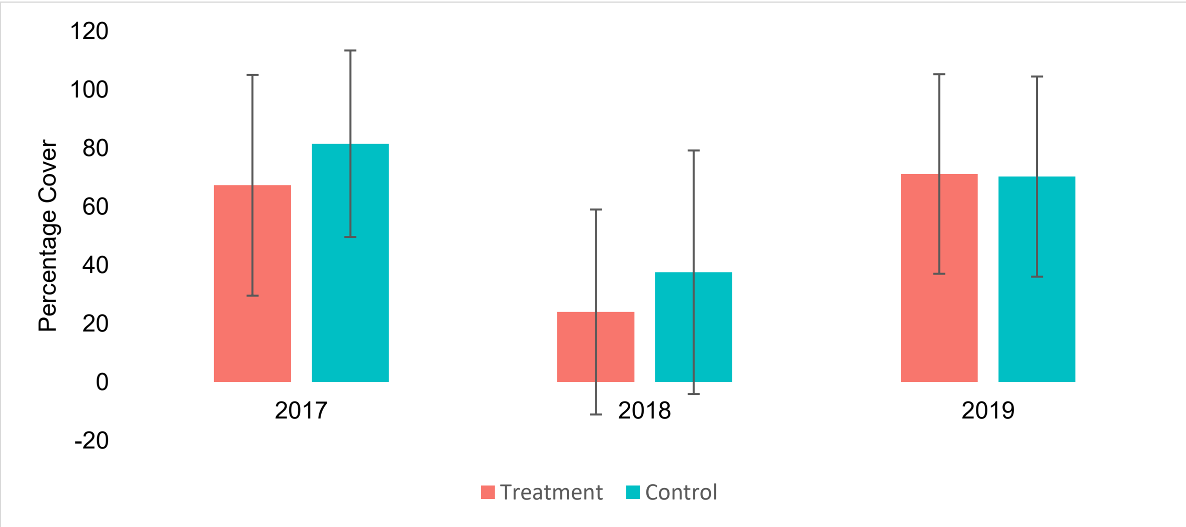

Figure 8: Bar graph showing annual average percentage cover of water plants between treatment and control

3.4 Species Composition

Species surveys supported the hydroacoustic monitoring of the treatment plots over the monitoring period. However, when it came to full analysis of the data, it became apparent that over the three years of monitoring, variations in how species data was gathered and quantified had occurred. As a result, a more limited data set is presented than set out in the methodology.

Figure 9 shows the variation over the monitoring period of intermediate stonewort, which has the scientific name *Chara intermedia*. *Chara intermedia* was initially the dominant stonewort species present in the experimental cutting area. The method used to quantify plant abundance was the same as used in the routine Broads annual water plant survey. In 2017 *Chara intermedia* had a greater abundance in the experimental cutting area compared to the whole of the broad. This is perhaps unsurprising, as the broad encompasses many different areas of mixed species, bare sediment areas and sample points within the marked channel. The experimental cutting was focussed within a large and contiguous stonewort bed.

However, by 2018 a significant drop in the abundance of *Chara intermedia* was observed in the treatment plots. This was mirrored by a similar trend across the broad a whole. Whilst the abundance of *Chara intermedia* increased again in 2019 in the treatment plots, it was still less abundant compared to 2017 (Figure 9). Given the similar patterns in the abundance of *Chara intermedia* over the three years, it would suggest that 2018 was generally a poorer year for *Chara intermedia* across the whole broad and not just in the treatment plots.

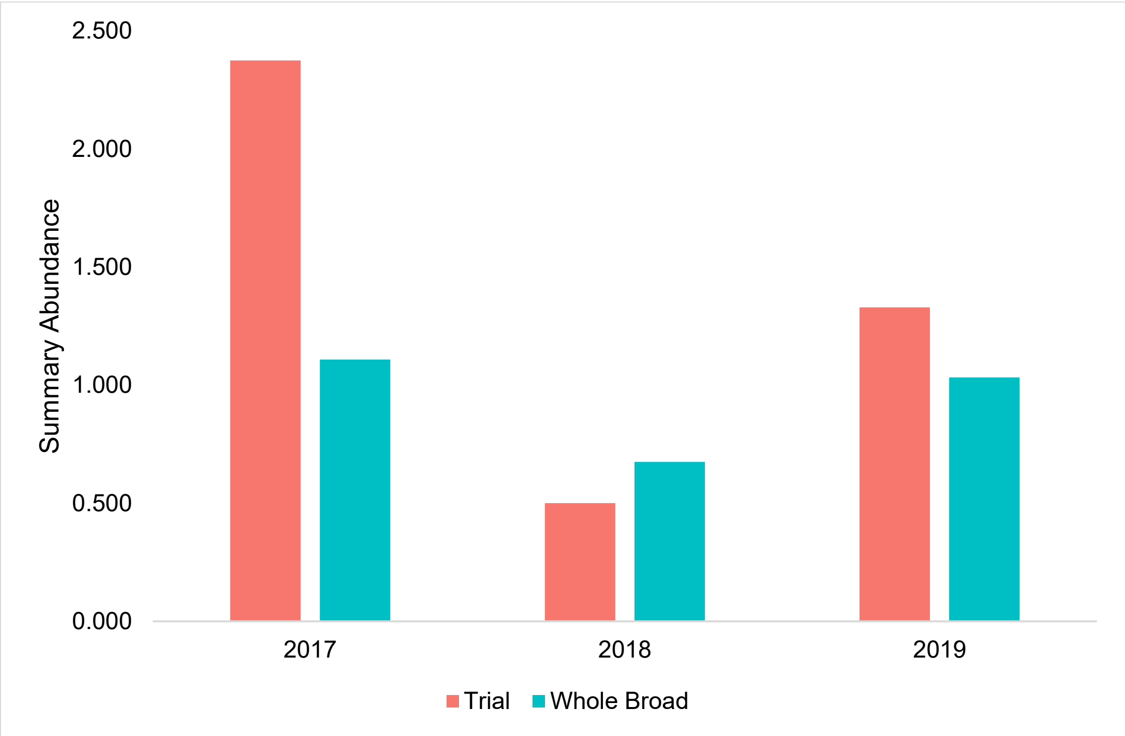

Figure 9: Abundance of intermediate stonewort in the treatment plots (red bars) and the whole broad survey (green bars)

The other consistently collected data was the relative abundance of the water plant species within the cut plots during 2017 and 2019 (Figures 10 and 11). Both years had 20 separate samples collected in the cut plots. Figure 10 shows the dominance of *Chara intermedia* in the cut plots during 2017, comprising 72% of the total abundance of all water plants. The second most abundant species was Baltic stonewort (*Chara baltica),* at 14%. In 2017 all stonewort species combined made up 93% of the total abundance of water plants species in the cut plots.

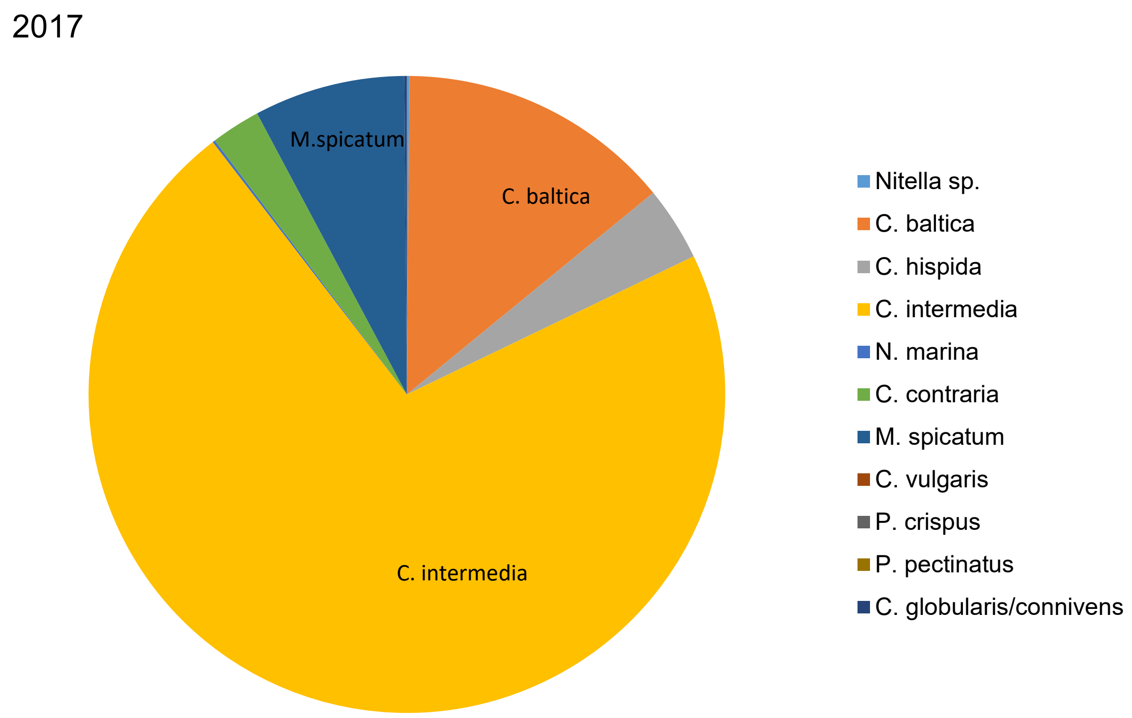

Figure 10: Relative abundance of plant species in "cut" plots during 2017

By 2019, the abundance of stonewort species in the cut plots had reduced to 46% of the whole water plant community. Presence of holly-leaved naiad (*Najas marina*) and spiked water milfoil (*Myriophyllum spicatum*) had increased, largely at the expense of *Chara intermedia.*

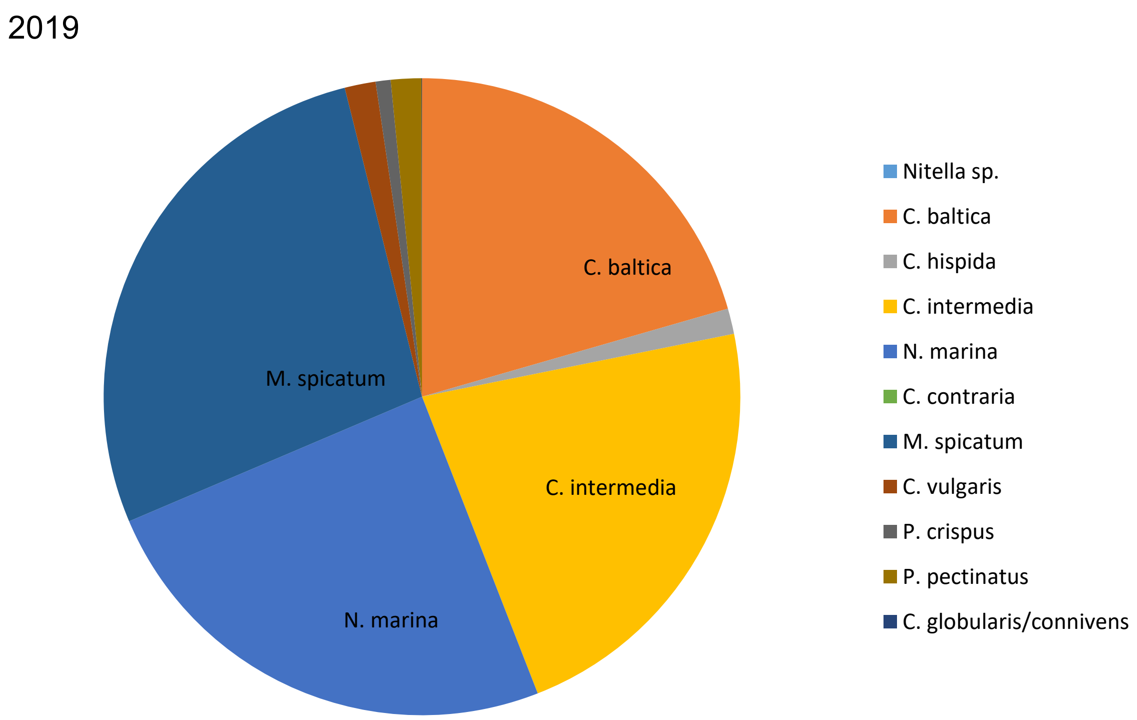

Figure 11: Relative abundance of plant species in "cut" plots during 2019

In comparison with the composition of the water plant community the whole broad (see Broads Annual Water Plant Monitoring Report 2019.pdf (www.broads-authority.gov.uk), graph 4 for Hickling), there was not a similar decline in stonewort species in the broad, as observed in the cut plots over the monitoring period. In 2017 stoneworts made up 41% of the total abundance across the broad. In 2019 this had increased slightly to 49%. This indicates that there was not a wider shift from stoneworts to other vascular plant species across the whole broad, and that the decrease in stoneworts observed within the cut plots was a local one. Whilst this observation is gained from data from just two years and cannot have the same kind of statistical treatment applied, due to the type of numerical data and the way in which it was collected, we can see that something happened within the cut plot areas to radically alter the plant community.

From the plant community composition data for 2017 and 2019, the Shannon-Weiner Diversity Index (H) was calculated. This index ranges from 0, which is low diversity, to 1, which is high species diversity.

Table 6. Shannon-Weiner diversity indices for plant community data in experimental plots

Plot type	2017	2019
Control	No Data	0.04
Cut	0.32	0.46

In the control plots in 2019 the Shannon-Weiner Index was very low (close to 0), suggesting dominance presence of a restricted range of species, as is typical in a stonewort bed. Compared to control, species diversity was significantly greater in the cut plots, *H = 0.46.* The greater species diversity in the cut plots is supported by the range and proportion of species shown graphically in Figure 11.

Between years in the cut plots, the Shannon-Weiner Index increased from, 0.32 in 2017 to 0.46 in 2019. Stonewort beds characteristically have relatively low species diversity (*H* closer to 0), so the increase in the Shannon-Weiner Index over time does not correspond with the conservation objectives for the site of stable, low diversity stonewort bed. The number of plant species present in the cut plots increased between 2017 and 2019. The increased Shannon-Weiner Index in 2019 was influenced by presence holly-leaved naiad (*Najas marina*), curled pondweed (*Potamogeton crispus*) and fennel-leaved pondweed (*Potamogeton pectinatus)*

The main conclusion from the experimental cutting area is that there was a large shift in the dominant species from *Chara intermedia* in 2017 to *Myriophyllum spicatum* in 2019.

In comparison to the trial cut area, there was no particular increase in the non-charophyte species recorded across the whole of Hickling Broad in the annual water plant survey from 2019.

4. Conclusion

Cutting had an immediate effect on plant height and cover. The checkerboard design of the initial "cut and "non-cut" plots as separate treatments, was shown to be a weakness in the experimental design and the data from these two plot types was successfully combined. The control plots were in close proximity to the treatments, but through robust statistical analysis of plant height and cover, the control was shown to be reliable. Planned repeat cuts of the water plants was not possible, as conditions in the wider broad changed. This took the experiment outside of the permitted criteria (see Appendix 1) in which repeat cutting could occur. However, hydroacoustic monitoring continued for three seasons after the cutting event, providing valuable data on the response of water plants to this impact.

The key findings of this trial are summarised, and whether each hypothesis could be supported.

4.1 Plant Height

The cutting did affect the mean height of water plants during the study period. In 2017 statistically significant differences were identified between treatment and control plots during the first season following cutting, but these were not observed in the following years.

The hypothesis that cutting would result in a reduction in overall plant height is supported by statistically significant differences in plant height, when compared to the control area, but only for a time-limited duration of one growth season.

4.2 Plant Cover

Percentage cover of plants was significantly lower in the treatment plots for two seasons following cutting. By the third season (2019) differences in cover were not apparent.

The hypothesis that cutting would result in a reduction in overall plant cover is supported by statistically significant differences in plant height, when compared to the control area, but only for a time-limited duration of two growth seasons.

4.3 Species composition

In the treatment plots, dominance by stonewort species, particularly *Chara intermedia*, had changed two years after cutting, to a more even mix of stoneworts and other vascular plants, mainly holly-leaved-naiad and spiked water milfoil. From the limited, but comparable species data in the cut plots, Shannon-Weiner Diversity Index indicates an overall increase in water plant diversity between 2017 and 2019. Increased species diversity the context of stonewort dominated plant beds is a negative trend in conservation terms, as it indicated other vascular and perhaps more common species have established in what was once dense stonewort growth.

The hypothesis that cutting would result in a decrease in charophyte prevalence within the plant community is not supported statistically, but the data gathered shows that the plant community in cut plots was more diverse, and contained less stonewort, than in control areas.