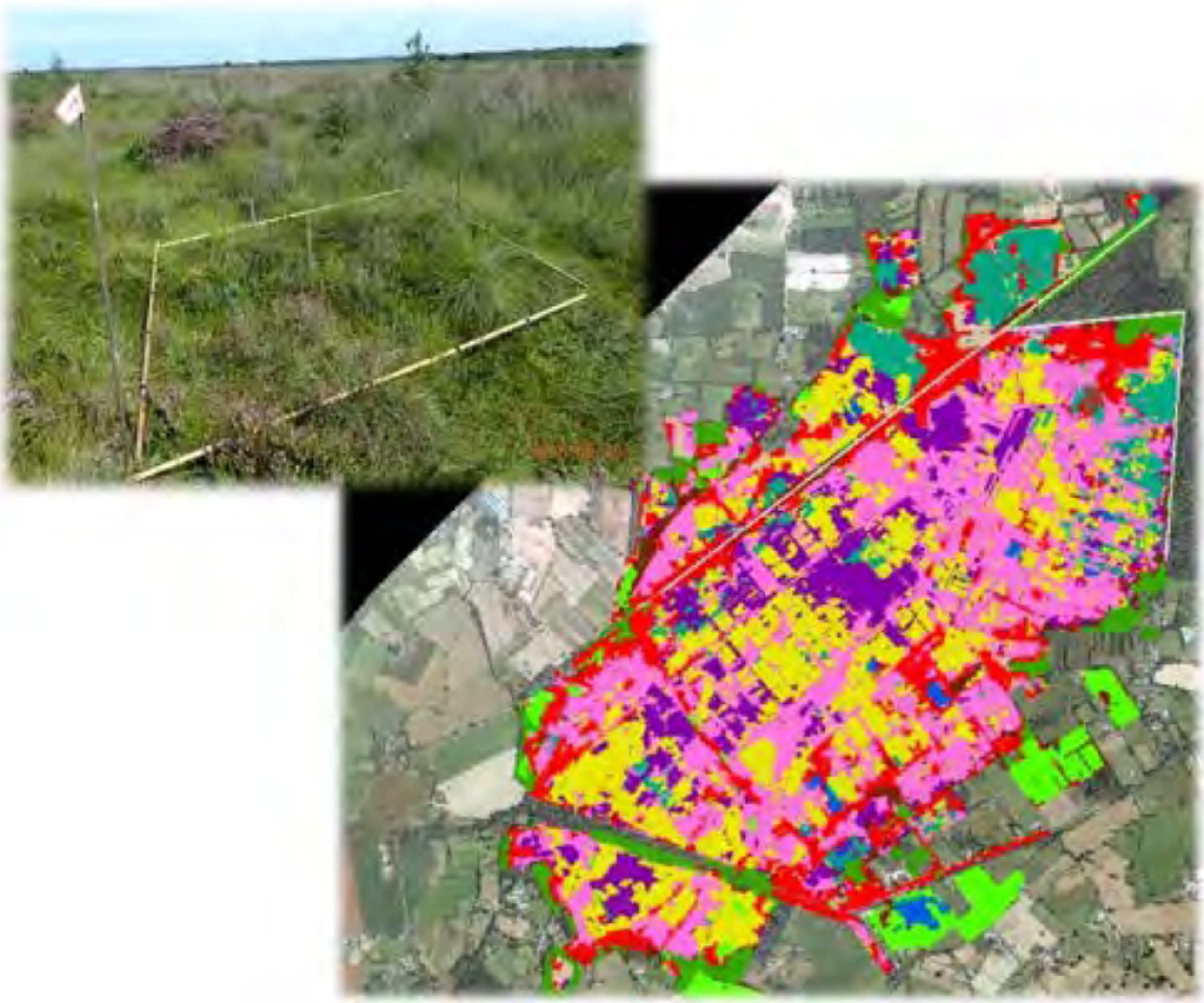
Marches Mosses BogLIFE Project – Final Monitoring Report

Sophie Laing – Monitoring Officer and Lead Adviser

With Contributions from Ellie Williams – Assistant Project Officer

Edited by Robert Duff - Project Manager

March 2023



Restoring Marches Mosses BogLIFE Project (LIFE15 NAT/UK/000786)

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1.0 Introduction

Introduction to the Marches Mosses BogLIFE Project

The Marches Mosses BogLIFE Project encompasses, Fenn's, Whixall, Bettisfield, Wem & Cadney Mosses Special Area of Conservation (SAC) which at 949.2 ha is the third-largest lowland raised bog SSSI in Britain. The majority of the SAC is designated as H7110* Active Raised bog habitat - one of the few 'Priority EU habitats' occurring in Britain for which the UK, with some 6000 hectares, has 'special responsibility' for. Much of the site is managed as a National Nature Reserve (NNR) by NNatural England (NE) under agreement with NRW. Wem Moss NNR is managed by Shropshire Wildlife Trust.

Drained to enable peat cutting, agricultural improvement and afforestation, the centre of the Mosses were rescued in 1990 from near destruction by large-scale commercial peat cutting. Through continued "first-fix" restoration work the centre of the SAC has relevant bog species returning and active peat formation commencing. However, the site faces a range of issues (evapo-transpiration, water/air pollution and unsympathetic land management by other landowners). With extra resources, a step change the restoration of its hydrology is achievable delivering the improvements necessary to progress towards Favourable Conservation Status. The project's overarching aim was to restore H7110* Active Raised bog habitat and convert part of the H7120 Degraded Raised bog habitat to H7110*.

The project's objectives were to:

1. Restore 660 ha of habitat to achieve a more sustainable, resilient, and better functioning active lowland raised bog including lagg restoration. This includes the restoration of 575ha of H7110* Active Raised bog and 67ha of H7120 degraded raised bog capable of natural regeneration back to active bog in the SAC and an addition 23 ha of important undesignated land adjacent to the SAC.

The restoration work involved:

- Acquisition of 63 ha of degraded raised bog in unfavourable condition;
- Removal of woodland & conifer plantations;
- Improving the bog's water quantity & quality through new water control structures, cell and contour bunding, dam adjustment, reducing evapotranspiration & diverting polluted water;
- Speeding up active bog processes, the amelioration of contaminated land and mitigating for the effects of air pollution via surface treatments such as turfing/re-seeding/scraping/mowing/containment.

2. Monitor recovery & disseminate best practice guidance about the restoration techniques to managers of similar habitats across Europe.

3. Establish a volunteer & placement Centre of Excellence.

4. Raise awareness of the importance of the SAC by increasing physical & intellectual access for a wide range of audiences.

This document reports on the monitoring undertaken between 2016 and 2022 as part of the Marches Mosses BogLIFE project.

Introduction to Marches Mosses BogLIFE Project Monitoring

A monitoring plan for the Marches Mosses BogLIFE Project was produced in 2017 (start of Year 2) by the Project's Monitoring Officer

The plan's main aims were:

1. To quantify, where possible, the impact of the project restoration works on bog vegetation composition, water levels, water flow, water quality, habitat condition, carbon storage, aerial nitrogen pollution, diffuse pollution sources, invasive species cover and ecosystem services.

2. To compare the efficacy of different restoration techniques in transitioning towards natural, autogenic bog conditions.

3. To carry out an audit of the extent of Concrete Conservation Actions which have been undertaken during the project.

Project Monitoring Objectives:

- D1.1, D2.1 & D3: **Hydrological Monitoring**: Assess the success of actions taken to raise water levels, including flow rates and water volume of the redirected Bronington Manor Drain and periodic assessment of pH and conductivity of water in and around the site.
- D1.2, D2.2 & D3: **Air and Water Quality Monitoring**: Assess the success of actions taken to improve water quality and reduce and ameliorate air pollution.
- D1.3 & D2.3: **Vegetation and Key Species Response to Applied Management**: a more detailed assessment of vegetation response will be undertaken to assess the ecological response to project actions (re-wetting and re-vegetation).
- D1.4 & D2.4: **Efficacy and Extent of Works Monitoring**: a combination of high resolution, colour aerial photography and fixed-point photographs will be used to compare before and after works undertaken.
- D1.5, D2.5 & D3: **Invasive Species Monitoring**: monitoring of areas where invasive species have been removed will be undertaken to assess success of the actions and highlight areas of re-growth for further treatment.
- D3: **Assessment of Contribution to Ecosystem Services**: an assessment of the contribution of the project's actions to ecosystem functions will be undertaken.
- D4: **Assessment of socio-economic impact of the project**: to undertake an assessment of the contribution of the project to sustainable development.
- D5 **Monitoring impacts on local communities**, **other user groups and professional engagement:** undertake an assessment of the impact of the engagement with a wide variety of societal groups.

This document produced in the final year of the project (Year 6) reports on the main findings of the project monitoring undertaken and available survey information. In many cases specific detailed supporting reports were produced on the parameters monitored and these are cited and referred to where relevant as appendices.

Please refer to other specific reports with respect to the assessment of Actions D3, D4 and D5.

	Report Title/Author/Date
D3: Assessment of Contribution to Ecosystem Services	Socio-economic analysis of the Marches Mosses BogLIFE Project September 2022 by Matt Georges – Orbital Applied Economics Ltd. for Natural England
D4: Assessment of socio-economic impact of the project	Ecosystem Services Assessment Report Marches Mosses BogLIFE Project 2016 – 2022 Sophie Laing – Monitoring Officer and Lead Adviser January 2023
D5 Monitoring impacts on local communities, other user groups and professional engagement:	Restoring the Marches Mosses BogLIFE Project Final Evaluation Report - Evaluation of Impact on Local Communities, Other User Groups and Professional Engagement Final: December 2022 Report by Dr Jane Holland, Jill Hall & Dick Willis of Plantagenet Consulting Ltd;

2.0 Hydrological Monitoring

2.1 Aims and Objectives

- D1.1, D2.1 & D3: Hydrological Monitoring: Assess the success of actions taken to raise water levels, including flow rates and water volume of the redirected Bronington Manor Drain and periodic assessment of pH and conductivity of water in and around the site.

A specialist assessment of the hydrological data (Leader, S. 2020) was produced by Sam Leader with support from David Gasca of Atkins. The main aim of this analysis was to assess the patterns in water levels and water flow across Fenn's, Whixall, Bettisfield and Wem Mosses NNR and to relate them to both climate patterns and management implemented. Graphical visualisations as time series plots, box plots, maps, and statistical analyses were used to address the following objectives:

1. Visualisation of long term and seasonal patterns in water levels and water flows
2. Assess changes in the following relative to management and climate:
   - mean annual/summer water levels in manual and automated level-loggers
   - seasonal water level patterns and/or stability (variability) in manual and automated level-loggers
   - time within target water levels (+/-10cm) in manual and automated level-loggers
   - discharge (m s_{-1}) and runoff co-efficient (%) at the higher and lower weirs

The analysis of water level results was updated by Sophie Laing in 2022 using the template for graphical plots devised by Sam Leader.

2.2 Methodology

Active raised bog requires mean water levels to be near or above the surface of the bog for most of the year. Seasonal fluctuations should not exceed 20cm, and water levels should be within 10cm of the surface, except for very short periods of time (Mackin, 2017). A stable and high-water table is an essential requirement to the maintenance of active raised bog habitat. The water levels are critical for peatland development because they control species composition through anoxia (lack of oxygen) at depth, which retards decomposers and so enables peat accumulation. Summer water table 40cm below ground is commonly accepted as a critical level for growth of raised bog plant communities (Peatland Hydrology Draft Scientific Review October 2010, IUCN UK Peatland Programme).

Hydrological monitoring was therefore carried out during the BogLIFE project to assess the success of actions undertaken to raise the water levels to within +/-10cm of ground level, under actions C3 (Raising water levels through bunding) and C4 (Raising water levels by adding and adjusting dams).

Water levels at the site have been monitored continuously since 1993 to the present day, using a combination of manual and automatic dipwells. A network of 107 manual dipwells are present on two transects across Fenn's and Whixall Mosses (the Railway transect that runs north to south and the Canal transect that runs east to west), with a further 52 dipwells located in two transects across Bettisfield Moss (**Figure 2.2.1).** These were monitored on a four-weekly basis by the project's volunteers. In addition, there are a further 23 manual dipwells located on Wem Moss. These are monitored monthly by Shropshire Wildlife Trust volunteers (**Figure 2.2.2**). The data collection period varies between sites: Railway and Canal transect dipwell data collection commenced in 1993; Bettisfield Moss sites in 2003 and Wem Moss sites in 2008.

As part of the BogLIFE Project a further six manual dipwells were added to the turfing fields area and five to the area known as the Sinker Fields (LP7) which forms part of the lagg restoration. This can be seen in **figure 2.2.3**. These dipwells are largely distributed in areas where bunding or damming work to raise water levels was planned.

To acquire data from a wider range of areas planned to undergo restoration works, 15 Level Scout automated data loggers were also installed in areas with no previous monitoring e.g. newly acquired land where water levels were expected to change in response to management interventions during the project. Due to the nature of some of the works e.g., clear-felling operations some of the Level Scouts had to be removed during ground operations to ensure that they weren't damaged by the machinery. The Level Scouts were also installed at different times during the project resulting in some having longer runs of data than others.

In addition, the Level Scouts automated data loggers had to be removed part way through the project to allow for battery replacement and this created a data gap. The loggers were reinstalled in the same locations, but it was not possible to position them at the exact same depth as they had been in previously. As a consequence, the data is split between two data sets - the first is referenced with suffix A and the second with suffix B. As the same type of Level Scouts automated data loggers were returned to the exact same place the data can be treated as a continuous data set. The Level Scouts record pressure (psi) every 6 hours. This is then compensated against a baro which records only air pressure so the air pressure can be removed to leave water pressure. This can then be turned into water depth with the following formula:

$$Wd = d - 70.307\,(P_1 - P_2)$$

When: Wd= Water Depth (cm), d= Diver depth (cm), P_1= recorded pressure by Level Scout (PSI) P_2 = Air Pressure (PSI).

Shallow groundwater levels and the lateral movement of water were monitored by three existing piezometers located on Fenn's Moss on a four-weekly basis as part of the manual dipwell transects.

An automated weather station present on Fenn's Moss since 2009, records solar radiation, wind speed and direction, humidity, temperature and rainfall on an hourly basis (**Figure 2.3.3**). This data has been used alongside the hydrological data to interpret changes in the site's hydrology.

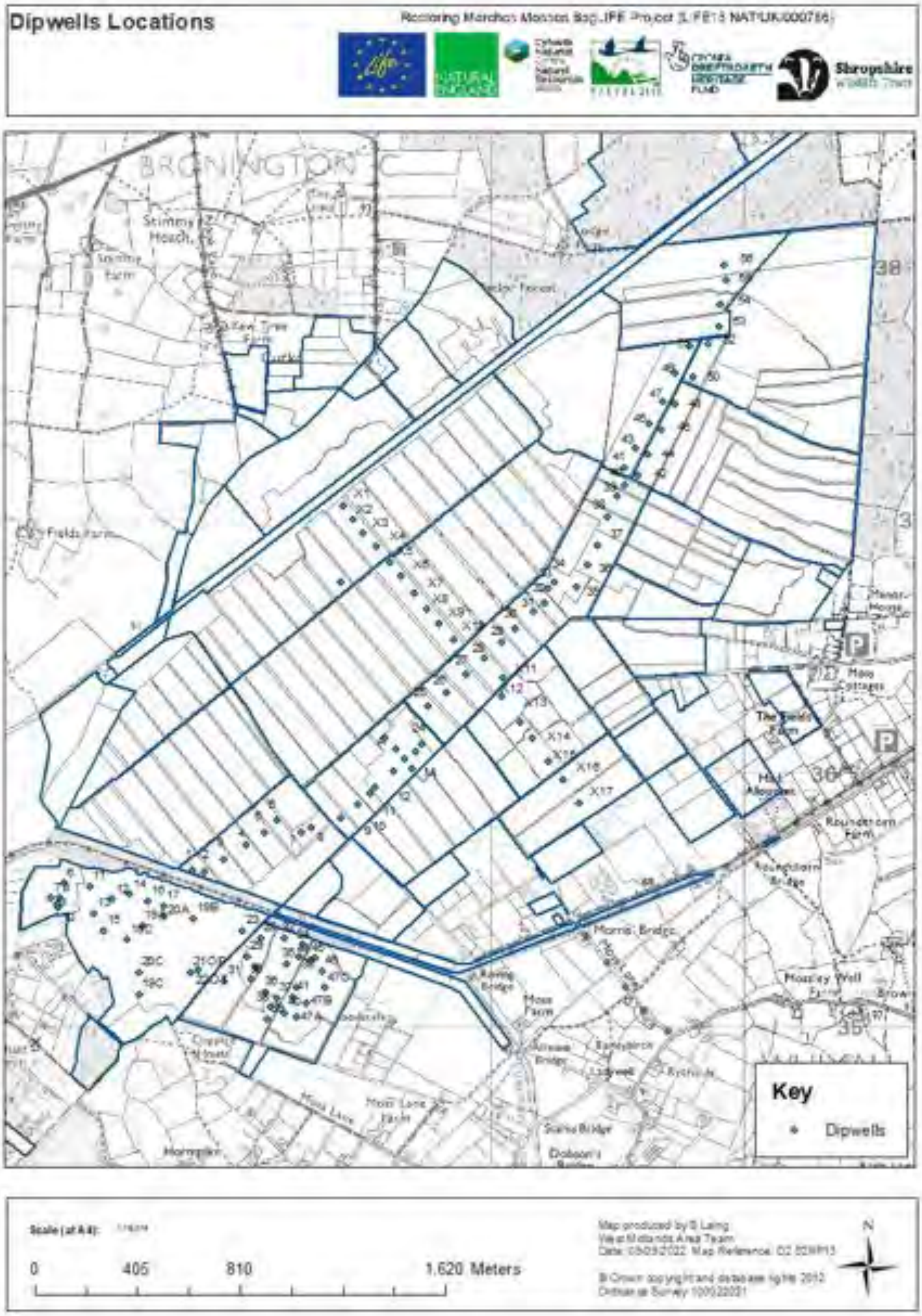

Figure 2.2.1 Locations of the manual water level dipwells that make up the Railway (X), Canal and Bettisfield Moss Hydro routes.

Figure 2.2.2 Location of the manual water level dipwells for the Wem Moss Hydro route.

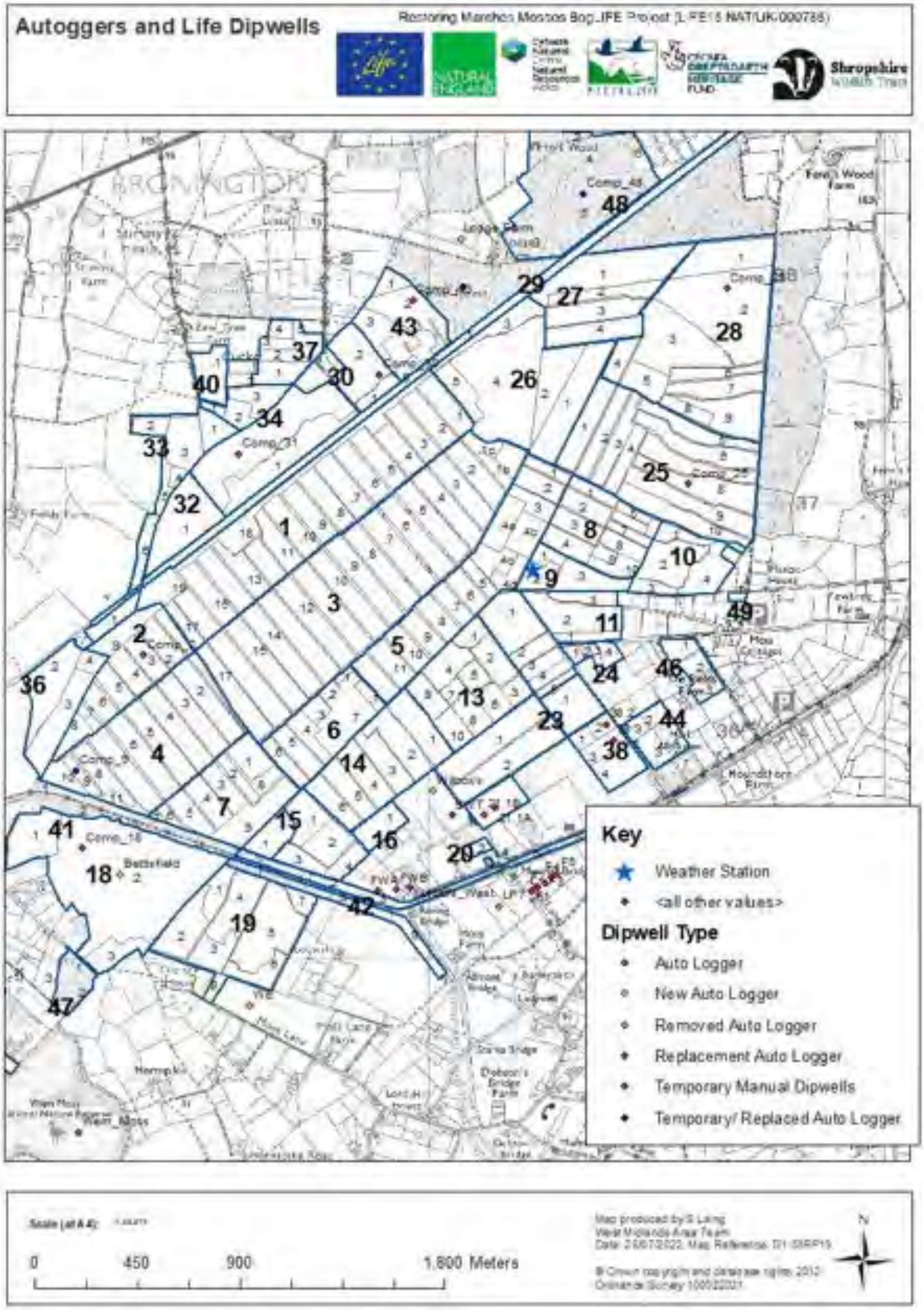

Figure 2.2.3 Location of new water level dipwells and automated water loggers installed during the BogLIFE project.

The original plan to determine the water volume and flow rate of Bronington Manor Drain by installing two V-notch weirs to inform the planning stage of the diversion of Bronington Manor Drain (C6) was changed after consultation with Brain Killingworth, a consultant engineer with in-depth knowledge of the local hydrology. He advised that the v-notch weirs would be unlikely to yield sufficient useful data in the timeframe necessary. As an alternative, flow level were calculated by a specialist contractor based on measurements of the existing weir. The methodology and the results are detailed in **Appendix 2.3.2**.

Plans to monitor monthly the height of 'within' ditch water levels on Fenn's Moss Main drain using the seven crest gauges situated along the drain were reviewed after discussion with hydrologist Sam Leader regarding the quality of the data. It became apparent that the existing aged crest gauges were no longer fit for purpose and the data collected was unreliable. New replacement crest gauges were purchased, but these were installed late on in the project so there was no meaningful results at the time of this report. They will however be used as part of the post-LIFE monitoring of water levels.

2.3 Results and Discussions

A full set of the hydrological dipwell raw data can be found in **Appendix 2.3.1**. The initial analysis was carried out by Leader Environmental Analyses and discussion of the findings can be found in **Appendix 2.3.2**. A summary of these results and an update carried out by the project's monitoring officer follows below:

Bettisfield Moss

As one of the first areas of the Marches Mosses to be bunded in 2017/2018 (Action C3) Bettisfield Moss is a good case study to analyse to determine the effects of bunding on its hydrology. **Figure 2.3.1** shows the water levels for Bettisfield Moss presented in three different formats - all three of which divide the data based on management type. The graph at the top shows mean water levels, the lower one shows annual water level data between 2003 and 2020. The annual variations over this extended period can be seen.

The map of Bettisfield Moss displays the spatial variation in water levels. The dots which are colour coded based on rewetting management/date represent the dipwell locations and the infill colours between are extrapolated based on these points.

All three show a noticeable increase in water levels in 2019 which is associated with the rewetting works bunding carried out in Winter 17/18 and 2019.

Annual water level graphs 2005 – 2021 for each of the dipwells are shown in **figure 2.3.2**. The most recent years are represented by darker blue colours. In most cases the data for 2020-2022 is within target of +/- 10cm of the surface for at most of the year. This is the desired level to optimise the growth of sphagnum moss and other bog vegetation. The analysis shown in **figure 2.3.3** further supports this shift towards more favourable levels. It displays the percentage of time that water levels were either at target level (+/- 10cm), too dry (<10cm), or too wet (>10cm). Note that dipwells with missing data were excluded.

Following the bunding work to rewet Bettisfield Moss there is a clear trend. The target or above target, water levels are reached for a greater proportion of the year indicating the intervention has been effective. Higher water levels were evident at 82% (34 of the 41) of the dipwells where data was available. Seven dipwells (39, 7, 8, 5, 1, 40, and 41) showed no clear trends. Moreover, in 2021, target or above water levels were achieved 100% of time at 60% (21 out of the 35) of dipwells compared to only 11% (4 out of 35) in 2005 when water level monitoring commenced. Even the two dipwells (10 and 46) which had not previously been within the target range, reached target range 25% of the time in 2021.

In the eastern part of Bettisfield Moss the improvement in water levels following bunding work sometimes exceeded the optimal target range set of +10cm of surface level. These areas are topographically lower than the western part of the moss and therefore may be receiving water shed from these higher areas. In considering if this a problem, account needs to be given to the relatively low annual rainfall the site receives (700 mm) and also that water levels typically drop markedly during the spring and summer months due to evapotranspiration and low rainfall. With changing climate conditions predicted such as warmer and drier summers (e.g., 6-month summer drought of 2022) the summer water levels in the these 'wetter' areas may provide more resilient conditions for the bog vegetation in the future. The target levels are likely to be maintained for longer during such dry periods. Another benefit of higher water levels is the effective suppression of, often, over-dominant Molinia grass allowing for bog vegetation rejuvenation.

Overall, there is strong evidence showing that rewetting using peat bunding has successfully improved the hydrological conditions of the Bettisfield Moss across a widespread area enhancing the development of characteristic bog vegetation leading to an improved habitat condition.

Aerial Photos of the eastern part of Bettisfield Moss before (2014) and after bunding in 2019 and 2021 - CLICK ON IMAGE

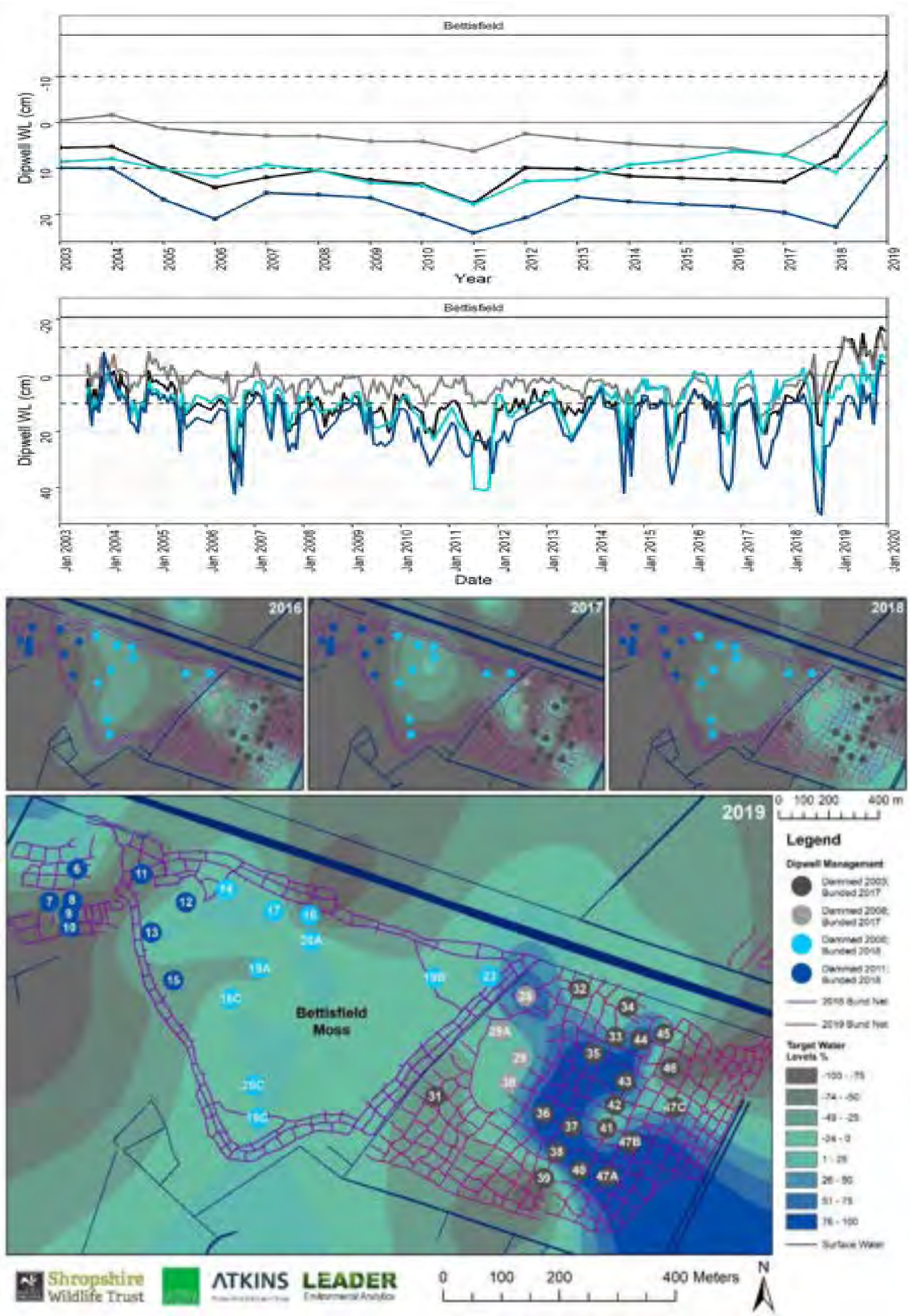

Figure 2.3.1 Graph and map showing water levels over time for different management types on Bettisfield produced by S.Leader from Leader Environmental analyses.

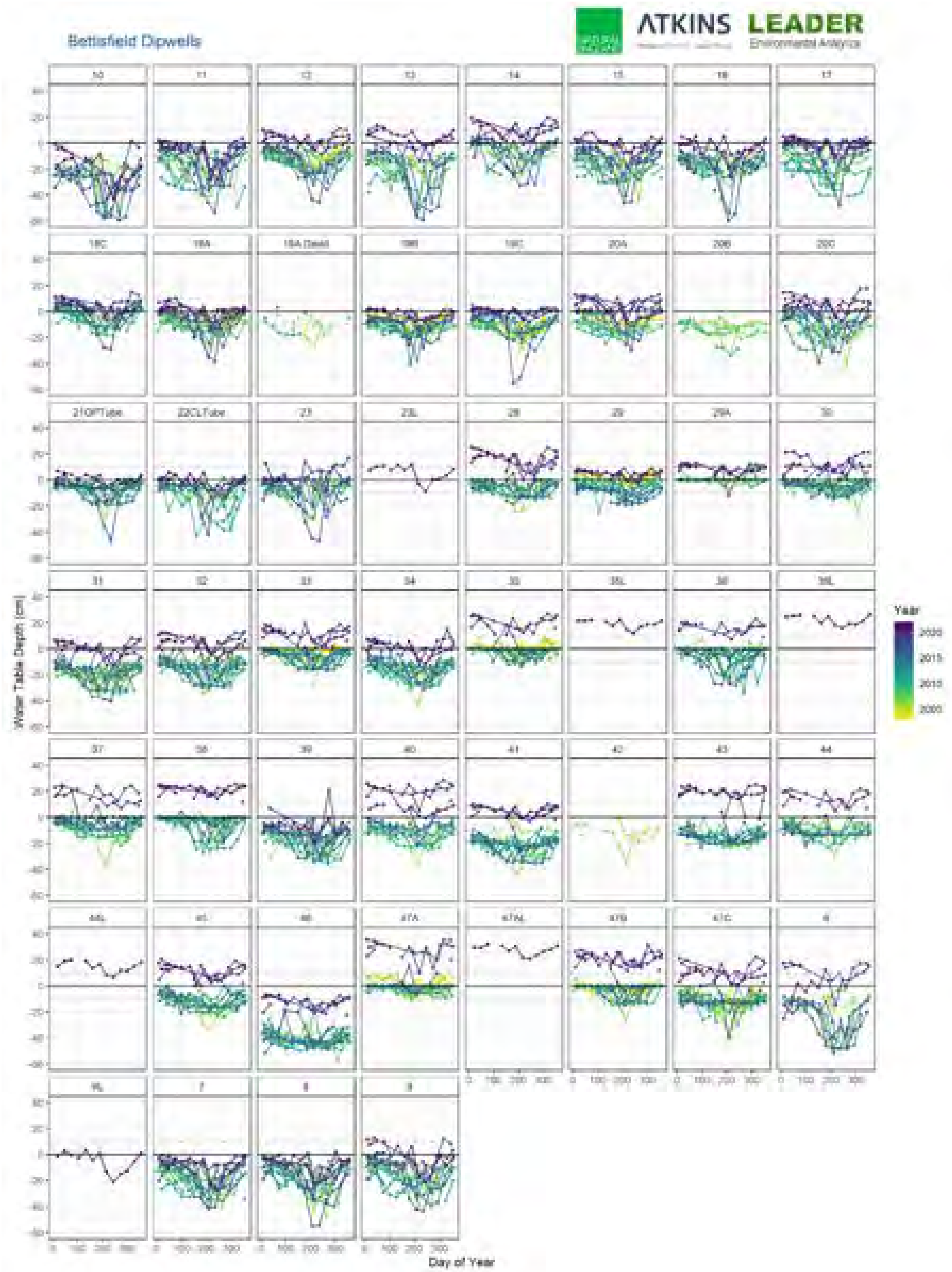

Figure 2.3.2 Overview of Bettisfield Moss dipwell data upto March 2022 plots for annual water levels for each dipwell. Updated by the Monitoring Officer, based on script provided by Leader Environmental Analyses.

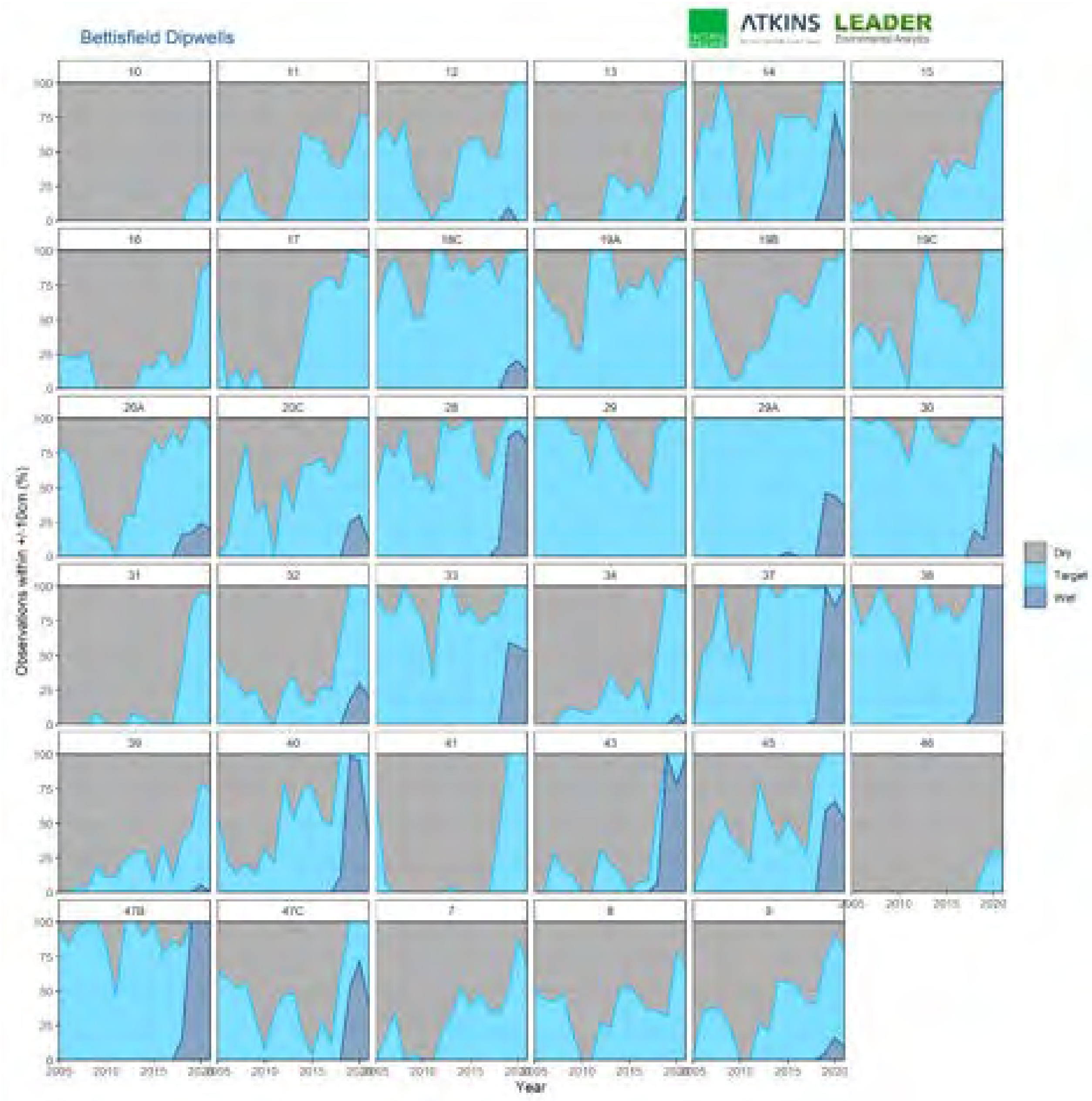

Figure 2.3.3 dipwell data for Bettisfield Moss between 2005 – to December 2021 coloured to show percentage of time within target range of +/-10cm (light blue) above it (wet) [dark blue] or under it (dry)[grey]. Updated by Sophie Laing based script provided by Leader Environmental Analyses.

Fenn's and Whixall Mosses (Canal and Railway Hydro routes)

Many of the dipwells along the two existing transects that cross Fenn's and Whixall Mosses (**Figure 2.2.1)** do not overlap with peripheral areas of the mosses subject to the intensive 20 x 20 metre and 30 x 30 metre cell bunding (Action C3) carried out between 2017 and 2020. Many dipwells do coincide with areas subject to 'second fix' contour bunding in the centre of the moss (Action C4). However, the latter bunding work was only undertaken at a late stage in the project in 2021 and 2022. Accordingly, at the time this report, the water levels at many of these dipwell at the time this report was prepared locations were at an early stage of responding to the impact of the rewetting works**.** For reference **Appendix 2.3.3** shows the areas bunded**.**

An example of a dipwell located in an area cell bunded at an early stage, during the winter 17/18, is Dipwell X17 situated in Section 22. The water levels show a marked rise after the rewetting work was undertaken (see **Figure 2.3.4**). Positive increases in water levels can also be seen for dipwell 2, 3, 4, 5, 5A (Section 27, dams installed 2017) and 15 located along the canal transect route and dipwell 53, 54, 55 and 56 (Section 7, bunded autumn 2019) on the railway transect route (see **figures 2.3.5 and 2.3.6**). Not unexpectedly the water levels graphs for most other dipwells that fall outside these bunded areas show no clear increase over the same period.

As much of the 2nd fix contour bunding that would impact the remaining dipwells was only installed in the later stages of the project the effects of it are not expected to be evident until the winter 2022 and beyond. It is recommended that monitoring continues, and the water level data is re-analysed in March 2024 when the response to recent rewetting works should be evident. **Figures 2.3.7** and **2.3.8** show the percentage of time that water levels were within target (+/-10cm to ground level), or below it (dry) or above it (wet). Most of the dipwell readings show no clear pattern at this stage.

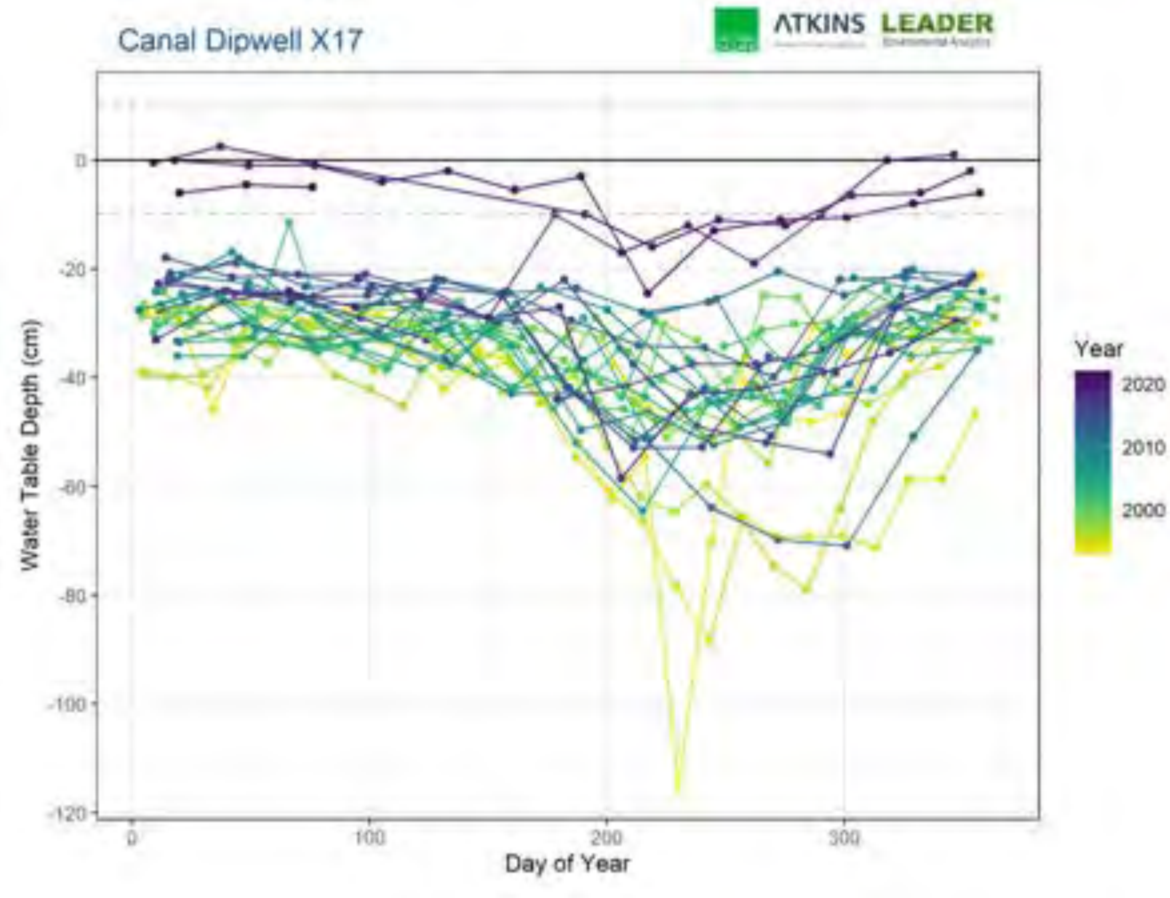

Figure 2.3.4. Hydrological data for dipwell X17 on Whixall Moss upto March 2022.

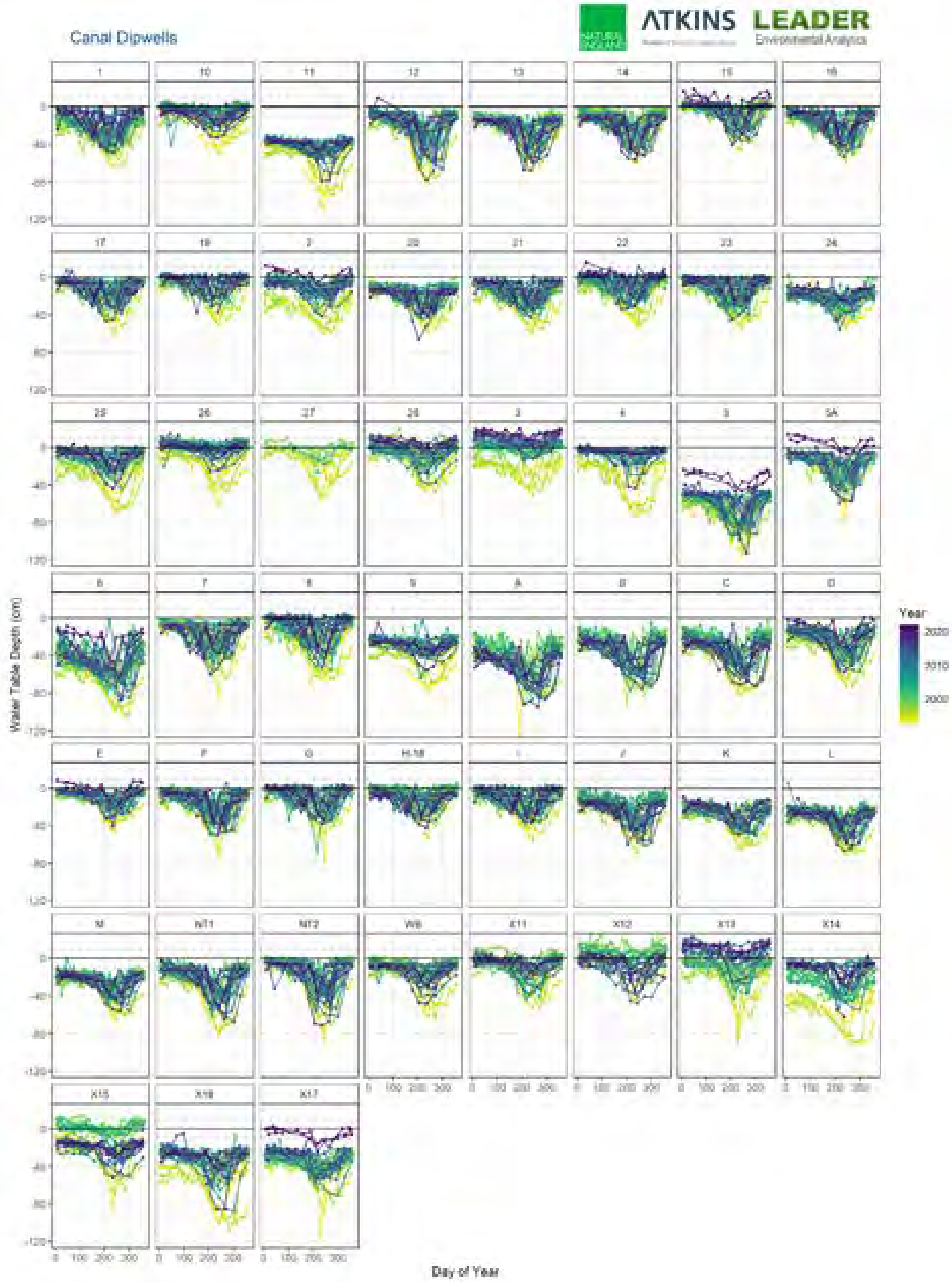

Figure 2.3.5 Updated plots of annual water levels for each dipwell in the Canal route transect across Fenn's and Whixall Mosses. Updated by the LIFE projects monitoring officer, based script provided by Leader Environmental Analyses.

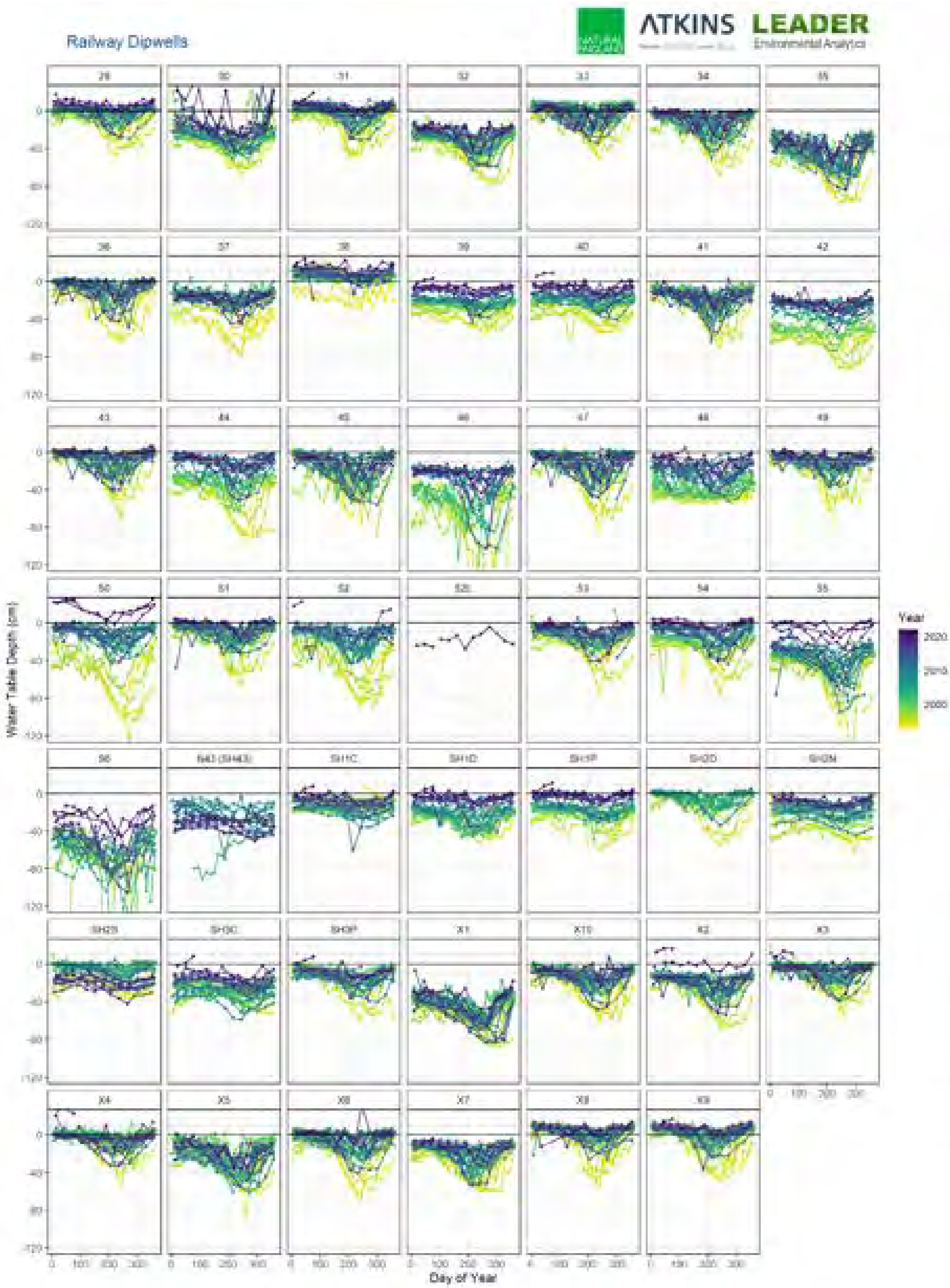

Figure 2.3.6 Updated plots of annual water levels for each dipwell in the Railway route transect across Fenn's and Whixall Mosses. Updated to March 2022 by the project monitoring officer, based on script provided by Leader Environmental Analyses.

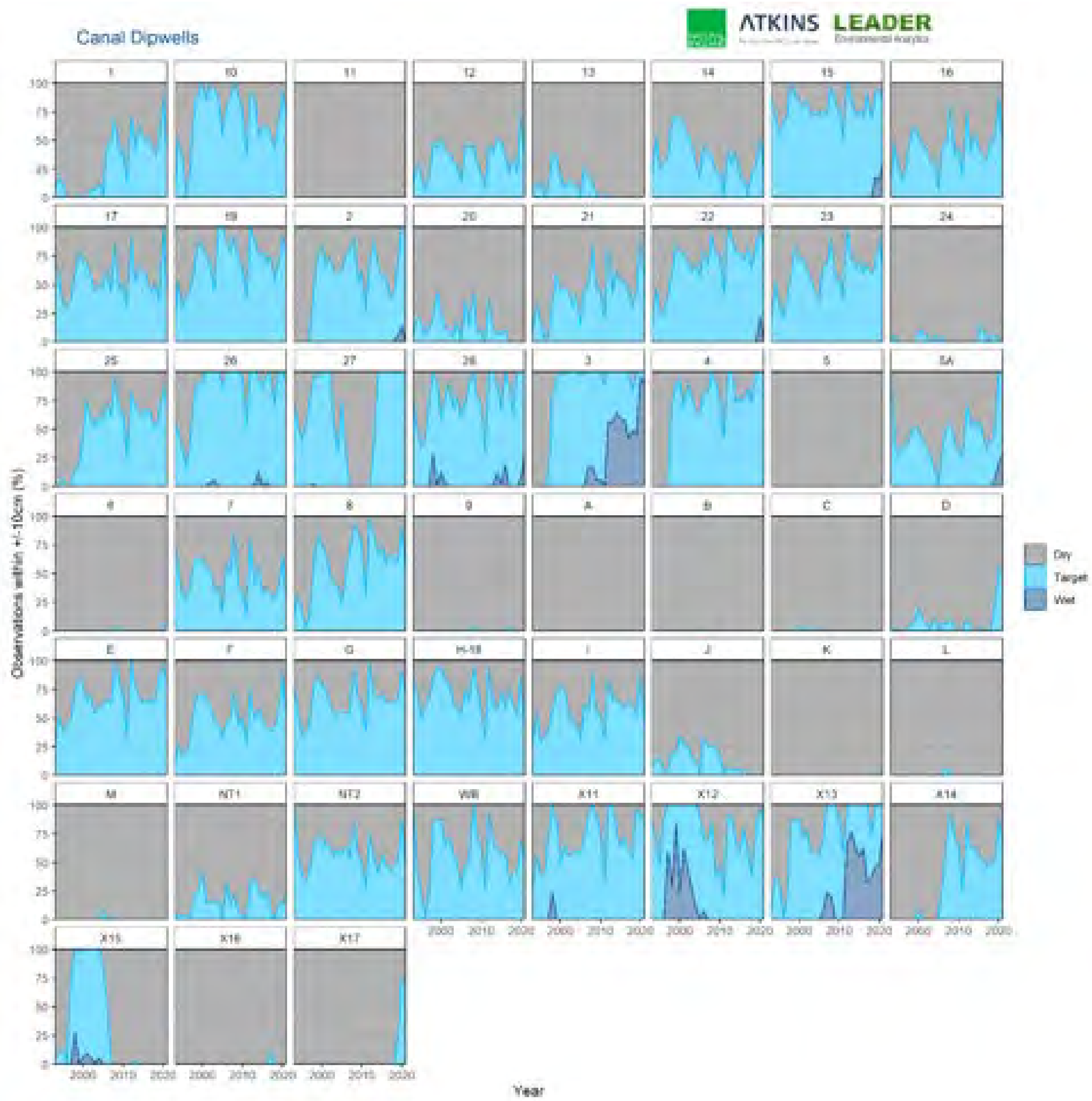

Figure 2.3.7 Updated overview of dipwell water levels for along the Canal Route on Fenn's and Whixall (1998 to December 2021). Plots showing percentage of time within target of +/-10cm of the surface. Updated by the LIFE projects monitoring officer, based script provided by Leader Environmental Analyses.

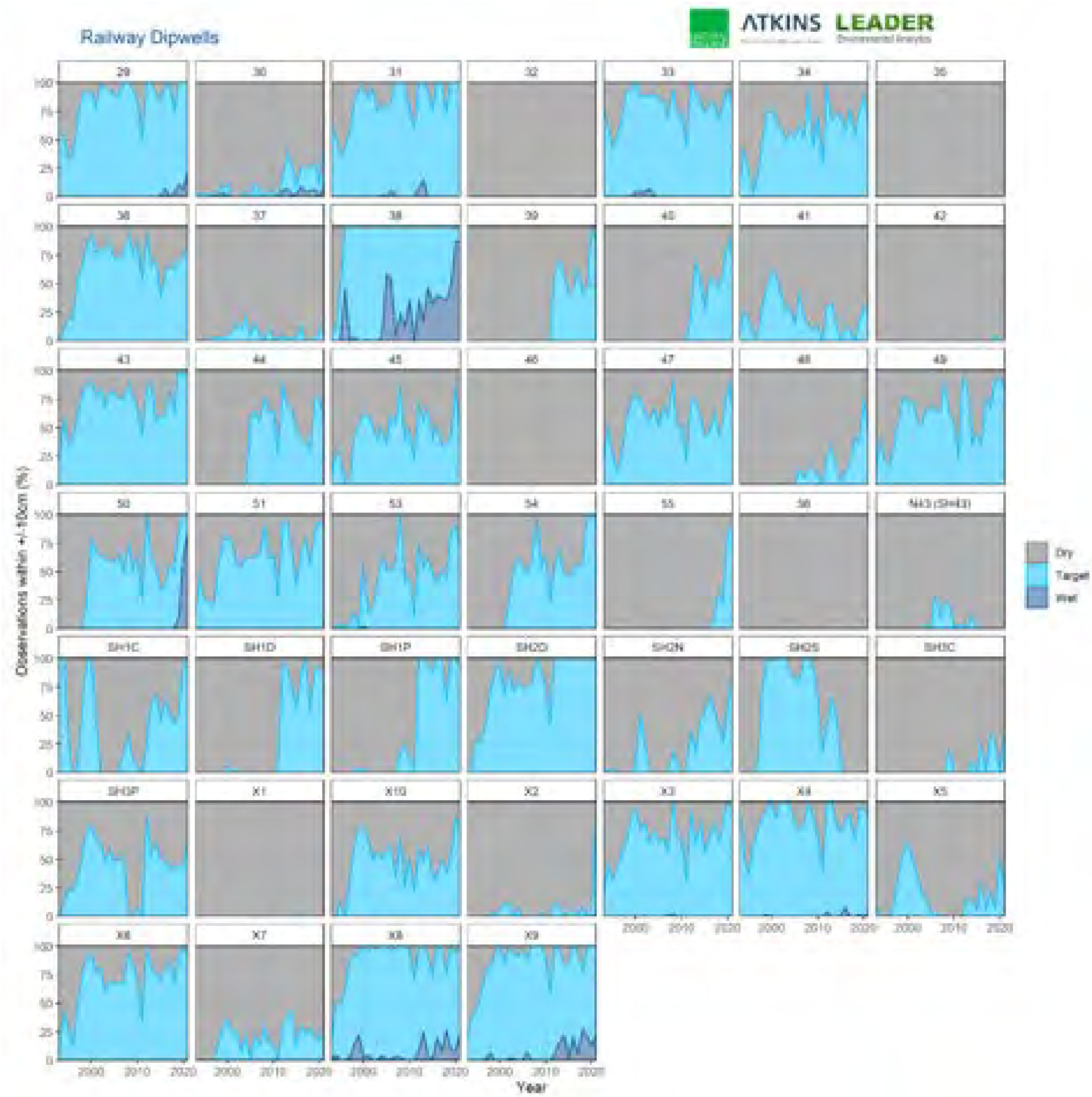

Figure 2.3.8 Updated overview of dipwell water levels along the Railway Route on Fenn's and Whixall (1998 to December 2021). Plots showing percentage of time within target of +/-10cm of the surface. Updated by the LIFE projects monitoring officer, based script provided by Leader Environmental Analyses.

Wem Moss

Data for dipwells at Wem Moss is presented in **figure 2.3.9**. Many of the dipwells are sited around the periphery of the moss and were installed to assess the effect of plastic piling installed in 2012 by Shropshire Wildlife Trust. There are few dipwells namely 2L and 6U located within areas bunded in 2018/19 (southern area) and 2019/20 (northern area).

Taken together the array of dipwells show a mixed response to the bunding with some such as 4U and 6L showing marked improvements in water levels whilst others appear to indicate little or no discernible response. This is also demonstrated in **figure 2.3.10** which shows the percentage of time within the +/-10 target. Water levels in several of the dipwells such as 1U and 7L located outside the bunding appear to have responded to the re-wetting. Overall, all 22 of the Wem Moss dipwells were within the target range for at least some of the time following the bunding, whereas prior to 2018, 13 had never reached the target range (**See figure 2.3.10**). In 2021 the water levels in 8 of the 22 dipwells met target or above conditions 50% of the time.

Aerial Photos of Wem Moss before (2014) and after bunding 2021 -CLICK ON IMAGE

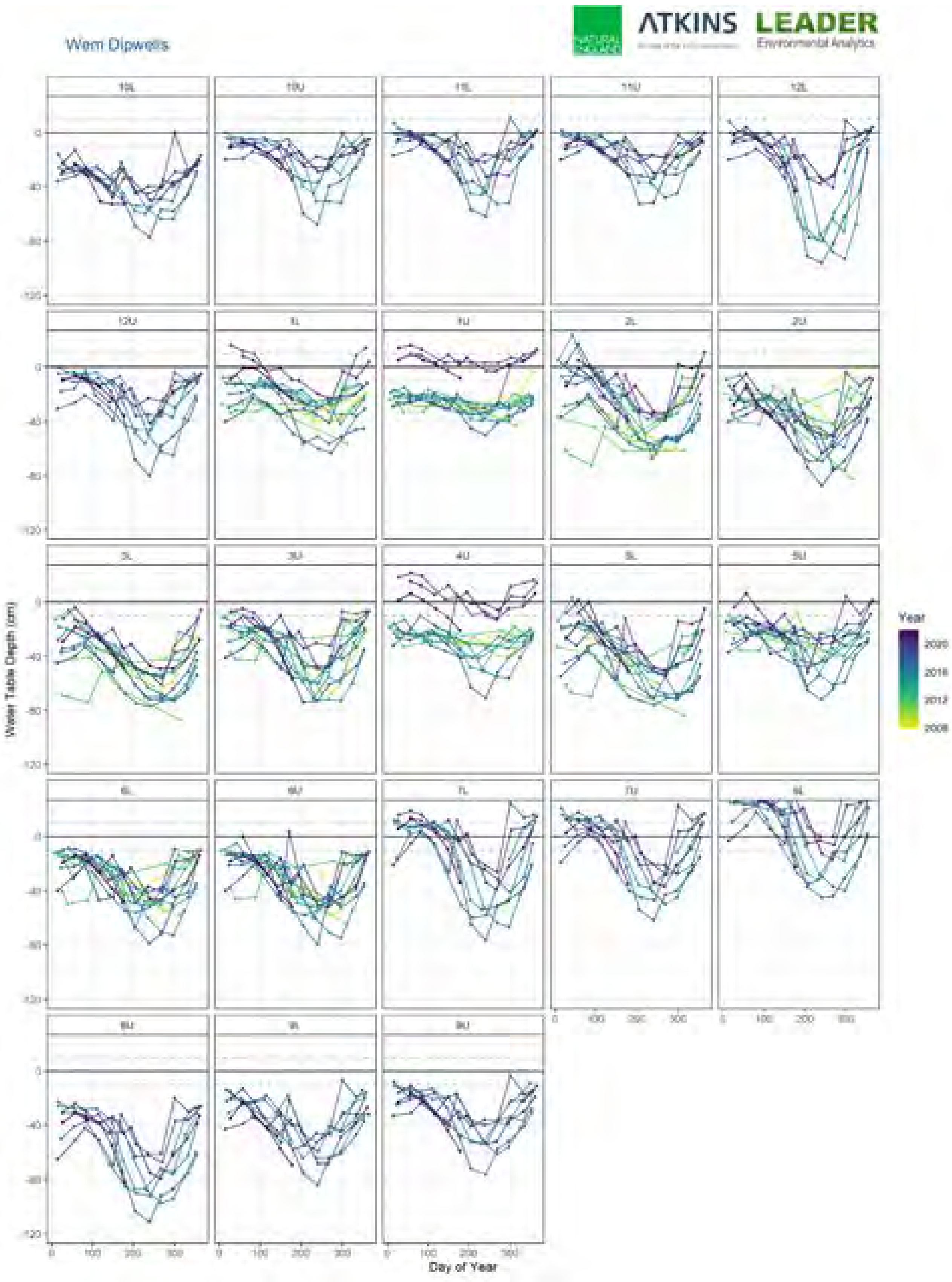

Figure 2.3.9 Updated overview of the Wem Moss dipwell water level data (2008 to June 2022). Updated by the LIFE projects monitoring officer, based script provided by Leader Environmental Analyses.

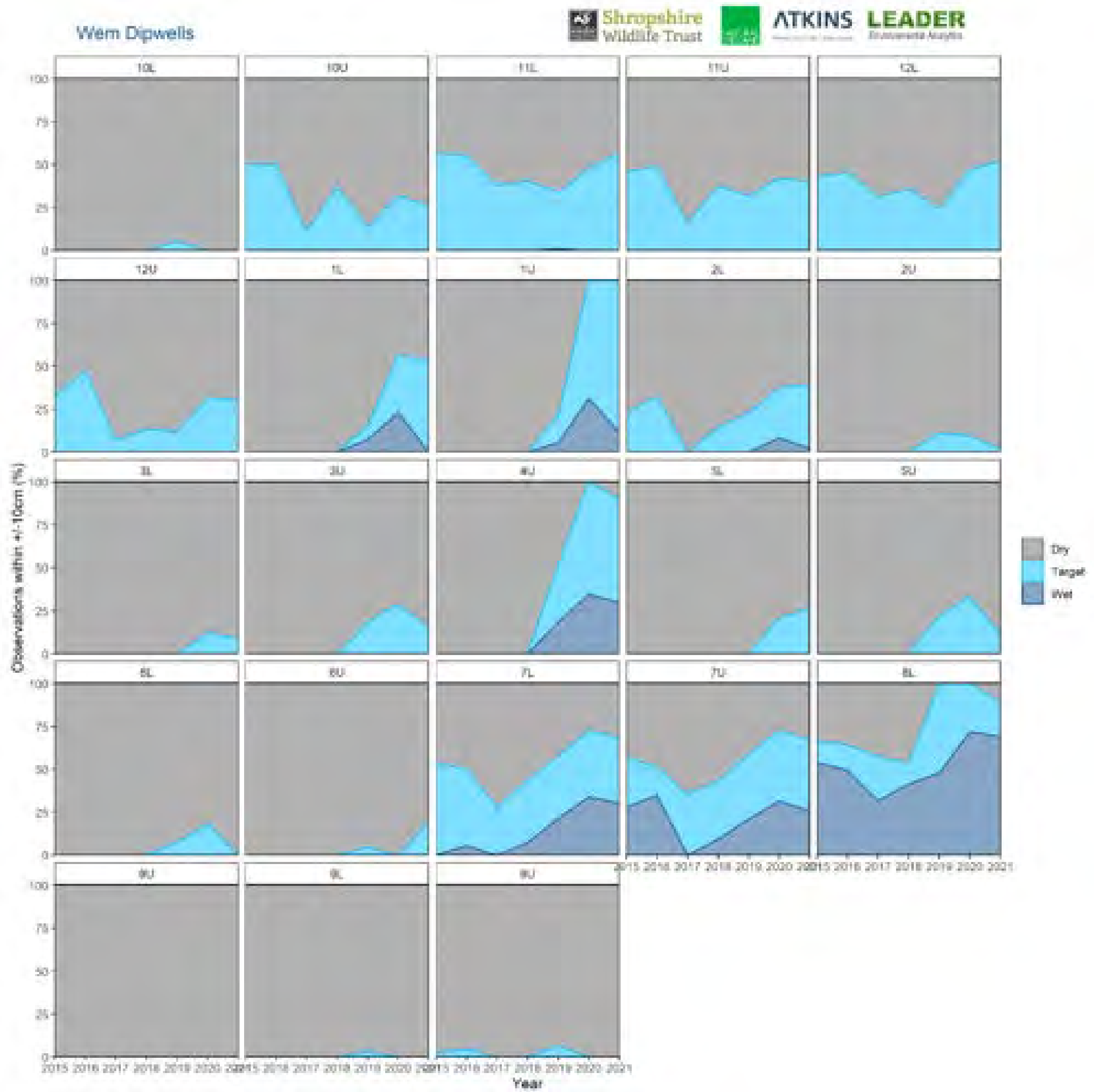

Figure 2.3.10 Updated overview of Wem Moss dipwell water levels between 2015 and December 2021. Showing percentage of time within target of +/-10cm of the surafce. Updated by the LIFE projects monitoring officer, based script provided by Leader Environmental Analyses.

Turfing Fields

Turf was stripped from fields 21 and FW but not Section 38. Section 38 therefore provides a 'control' for the comparison of water levels with the other two fields. The full set of the data for the turfing fields can be found in **appendix 2.3.1**. A visualisation of the dipwell data is shown in **figure 2.3.11**. Since the turf in Section 21 was stripped and bunded the water levels in two of the dipwells appear more stable with less variability. FWA also appears to show the same trend, however FWB shows a similar trend to the control dipwells in Section 38.

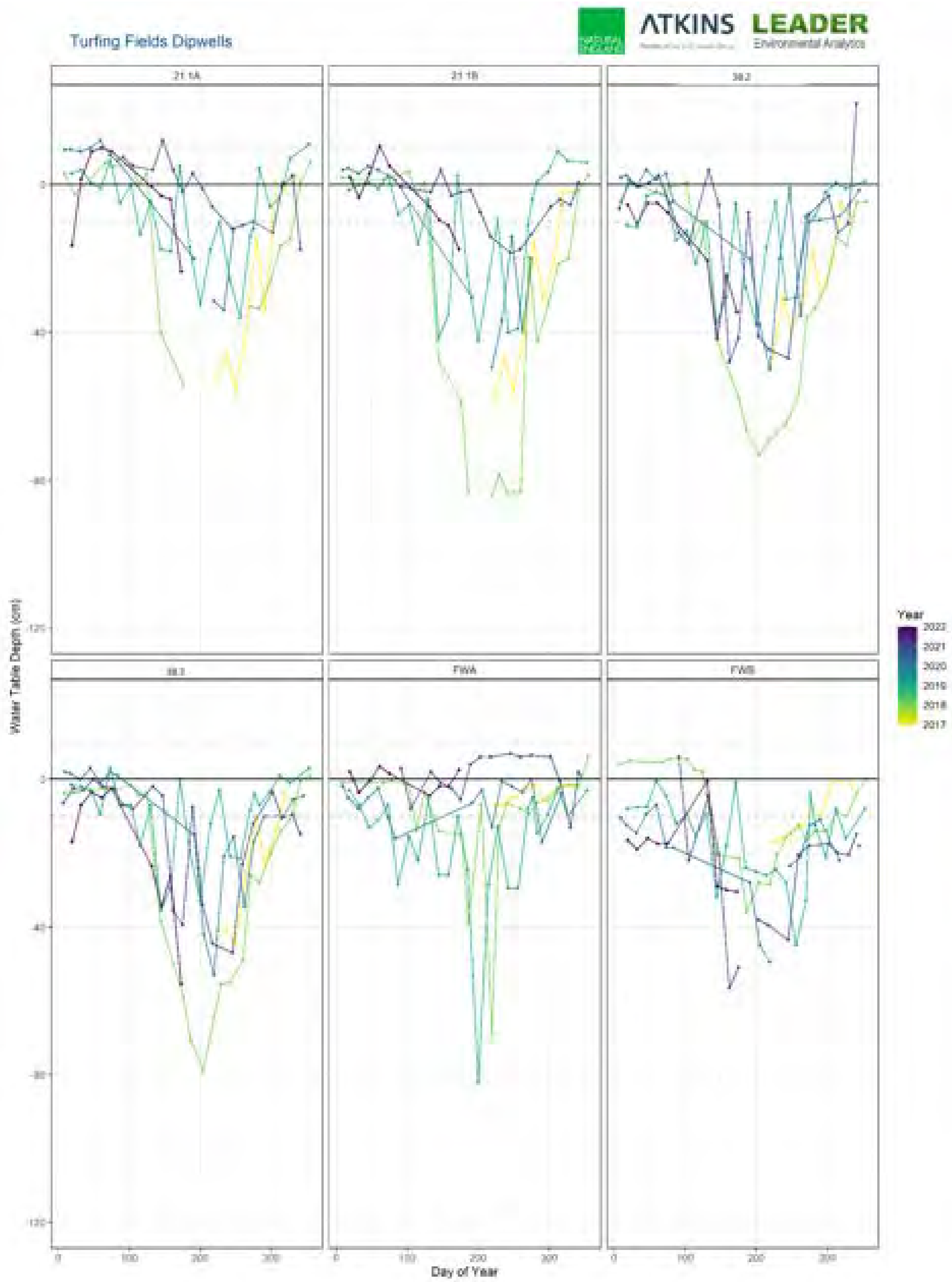

Figure 2.3.11 Overview of Turfing Fields dipwell water level data up to July 2022. It is important to note that works carried out in 2019/2020 caused the ground level to drop by 25cm in the fields (apart from 38.2 and 38.3) but the dipwell data is given referenced to the original ground height.

It is worth noting that during the monitoring period the ground level in close proximity of the dipwells remained unchanged whilst surrounding parts of the field were lowered by approximately 25cm by turf stripping. As a result, for the stripped land the actual water table level relative to the new lowered surface level is 25cm higher approximately than is indicated on the results.

Sinker's Fields (Section 56) (LP 7)

The water level results from the dipwells located in the Sinker's Fields (LP7) are given in **appendix 2.3.1**. There are several data gaps caused by the flooding of the land and inaccessibility. A visualisation of the data is shown in **figure 2.3.12**.

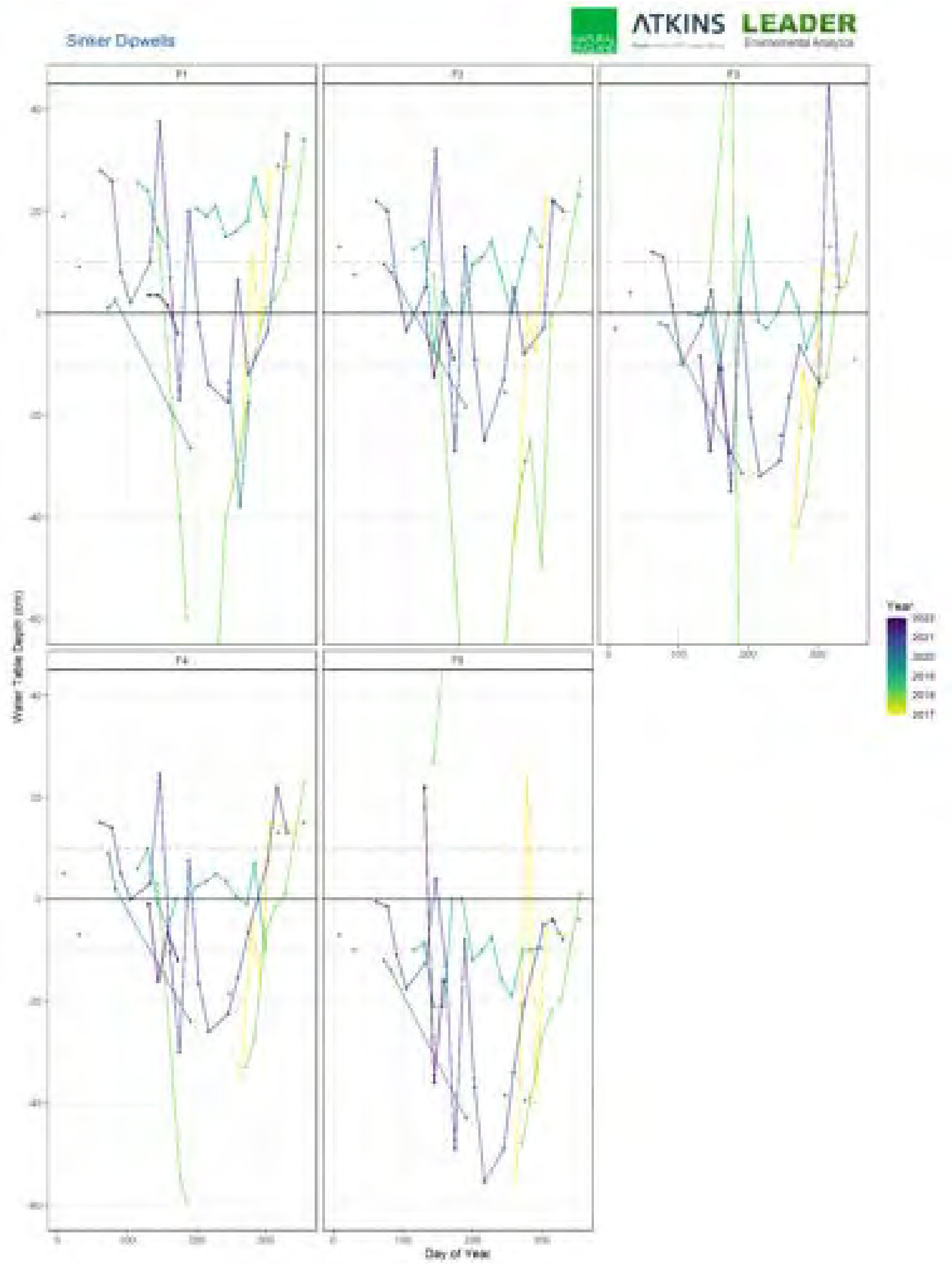

Figure 2.3.12 Overview of Sinker Fields dipwell water level data from 2017 up to July 2022.

The planned water level management scheme on the eastern part of the Sinker's Fields has not to date been implemented due to a lack of funds following the completion of the works on the western area. Accordingly, no action was undertaken to raise the water levels in the fields containing the dipwells. Not unexpectedly the water levels are highly variable reflecting the frequent overtopping of drainage waters carried by Slack's Drain. This does however usefully provide an indication of the water levels patterns experienced in the western fields before the water level management scheme was implemented and levels became controllable.

Automated Water Loggers

A full set of the Level Scout automated water logger data is found in **Appendix 2.3.4**. Graph plots of the data are shown in **Figure 2.3.13**. The batteries of the water loggers had to be replaced part way through recording which created a gap in the dataset. Consequently, the data is split between the original data set (**Suffix A**) and a new one (**Suffix B**). The location and type of logger used remained unchanged, so the data shown indicated by Suffix A and Suffix B is directly comparable.

Even though the depth of the water table varies, the results from each of loggers follows a similar pattern of fluctuation suggesting that the response to climatic variables is similar across the whole site. Some of the dipwells were only installed in the final year of the project so there was insufficient data available to determine trends from.

Pre-rewetting works water measurements from the Sinker fields (LP7) showed the flood level reached over a metre above ground level in 2019 however the water logger had to be removed prematurely after it repeatedly filled with silt which made the pressure measurements unreliable.

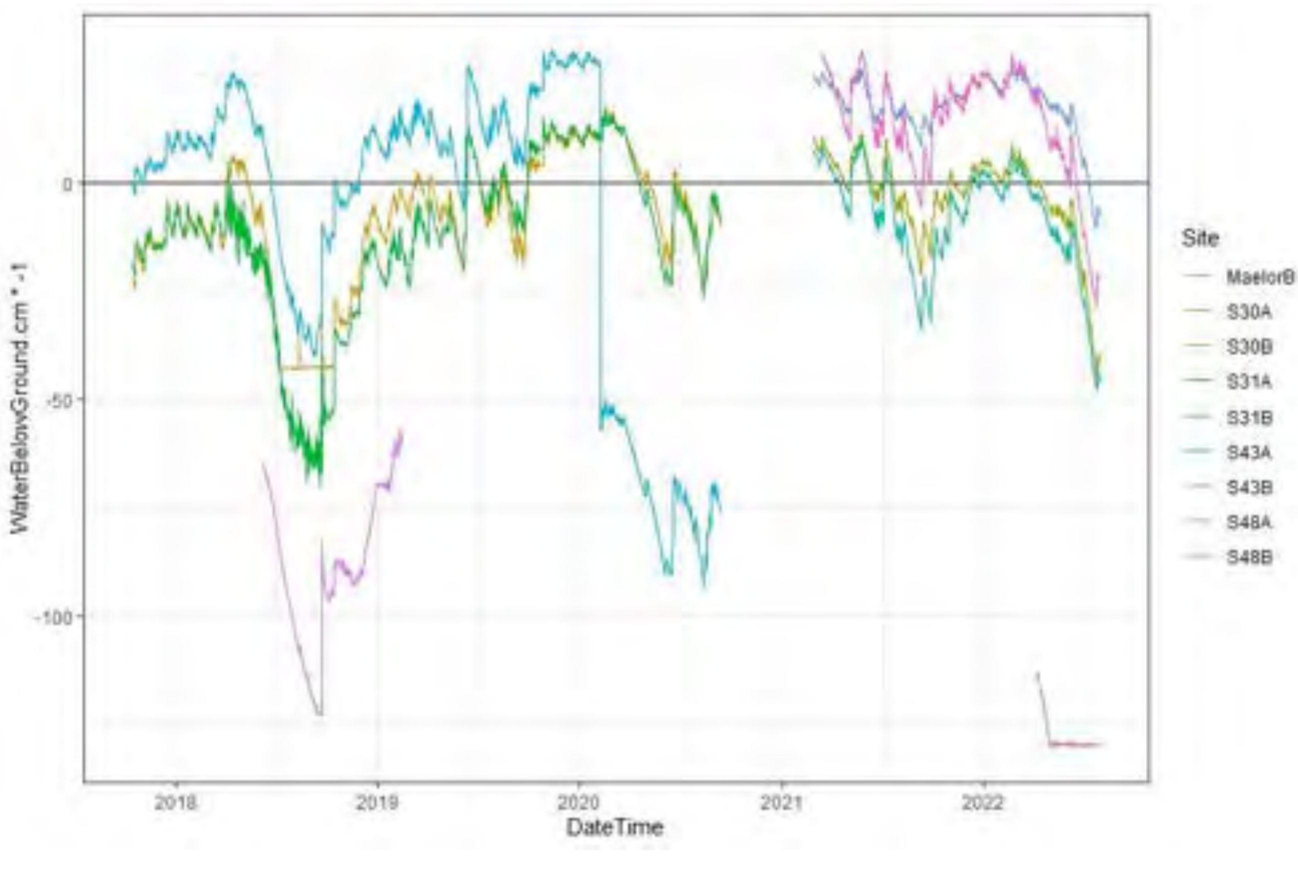

Figure 2.3.13 Overview of water level data from the automated water loggers north of the railway line.

Figure 2.3.14 Overview of water level data from the automated water loggers south of the railway line.

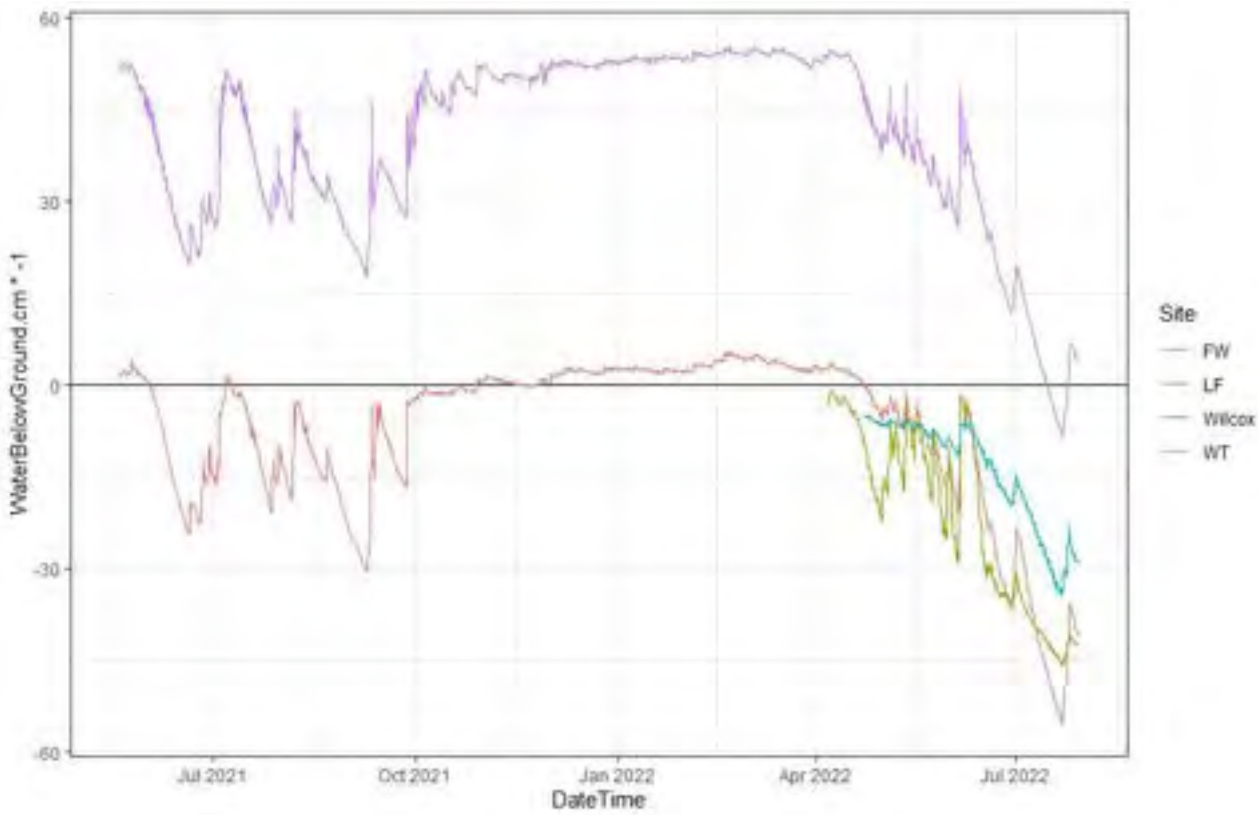

Figure 2.3.15 Overview of water level data from the new automated water loggers.

Discharge Flow from the Main drain, Fenn's Moss

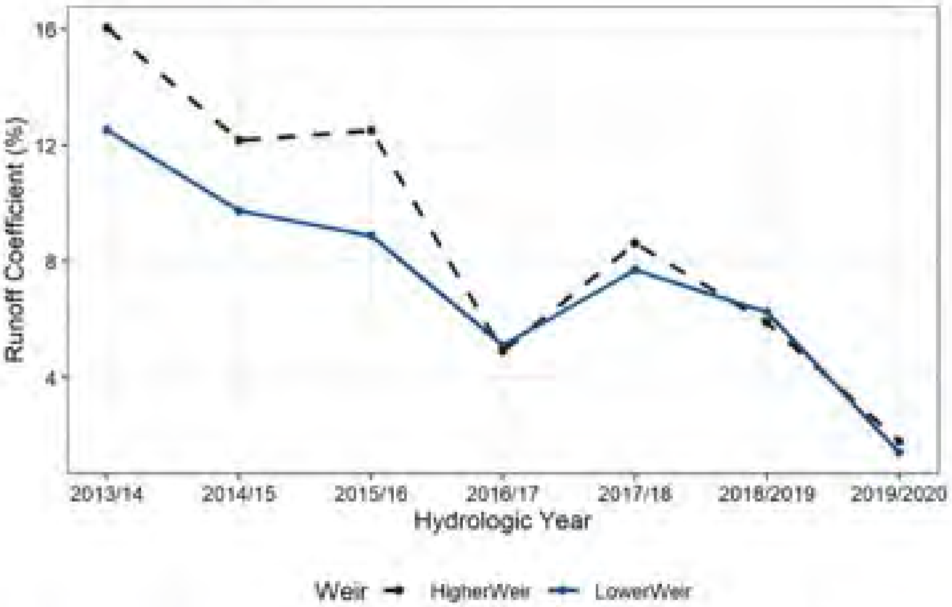

Figure 4.3. Annual runoff coefficients for each hydrologic year (July 1st – June 30th) of the higher and lower weirs.

Water flow data from monitored at two weirs (Main drain, Fenn's Moss) appears to follow a seasonal trend, with peak flows over winter (up to 0.28 m s-1) and zero or near zero flow in the summer months. The runoff coefficient (percentage of rainfall that runs off) shows a decreasing annual trend since 2013, and peaks appear to be occurring later within the year. The runoff coefficient has decreased from 49% in February 2015 to 20% in February 2019 at the higher weir, and from 35% to 18% at the lower weir for the same periods.

Reduced flow, runoff coefficients and higher water table observations in 2019 indicate greater retention of flow within the project site following the restoration management. Further monitoring of flow and water tables would be beneficial to understand how the now completed bunding management has changed the hydrological responses on the Mosses, to understand whether a new equilibrium is established hydrologically, and to observe responses during dry conditions.

2.4 Conclusion

Overall, there is evidence that bunded areas are more likely to be within the target water level range of +/- 10 cms for a greater part of the year. This is particularly evident for Bettisfield Moss which has a good coverage of dipwells and was one of the earliest areas to be bunded. It is too early to say for certain if this trend will be replicated across other areas of the site but given that the Level Scout automated logger data shows similar responses to weather events across the site it seems highly probable that, given time the rest of the site will follow the same trends as seen at Bettisfield Moss. A continued period of monitoring is recommended to more fully assess the effectiveness of the bunding undertaken elsewhere. The use of the existing extensive networks of dipwells across the site in place prior to the project has the benefit of providing, in some cases, 15 years' worth of pre-intervention baseline data for comparison purposes. However, the location of most of these (other than Bettisfield Moss) are situated in areas only bunded late on in the project i.e. in the centre of moss. Consequently, it is too early to assess the full impact of the bunding on water levels for these areas. Discharge flow monitoring indicates that overall, there is better retention of rainfall in situ on site and there has been a steady decline in water loss from the project site following restoration management.

3.0 Air and Water Quality Monitoring (D1.2 and D2.2)

3.1 Aims and Objectives

- D1.2, D2.2 & D3: Air and Water Quality Monitoring: Assess the success of actions taken to improve water quality and reduce and ameliorate air pollution.

Raised bogs such as Fenn's and Whixall Mosses are entirely ombrogenous (fed only by precipitation) and are characterised by low nutrients and low pH. Accordingly, where high conductivity and pH occurs across the peat body can be an indicator of possible pollution, or the upwelling of mineral groundwater.

The aim of surveys were to:

- Assess the effects on water quality in the original Bonington Manor drain following the diversion nutrient rich water away from it (Action C6);
- To assess any changes in water quality in ditches around the periphery site identified to be at risk from higher nutrients;
- To assess the condition of the known nutrient upwelling areas and to compare the results with those from previous studies to identify any areas of improvements or any areas of concern.

The data is presented as graphical visualisations in the form of box plots and maps.

3.2 Methodology

Air and water quality monitoring has been carried out to assess the success of actions to improve water quality and ameliorate air pollution via actions under C5 (Air and Water Pollution) and C6 (Diversion of Bronington Manor Drain).

Water conductivity and pH was measured using a portable water meter with sampling targeted in high-risk ditches, drains and upwellings locations identified at the start of the project. This included surveys of the original Bronington Manor Drain, parts of Whixall Manor Drain and of ditches feeding into key areas, such as the turfing and re-seeding fields (C7) (**Figure 3.2.1**).

Sampling points selected and surveyed at the start of the project to provide a set of baseline data, were re-surveyed near the end of the project. At each sampling point three readings were taken, and a mean pH and conductivity value calculated to generate the data used for the assessment of changes. Mean pH was calculated using the following formulas:

pH = -log[H+]

Mean pH = -log_10[(ΣH+)/(n)]

Where n= number of values

In the case of the Bronington Manor Drain extra readings were collected given that a change in the nutrient status was likely following the diversion works. Conductivity and pH readings were repeated on four occasions, at different seasonal points throughout the year to gain an understanding of changes to water quality under different hydrological and meteorological conditions. This was used to help inform the interpretation of the data from the other ditches and drains used in the study.

An investigation was carried out into elevated nutrient levels at locations where water quality issues have either been a historic feature of the site or it was indicated by the presence vegetation indicative of enrichment e.g. *Typha* sp. The same sampling method used for the ditches and drains was followed. A single survey was carried out in the final year of the project with the results compared to a previous study carried out in 2012.

A detailed water quality assessment of Wem Moss was carried out in 2018 by Stantec, a specialised consultancy in this field. A similar tailored contamination survey was also commissioned for the former scrap yard known as Furber's Scrap Yard (LP4) and was carried out by Ground First Ltd in 2019. Findings from these reports are summarised in the results section. Detailed methodologies are given in the reports included in **Appendix 3.3.1**.

pH and nutrient analyses was also carried out on soil samples collected from the lagg restoration sites (C5) and newly acquired forestry block (**figure 3.2.1**). The samples were analysed by NRM Laboratories, specialists in analytical laboratory testing for the land-based industries. The number of sampling points varied depending on the size of the area represented but was guided by best practice soil sampling advice provided by NRM Laboratories. To determine the variation in nutrients through the soil profile samples were taken at 10 cm intervals to a metres depth or until hard substrate was struck. For each given unit area, the results of the samples taken at corresponding soil depths within that unit were combined to give a single result. Information on the variation of the soil quality and nutrient levels through the profile for the turf stripping fields was used in making decisions regarding the depth of soil to remove.

Previous vegetation surveys and atmospheric ammonia monitoring and modelling data at the NNR indicated the site received high levels of atmospheric nitrogen pollution. As part of Action C5, the project developed a Shared Nitrogen Action Plan (SNAP). The monitoring component of this involved the installation on site of three additional high sensitivity UKCEH passive ALPHA® samplers to measure atmospheric ammonia (NH3) gas. NH3 data from the three sites (MM1, MM2, and MM3) over a 4-year period between July 2018 and June 2022 have been analysed (**see Figure 3.2.2**). NH3 data over the same period from the existing long-term National Ammonia Monitoring Network (NAMN) site, Fenn's Moss 1 (S52A, UKAIR ID = UKA00291: at centre of Fenn's Moss) was also included. The analysis, evaluation, and the production of a report on air quality data was undertaken by the Centre for Ecology and Hydrology (CEH), a specialist contractor. A summary of the findings is given in results section. In addition, in the early phase of the project a desk-based study was carried out modelling the sources of nitrogen impacting the site.

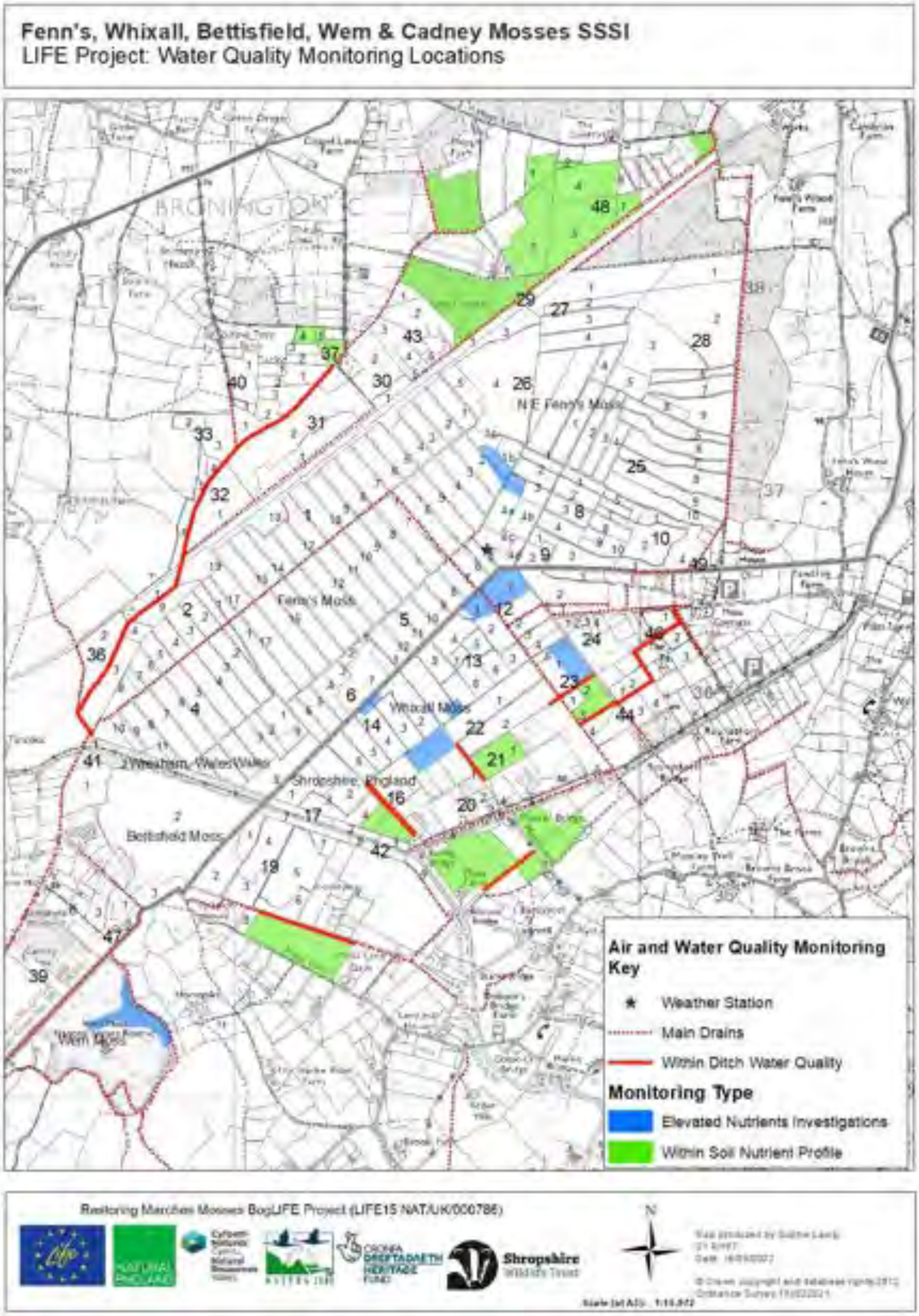

Figure 3.2.1 Water Quality and Soil Monitoring Locations.

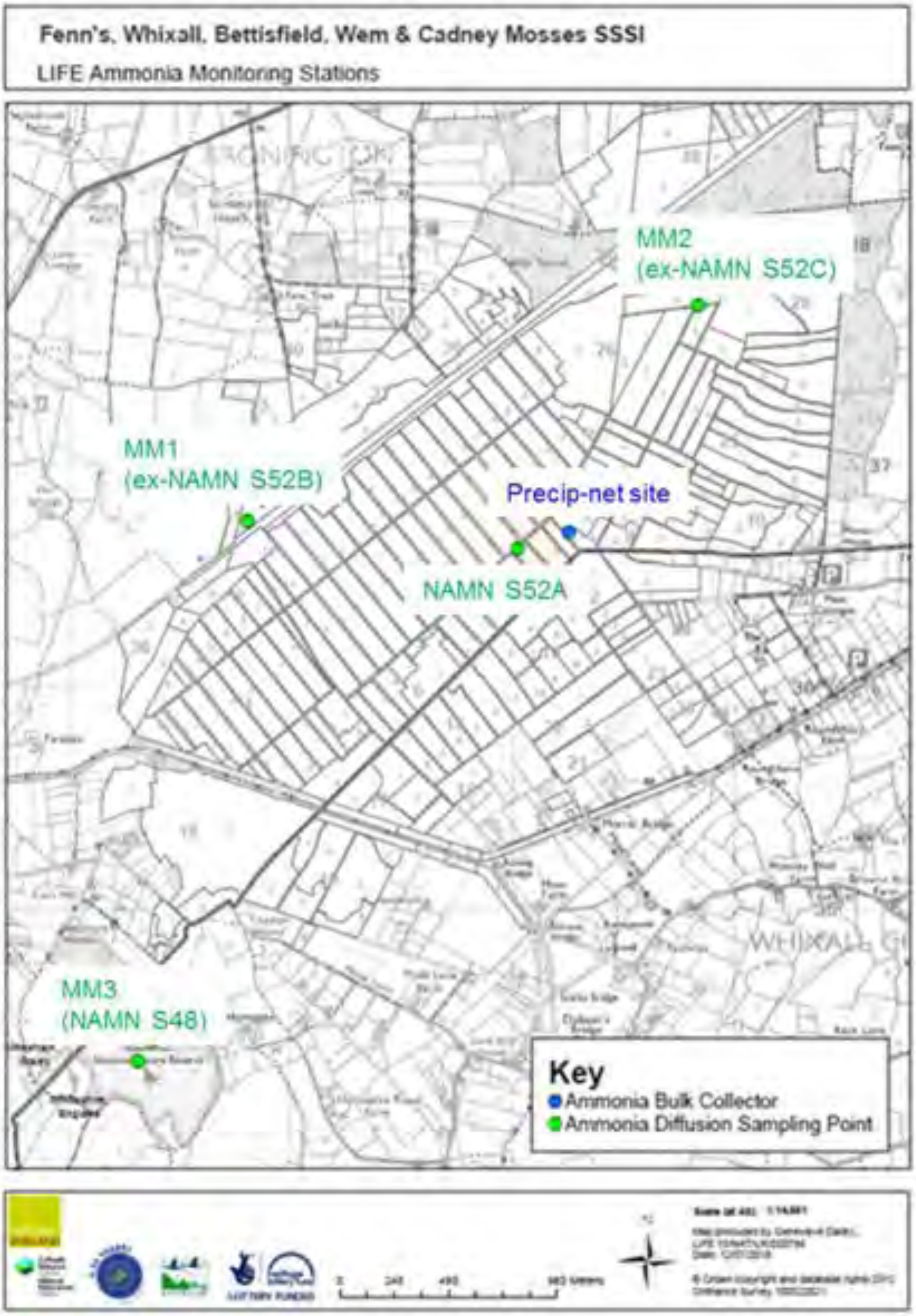

Figure 3.2.2 Locations of Ammonia Monitoring Stations.

3.3 Results and Discussion

Key finding from the water quality investigations and monitoring are given below however for a more detailed discussion of the results please refer to the specific reports by Ground First Ltd 2019, Stantec 2019, Walters, 2022 and Laing, 2022 attached in the **Appendices 3.3.1 and 3.3.2**. A summary of the results of soil analyses are provided but a complete copy of the data can also be found in **Appendix 3.3.3.**

Figures 3.3.1 and 3.3.2 show the average winter pH results before (2020) and after the Bronington Manor Drain (BMD) diversion was completed (2022). **Figure 3.3.2** also shows pH results both the original and the new diversion routes. The noticeable lowering in the pH is observed in stretch C of the BMD. This is a section through deep peat that has been dammed up and isolated from the flow of the diverted BMD. It now receives rainwater and 'bog' water from the surrounding areas of restored peatland habitat either side. The mean pH for each section of the BMD and the seasons the data was collected can be seen in **table 3.3.1**. This along with results shown **figure 3.3.3** confirm that the pH averages for 2022 in Section C are the lowest recorded. This may be a sign that the original BMD no longer carrying mineral nutrient water is reverting toward conditions you would expect for a peat bog environment. Analysis of conductivity values show no conclusive changes to date (**figure 3.3.4**).

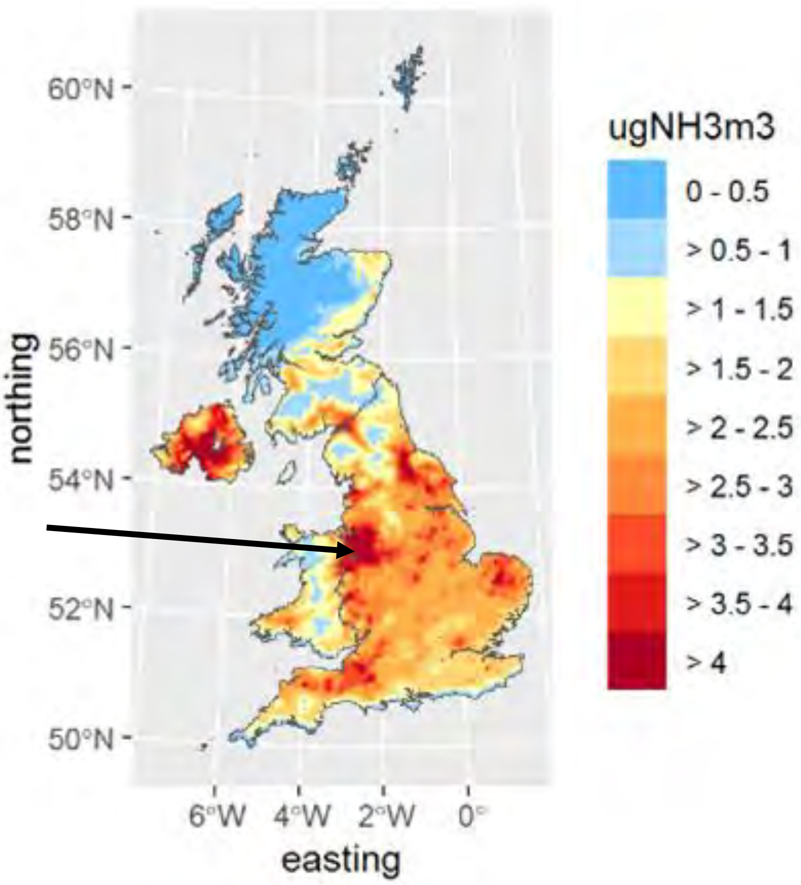

Figure 3.2.2.A – Map of modelled Ammonia Background levels for the UK (2018-2020) APIS with the location of the project site indicated

For a full discussion of the air quality please see Tang, 2022 in **Appendix 3.3.4**. Annual mean NH_3 concentrations for different averaging periods (project and calendar years; data shown for complete periods only) are summarised in the table below. Due to a gap in measurements, there are 10 months of data only in project year 4.

The monitoring data shows that long-term NH_3 concentrations at Fenn's, Whixall, Bettisfield, Wem & Cadney Mosses exceed the United Nations Economic Commission for Europe (UNECE) critical level of 1 µg NH_3 m^{-3} annual mean which are relevant for the protection of bryophytes and lichens

Table 3.2.2.1 Annual mean ammonia concentrations at the 4 project monitoring sites between 2018 and 2022 (CEH)

Annual mean NH_3 (µg NH_3 m^{-3})	**MM1** western edge of Fenn's Moss	**MM2** northern edge of Fenn's Moss	**MM3** on Wem Moss	**S52A** at centre of Fenn's and Whixall Mosses
Project Year 1 (Jul18 - Jun19)	2.7	4.9	3.4	3.3
Project Year 2 (Jul19 – Jun20)	2.1	3.3	2.7	2.4
Project Year 3 (Jul20 – Jun21)	1.8	2.6	2.4	2.3
Project Year 4 (Jul21 – Jun22)	1.7 (*n* = 10)*	2.2 (*n* = 10)*	2.1 (*n* = 10)*	2.3 (*n* = 11)**
2019 (Jan – Dec19)	2.2	3.0	2.8	2.6
2020 (Jan – Dec20)	2.0	3.4	2.7	2.5
2021 (Jan – Dec21)	1.7	2.3	2.3	2.2

* no data in April and May 2022 (due to gap in measurements between contracts)
** no data in February 2022 (all samples lost due to vandalism) (Tang, Y. 2022)

All four sites showed a decreasing trend in annual mean monitored NH_3 concentrations across the 4-year period (July 2018 to Jun 2022) covered by the monitoring.

The largest NH_3 concentrations were recorded at MM2 (northern periphery), nearest to an aluminium smelting plant located on the northeast boundary of the project site. A large decrease in annual mean (32 %), from 3.37 µg m^{-3} in 2020 to 2.31 µg m^{-3} in 2021 was coincident with closure of the plant.

N deposition from dry NH_3-N deposition and wet N deposition (NH_4^+ and NO_3^-) in 2021 are estimated to be between 13.4 – 16.5 kg N ha^{-1} yr^{-1} at the four monitoring locations. These values alone are in exceedance of the critical load set for the protection of raised and blanket bogs of 5-10 kg N ha^{-1} yr^{-1}.

Historic NH_3 data from NAMN for the four sites were also extracted from the Defra UKAIR website with some data going as far back as October 1996. The long-term time series data show substantial variability in concentrations, both within and between years. Overall, there are no clear trends in the long-term data.

The water quality survey in and around the former Furber's scrapyard by Ground First (**Appendix 3.3.1**) was undertaken in June 2019 and the results were compared to pre-clean-up baseline survey results obtained March and June 2014 and February 2017. The results suggest that the substrate of the former scrapyard remains likely to contain localised lead and nickel contamination. However, the results of surface water quality i.e. ditches indicate that there is no noticeable effect on either the lead or nickel concentrations in the 'main drain' close by the former scrapyard. Moreover, the intermittently poor water quality noted in a secondary drain did not appear to unduly affect lead or nickel concentrations at the main downstream sampling location.

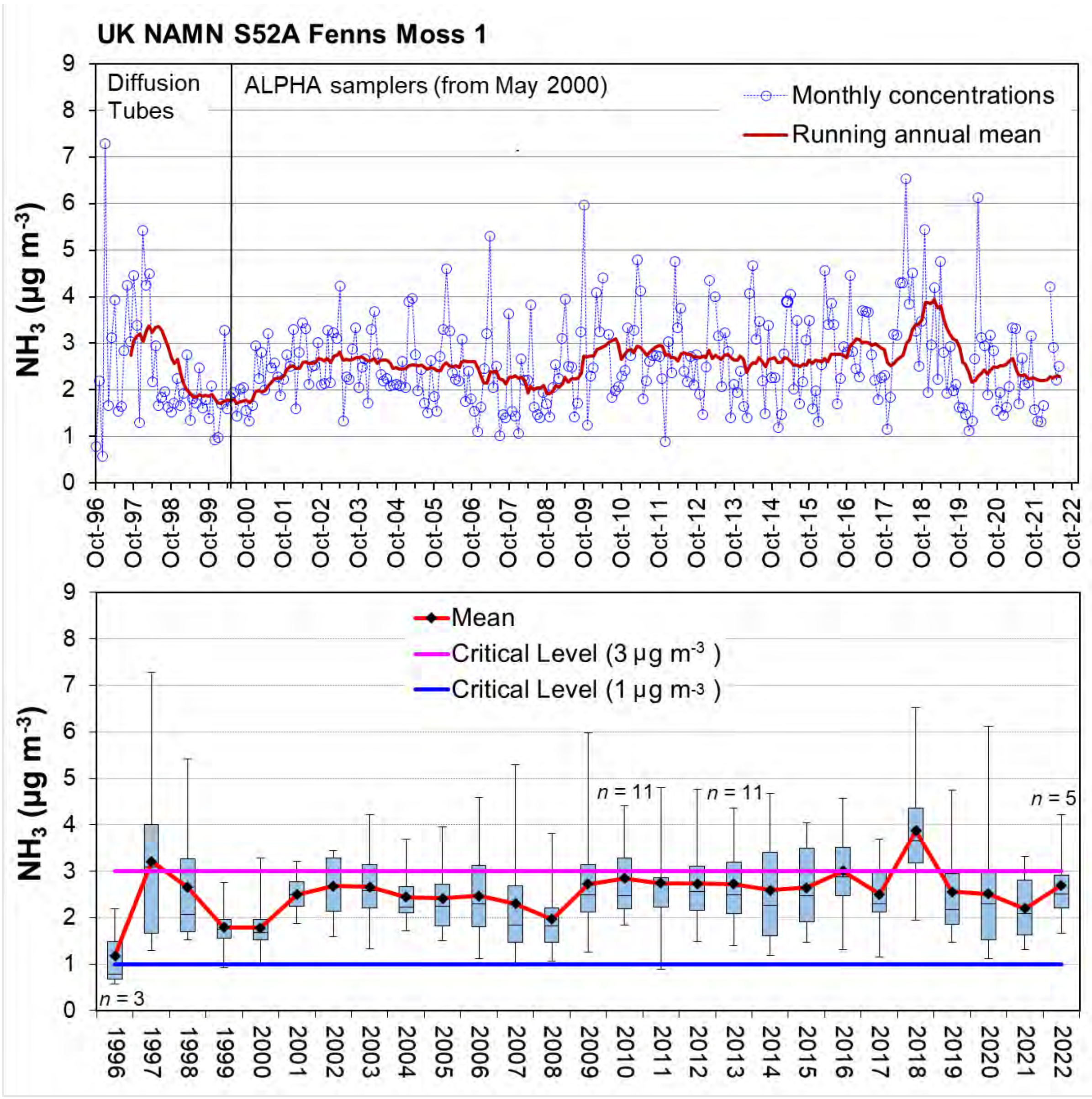

Figure 3.2.2B Long-term trends in monitored atmospheric ammonia (NH_3) gas concentrations at Fenn's Moss 1 (Site ID: S52A; UKAIR ID: UKA00291), an active site in the UK National Ammonia Monitoring Network (NAMN). (TOP) time series in monthly data and running annual mean. (BOTTOM) box plot showing trends in annual data. The diamonds show the annual mean NH_3 concentration, with the blue boxes indicating the median and interquartile range, while the whiskers show the range (minimum and maximum) of monthly concentrations, *n* = number of monthly data, which should be 12 for full data capture. UNECE Critical Levels set for annual mean NH_3 concentrations are also plotted to show exceedances. Diffusion tubes (3.5 cm membrane-type) were used when monitoring began in October 1996 until they were replaced by the more sensitive ALPHA sampler from May 2000 (Tang, Y [2022] CEH report)

The water quality results also suggest that the former scrapyard site was previously a source of localised zinc contamination although available data indicates that zinc concentrations may be reducing over time following the cessation of the commercial scrap yard operation. Surface water quality in the secondary drain remained affected by zinc in 2019.

The results show that hydrocarbon concentration levels in groundwater continue decline with distance from the scrapyard. In 2019 all off-site concentrations for Total Petroleum Hydrocarbons (TPH) groundwater were below the limits of laboratory detection and the available time series data indicate an improvement in groundwater quality (with reference to TPH) between March/ June 2014, February 2017 and 2019.

The observed water quality distribution was found to be consistent with the prevailing conceptual model adopted in as much as the high organic matter content of the peat appears to encourage the absorption of organic contaminants and thus gives rise to a reduction in the dissolved phase contaminant mass with distance along the groundwater pathway. Most analytes showed a clear reduction in groundwater concentration with distance from the scrapyard, suggesting that groundwater impacts are typically localised. This may reflect both the high organic matter content of the peat, which will promote sorption/retardation of organic contaminants, and the likely presence of a reverse hydraulic gradient towards the scrapyard from the Shropshire Union Canal. It is considered unlikely that surface water or any associated ground surface pollution will increase in the future. This is in part due to the concrete surface cover of the former scrapyard acting as a cap and reducing any polluted water mixing with rainfall. The timeseries data also suggests a general improvement in observed water quality at the locations further away from the former scrap yard between 2014 and 2019. It is particularly, noteworthy that all organic analytes were recorded at or below their respective limits of laboratory detection during the 2019 sampling round.

Stantec 2018 water quality site investigation at Wem Moss suggests the continuing presence of inorganic contamination which is thought to be derived historic contamination from the neighbouring farmland (**Appendix 3.3.1**.) It is believed that that the input of agricultural contamination from the farmland positioned directly to the east of the site occurred predominantly via overland flow and point discharges associated with ephemeral drainage channels.

Most analytes tested for show a clear pattern of higher dissolved phase concentrations along the north-eastern edge of the southern mire and also within the central lagg. Groundwater quality improved rapidly from east to west however the relatively elevated results in the central lagg, suggested a preferential flow path though this central section of the moss.

The pH results for the water were in line with what was expected with average values consistently falling in the range 4.1 to 4.8 pH units. It is noted that the average pH for the central lagg area was slightly higher (less acidic) than the surrounding areas of bog vegetation.

The mean electrical conductivity values were the highest near to the eastern site boundary and appeared to steadily reduce in concentration westwards. The 2018 results were broadly comparable to a previous study carried out in 1984, with some evidence of localised increases. Chloride concentrations were also observed to be highest in the east and the central lagg area.

The average nitrate concentrations were notably elevated near the eastern boundary compared to the remainder of the sampling locations with the results from the eastern boundary being 4 times as high as anywhere else.

The average potassium concentrations were highest within the central lagg and at the Eastern edge however there was also significant spatial variability within the southern mire and central lagg. The results do not suggest that potassium levels have increased greatly since the 1980s.

Similarly, the average magnesium concentrations were also highest within the central lagg and the eastern edge. They were broadly comparable to the levels recorded in the 1980's with some localised increases.

The average calcium concentrations were highest at the eastern edge but appear to steadily decline towards the west. The concentrations along the central lagg area were however comparable to those levels observed at the eastern edge. Again, the results were comparable to the previous study with some localised increases.

The average total organic carbon concentrations showed some evidence of a declining trend from west to east.

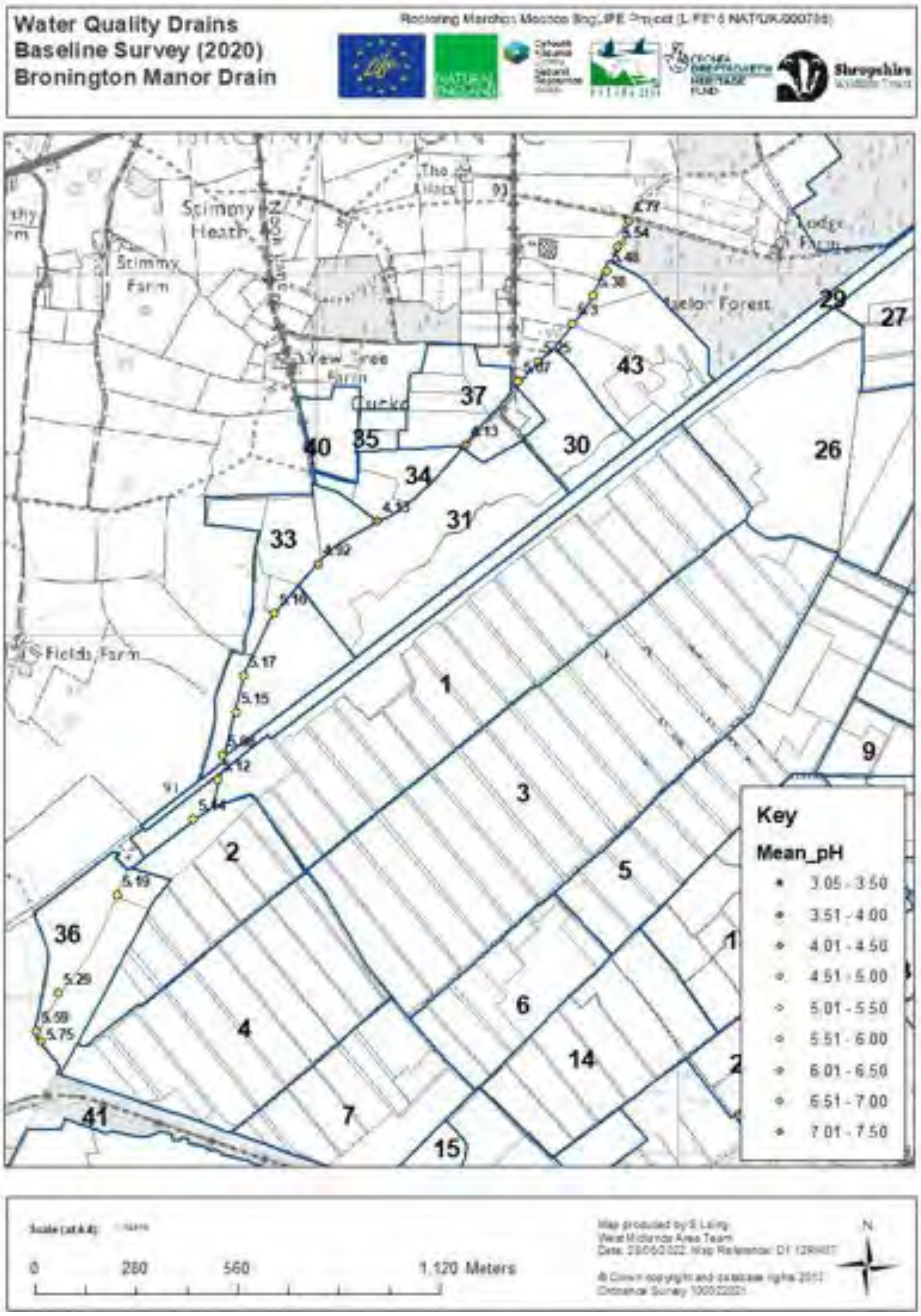

Figure 3.3.1 Map of the baseline pH values for the Bronington Manor Drain recorded in 2020.

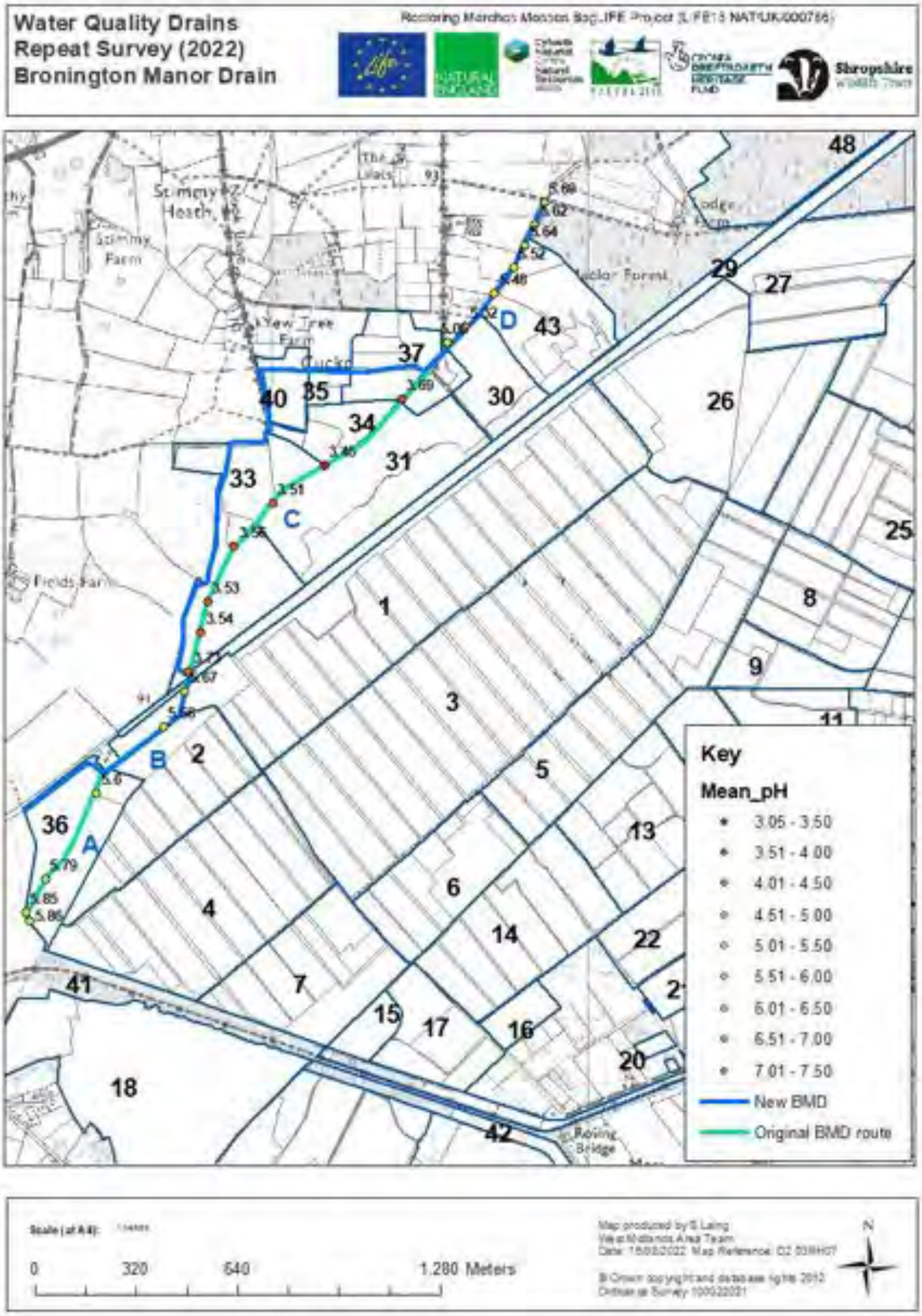

Figure 3.3.2 Map showing end of project pH values recorded for the Bronington Manor Drain 2022 (Blue letters A-D are ditch sections)

Table 3.3.1 Mean pH values along the Bronington Manor Drain by ditch section

Average pH				
	A	B	C	D
2018	**5.14**	**4.71**	**4.39**	**4.80**
Spring	5.14	4.71	4.39	4.80
2019	**5.80**	**5.40**	**5.00**	**4.79**
Summer	6.72	6.43	5.76	4.82
Autumn	4.69	4.22	4.23	4.71
Winter	5.57	5.19	4.76	4.68
Spring	6.44	5.95	5.48	5.04
2020	**6.16**	**5.66**	**5.28**	**4.91**
Summer	6.78	6.50	5.88	5.02
Winter	5.55	4.83	4.69	4.80
2021	**6.09**	**6.14**	**4.86**	**5.51**
Spring	6.09	6.14	4.86	5.51
2022	**5.72**	**5.68**	**3.82**	**5.42**
Winter	5.78	5.62	3.57	5.47
Spring	5.65	5.74	4.07	5.37

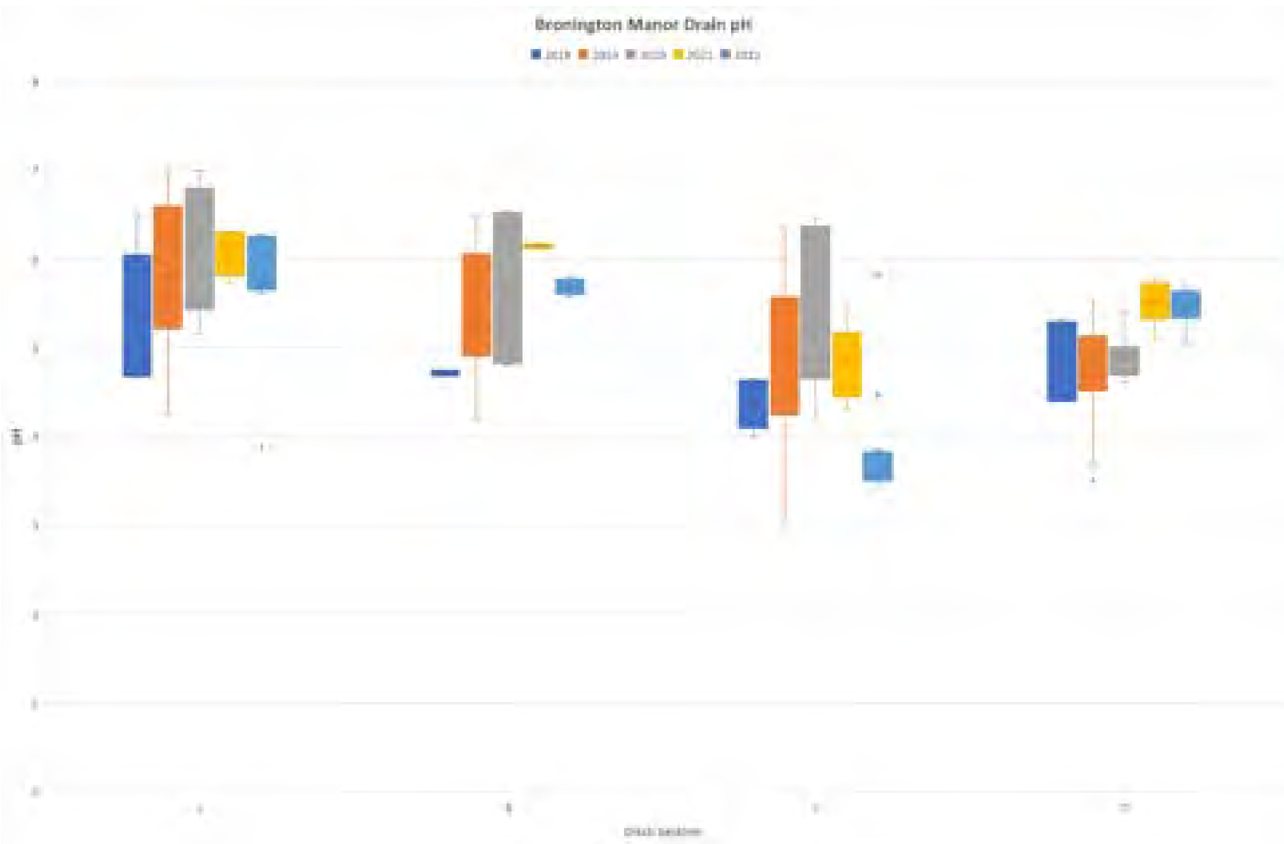

Figure 3.3.3 Graph of pH values for the Bronington Manor Drain by ditch section.

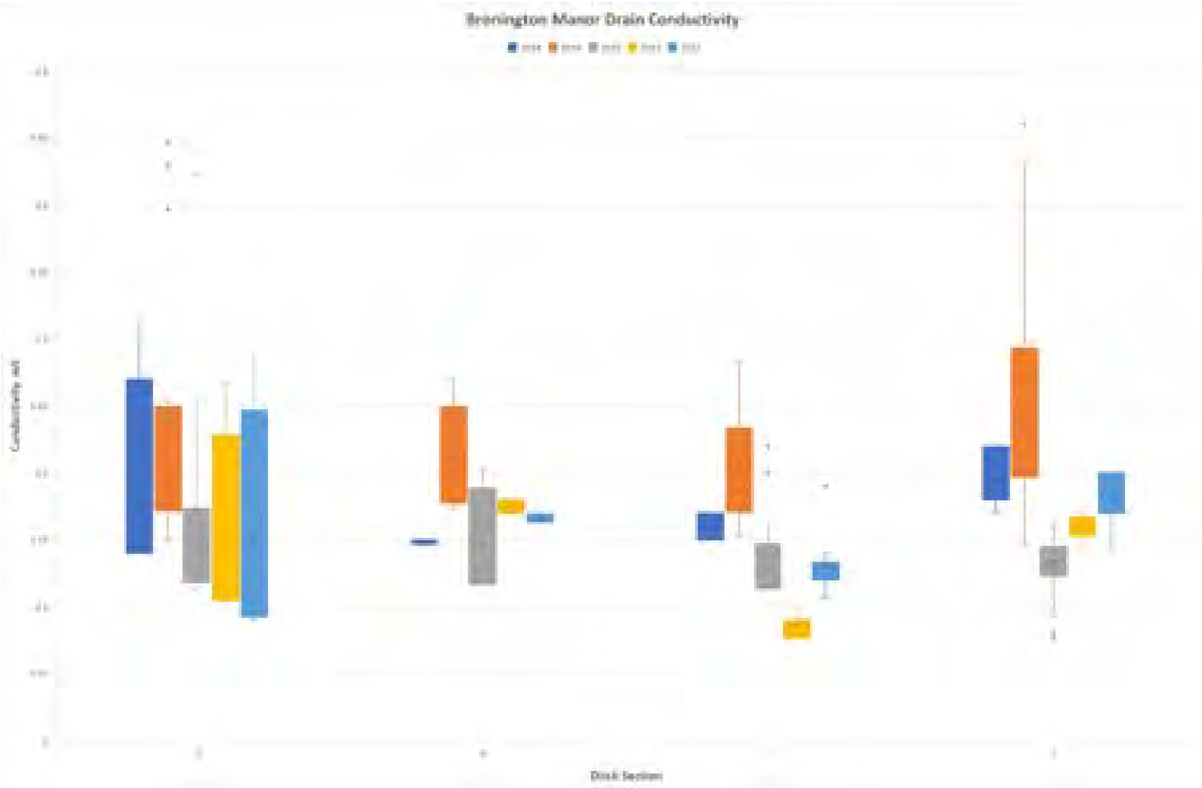

Figure 3.3.4 Graph of conductivity data for the Bronington Manor Drain by ditch section.

Soil samples were collected from fields where turf removal was planned and, in the areas, where conifer removal had already been carried out. Soil samples were taken prior to turf cutting. The full soil profile depth samples could not be collected in instances where the peat was too shallow and in the case of field 38.2 the top layer was too wet to be analysed. The samples were analysed for their nutrient levels (Phosphorus, Potassium and Total Nitrogen).

The histograms below show results for full soil profile samples however full data is contained in **Appendix 3.3.5**. Not unexpectedly given their past agricultural use the turfing fields show elevated nutrient levels in the first 0-10 cm (see **Figures 3.3.5 - 3.3.1**). 1There was then a steep drop in the 10-20 cm depth, although levels still remained elevated. Below this however the nutrient levels began to level off in most cases. Section 21 had higher nutrient levels for some of the deeper samples possibly reflecting historic disturbance to the soil layer. All the fields referred to in this part of the report apart from 38.3 and 38.4 were subject to turf stripping.

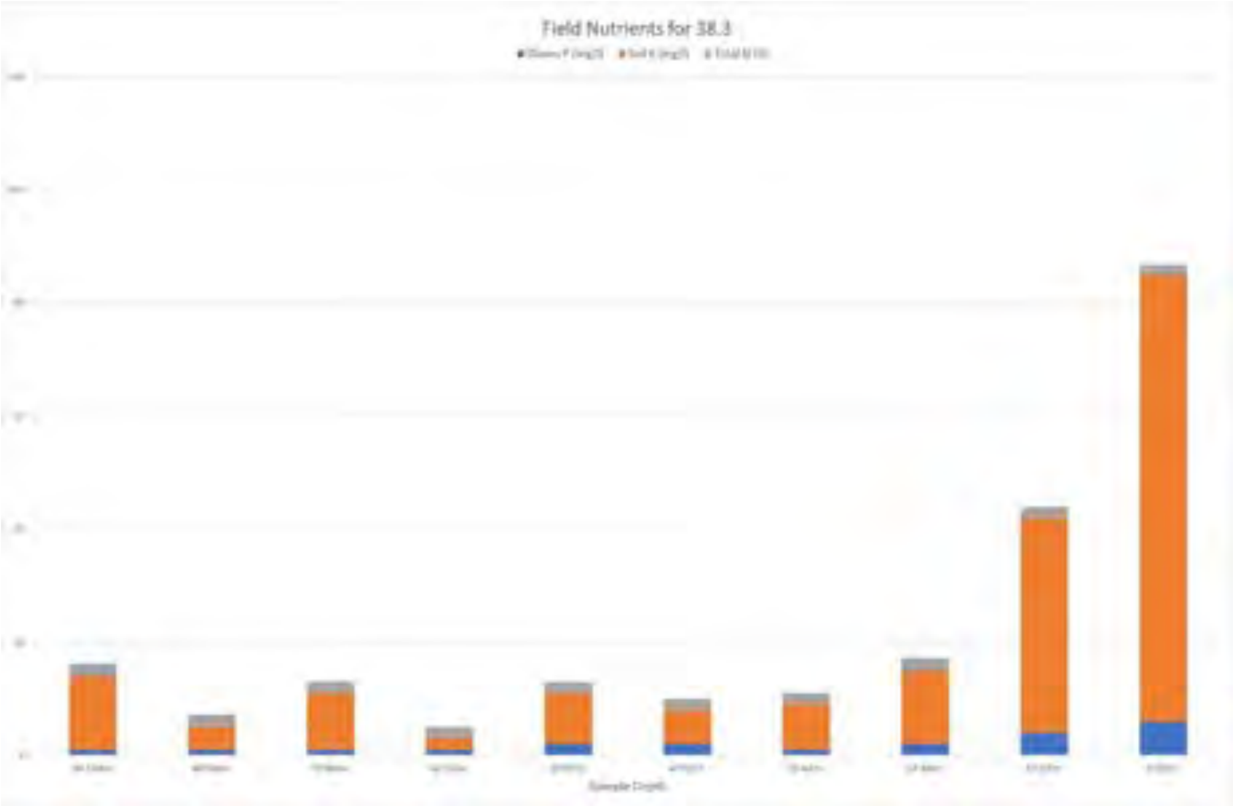

Figure 3.3.5 PKN nutrients by depth for Section 38.3.

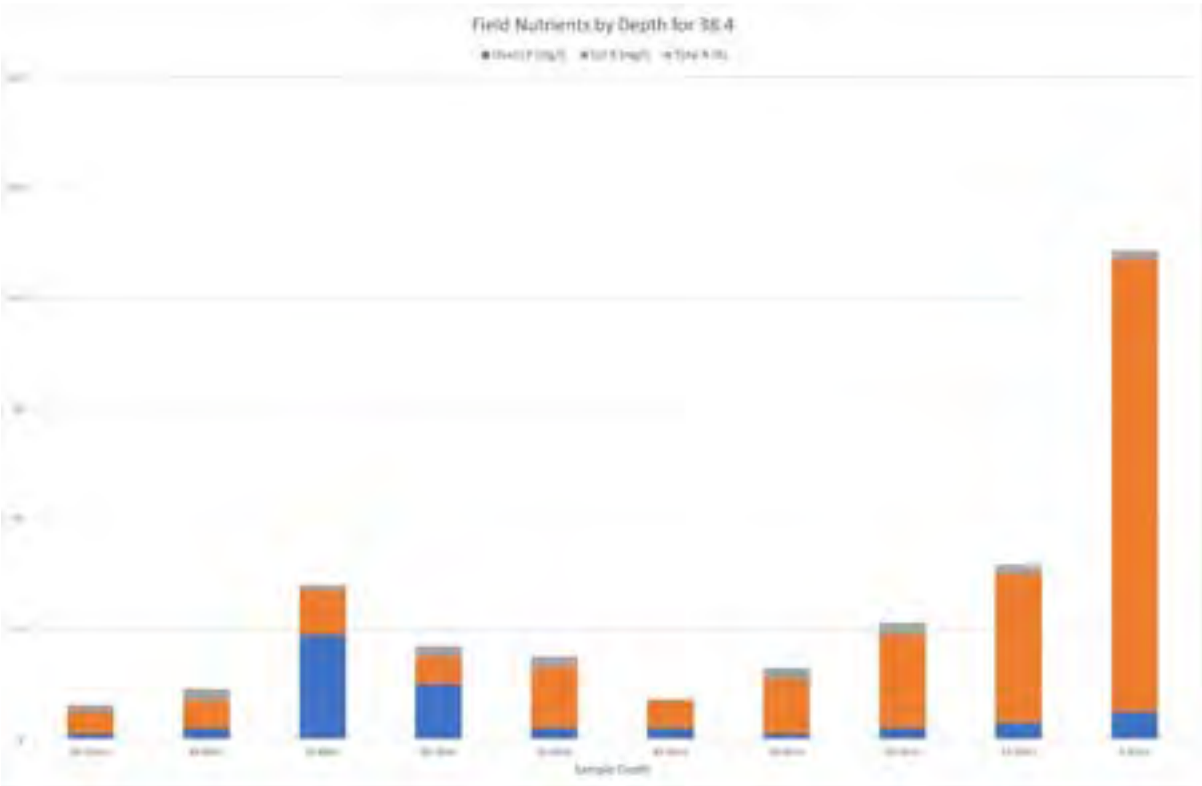

Figure 3.3.6 PKN nutrients by depth for Section 38.4.

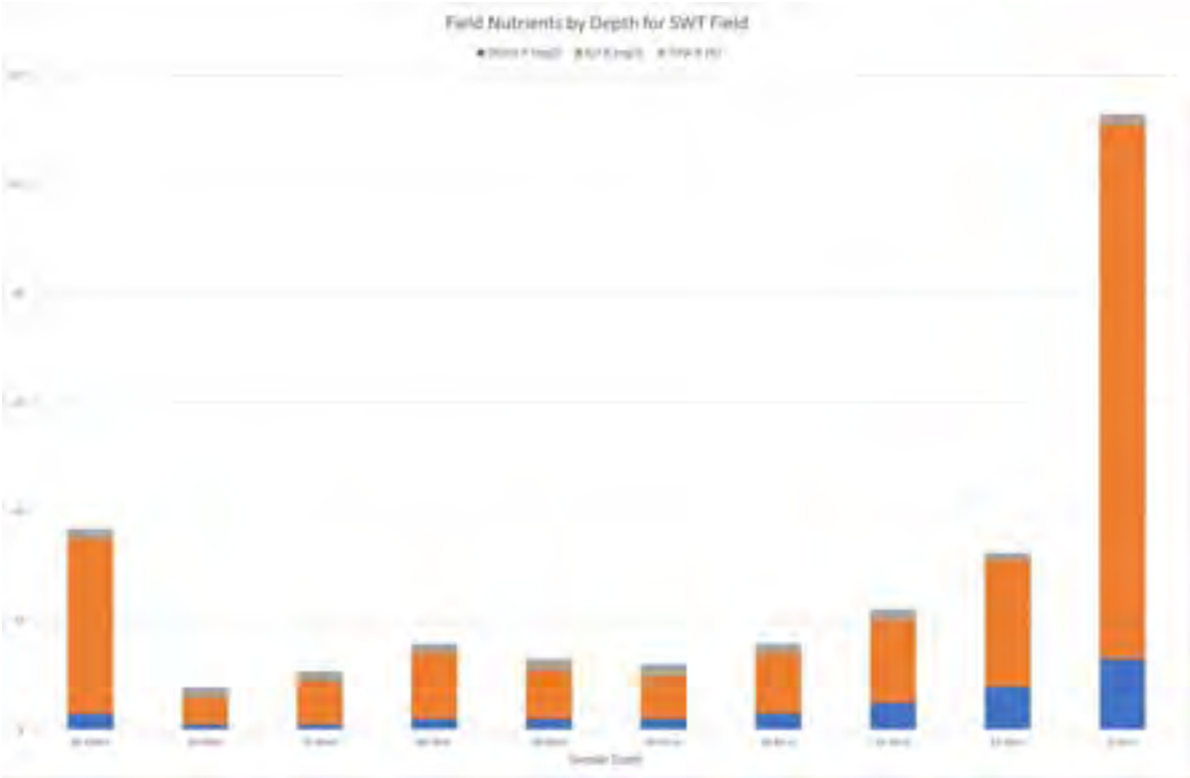

Figure 3.3.7 PKN nutrients by depth for SWT Field.

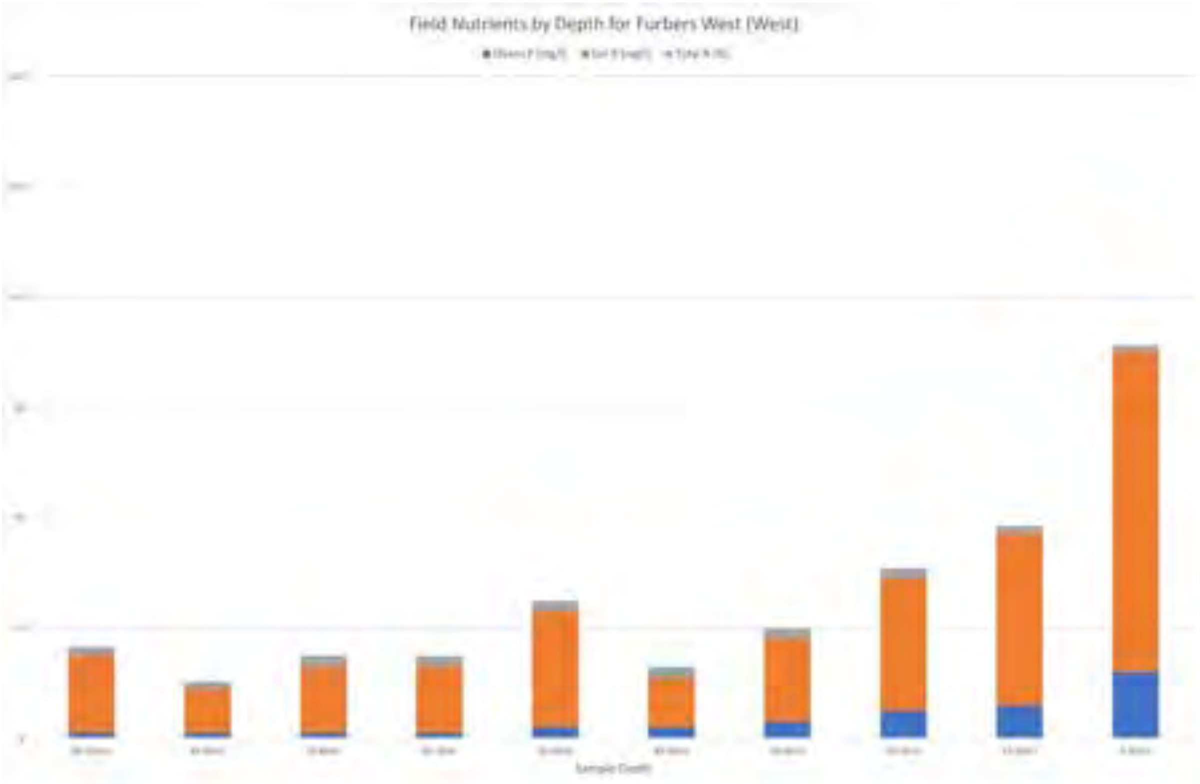

Figure 3.3.8 PKN nutrient by depth for Furber's West (Western field).

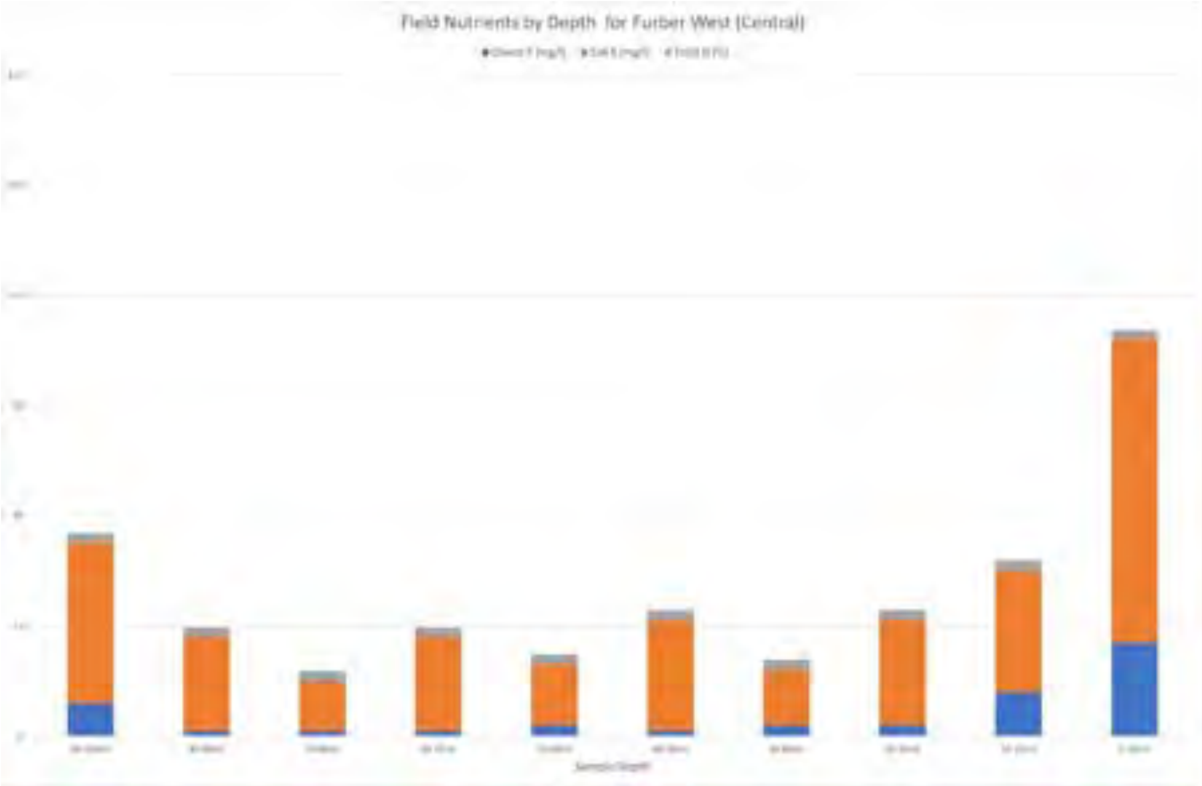

Figure 3.3.9 PKN nutrient by depth for Furber's West (Central field).

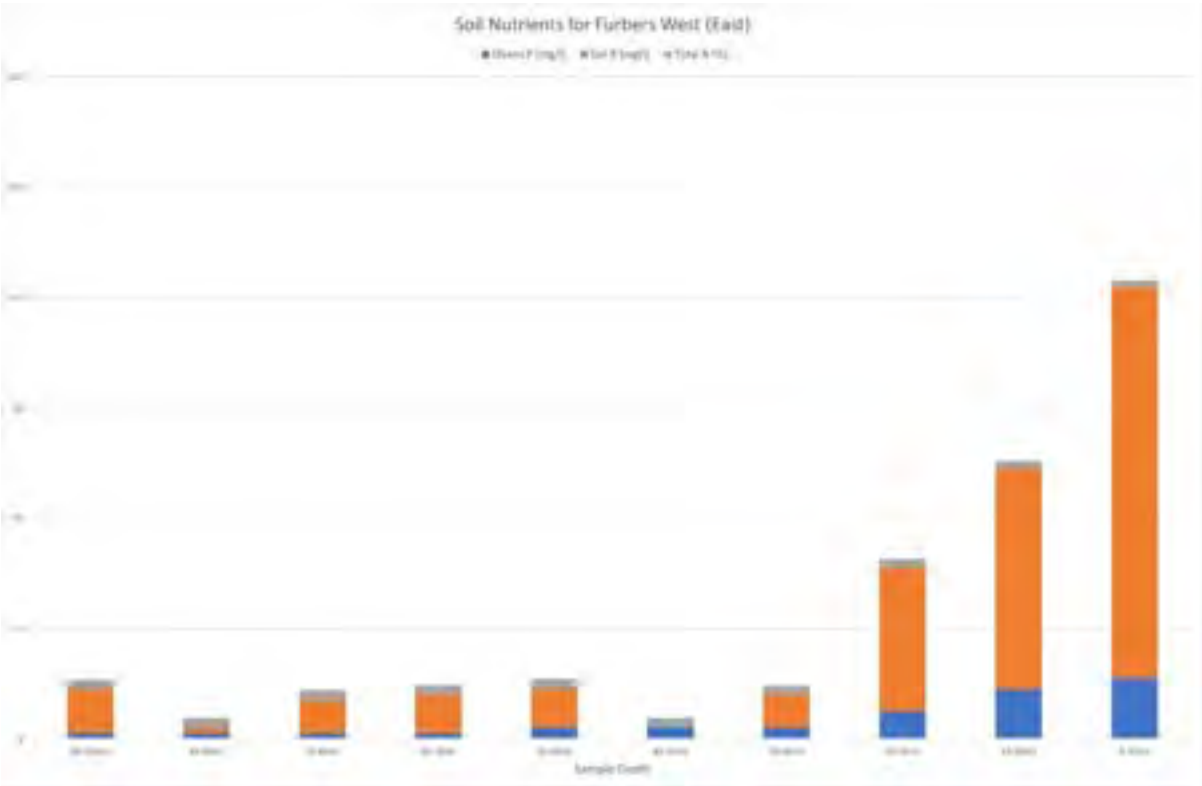

Figure 3.3.10 PKN nutrient by depth for Furber's West (East field).

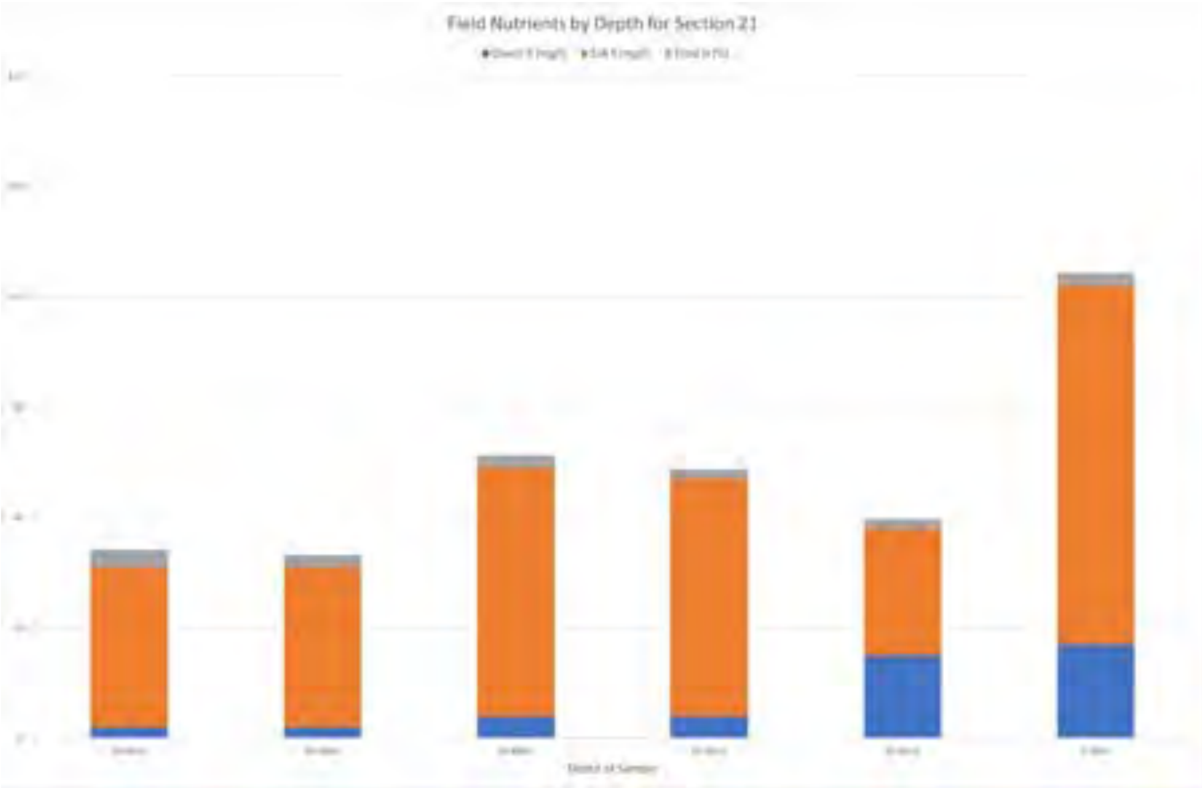

Figure 3.3.11 PKN nutrients by depth for Section 21.

3.4 Conclusion

Below ground the former scrap yard is contains localised pollution, however this is contained and not likely to pose a threat to the wider area following the implementation of an agreed amelioration strategy agreed by the local authority. The risks associated with it appear to be reducing over time and it is judged there is no need for further mitigation.

There are some signs of ongoing nutrient enrichment at Wem Moss derived from adjacent agricultural land, but these are mainly affecting two localised areas. Recent site bunding works may be helping to limit the spread of nutrients to the lagg zone.

The new route for the Bronington Manor Drain appears to be effective in channelling water with a high pH to the outer edges of the bog allowing the dammed sections of the original route that no longer carry flows of mineral rich water to develop conditions more in line with those expected on a peat bog.

The data from soil samples was effective in informing management decisions regarding the depth of topsoil removal necessary to lower the nutrient levels to those suitable for the restoration bog plant communities.

Recorded aerial ammonia levels are significantly higher than is recommended for the lowland raised bog habitat but there appears to have been some reduction in levels over time.

4.0 Vegetation Monitoring (D1.3 and D2.3)

4.1 Aims and Objectives

- D1.3 & D2.3: Vegetation and Key Species Response to Applied Management: a more detailed assessment of vegetation response will be undertaken to assess the ecological response to project actions (re-wetting and re-vegetation).

4.2 Methodology

Vegetation monitoring was carried out to assess the vegetation response to the various restoration works undertaken during the project including: raising water levels through bunding (C3) with further sub-categories of removal of woodland (conifer and deciduous woodland treated separately) (C2), raising water levels through adding and adjusting dams (C4), turf removal and re-seeding (C7) and Molinia trials (C5).

Small scale vegetation monitoring was carried out at approximately 20 fixed, randomly stratified sampling points within each of the four management areas outlined above (excluding Molinia Trials and turfing removal and reseeding which were treated separately). Five quadrats were also included from the turf removal areas (C7). Where appropriate, the sampling points were stratified across each management area, with a variable number of points located on areas affected by different historic peat extraction methods (Old Commercially Cut Peat, Recently Commercially Cut Peat, Uncut Peat and Hand Cut Peat).

At each of the 1m x 1m quadrat sampling points surveyed the percentage cover of the main plant species was recorded. Where possible bryophytes were identified. In some instances where recently colonised plants were small this was not possible. Percentage cover of bare peat and open water was also recorded. In addition, an assessment of plant height was undertaken in each of the four corners of the quadrat using the drop disc technique. All 20 quadrats were surveyed twice: before management has been carried out, during August 2018 & February, July and August 2019, and then after in March, April, August and September 2021. Markers could not be used to mark the individual quadrat locations as these would have been lost or damaged during site works. Consequently, quadrat locations were relocated using GPS co-ordinates. Vertical photographs of each quadrat from above were also captured but these have not been included in the results. CAP5 software was used to run Twinspan analysis to examine whether the baseline vegetation data could be separated from the final survey data. The number axiophytes species (notable plants of conservation interest) were determined and compared for differences. The axiophyte lists on the BSBI website (link provided in the bibliography) were used for this purpose.

In addition, 2m x 2m Long Term Monitoring Network (LTMN) quadrats originally established in 2012 were surveyed in 2016 and again in 2021. The vegetation data collected was used to produce National Vegetation Classification (NVC) analysis of the LTMN units using MAVIS and mapped in ArcMAP.

In addition, a selective resurvey of areas first surveyed by Horton in 2008 was undertaken by volunteers involving 1m x 1m quadrats . Higher plants were recorded to species level and bryophytes were recorded as either sphagnum or non-sphagnum. Key species which could be reliably identified were picked out for comparison to previous historic survey data.

To assess the effects of the Molinia control treatments on the vegetation each trial area unit was surveyed along a transect with plants recorded 1 m either side. Each survey area was photographed. This was undertaken during autumn 2018 and repeated in September 2021. The treatment of the units which were also all bunded comprised of either mowing, herbicide application, turf removal or no treatment to serve as a control. The management work was undertaken between September 2018 and March 2019. CAP5 software was used to run Twinspan analysis to determine if the vegetation communities of the 4 treatment categories could be separated from each other. The number axiophytes species were also determined and compared for differences.

For the trial areas (see **figure 4.2.1 and 4.2.2**) subject to turf stripping, cell bunding and the introduction of pre-determined mixes of micro-propagated plugs of sphagnum species, simple monitoring covering 21 bunded cells was established to represent the range of conditions and planting methods. The percentage cover was recorded for each of the bunded cells. Sphagnum was recorded at the genus level only, as identification to species level was considered too destructive given that many of the specimens were very young and fragile. Photographs were taken at the locations within selected bunds shown in **figure 4.2.1 and 4.2.2**.

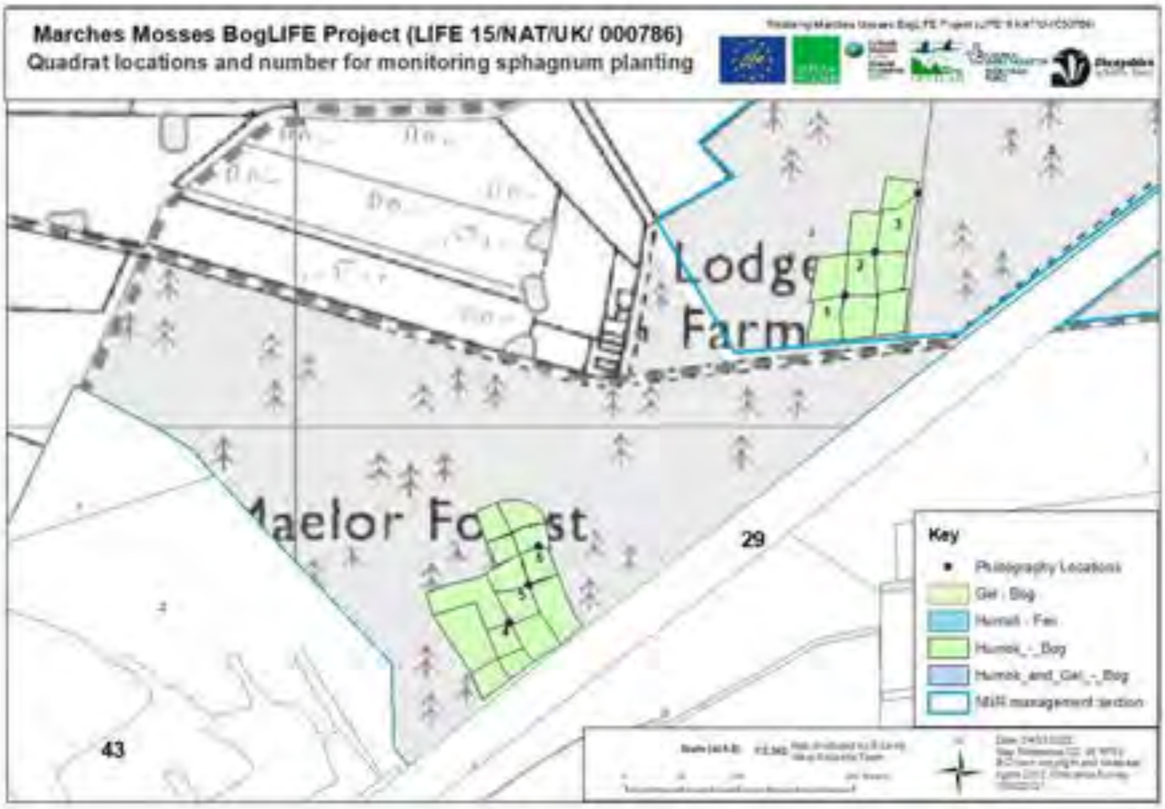

Figure 4.2.1 Quadrat locations and Fixed-Point Photography Points (North) ex-forest.

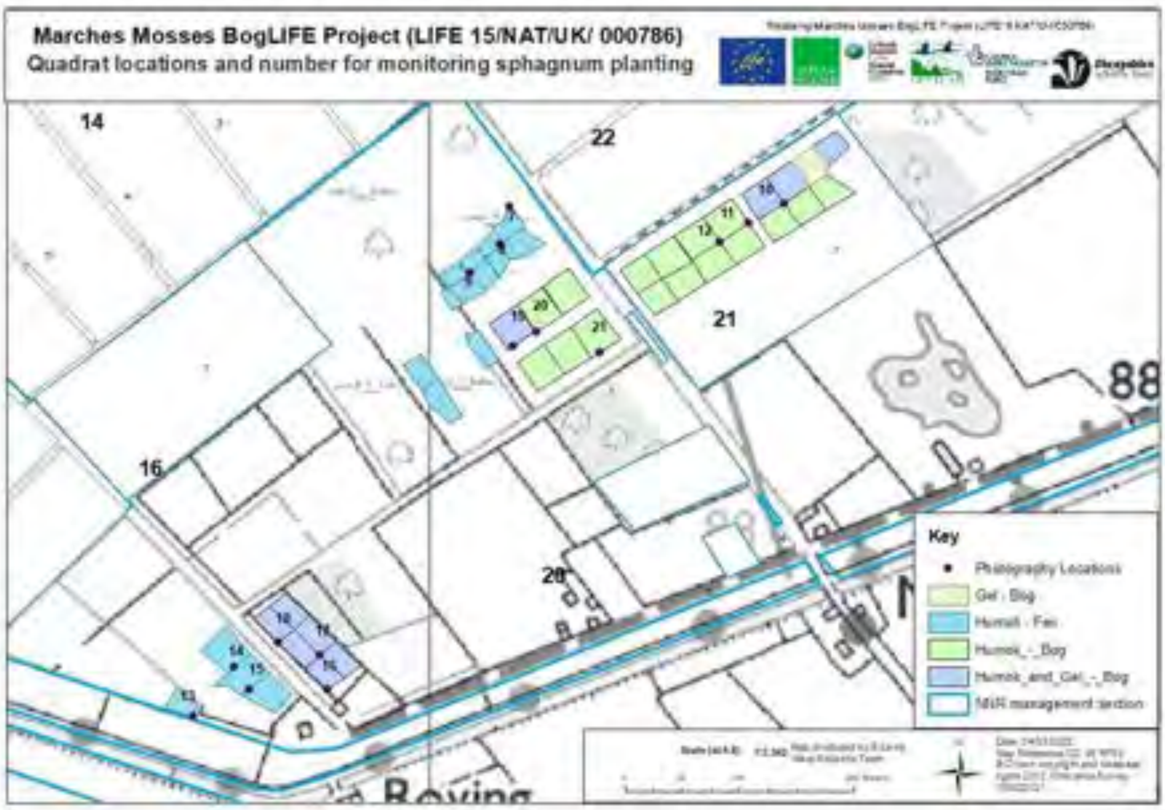

Figure 4.2.2 Quadrat locations and Fixed-Point Photography Points (South).

Fine-scale vegetation monitoring allow the effects of conservation actions to be assessed in detail however, these surveys are spatially limited in their representation given the heterogeneity of the vegetation. To assess the vegetation at a broad whole site level aerial photography was used. As a baseline comprehensive photographic coverage of the site was captured by a drone survey in 2015 prior to the start of the project for future reference. A second survey carried out by an Environment Agency aircraft was undertaken in July 2021 to capture comprehensive photographic coverage of the site. The commission also included the acquisition of Lidar and multispectral imagery.

The latter was analysed using the latest advanced techniques. Using this imagery Natural England's Evidence and Earths Observation team produced a habitat map for the project site. It was created using an object-based image analysis process. This is where pixels are clustered on a) similarity in spectral signature and b) the shape of a collection of pixels. This methodology allows large-scale, uniform features such as water bodies to be classified accurately. It also reduces noise from individual pixels as the habitats are a mosaic of many different species. The classification was rule based and a series of rules were defined for each habitat category; these were constructed using Boolean and fuzzy logic. If an object corresponded to the rules of a given habitat, it was classified as such. If the object corresponded to multiple habitats, the habitat was assigned to the one with the highest probability. The habitat classification was developed based on the main broad vegetation types that occur on the site and which could be discriminated with a reasonable probability using the chosen analytical technique. The accuracy of the classification was tested and improved by comparison with sample habitat points records collected and visually classified by project staff in the field supported by photographs.

The plant of highest conservation concern found on the Mosses is the rare moss *Dicranum undulatum*. The species is listed as 'Vulnerable' in the Red List of bryophytes in Britain and is listed as 'Endangered' in Wales (Bosanquet and Dines 2011). In England the moss is considered of principal importance for conservation under Section 41 of the Natural Environment and Rural Communities Act 2006. Fenn's and Whixall Mosses form the species' only surviving location in southern Britain. To assess it condition and help inform future management Dr Des Callaghan was commissioned to assess its status and ecology. The distribution and abundance of *Dicranum undulatum* was documented with GPS-based survey and habitat and community composition via relevés. Elevation of *D. undulatum* and Rest Water Level (RWL) relative to the peatland surface was measured at a sample of colonies and a search for sporophytes undertaken at all colonies.

The species was found in two areas. The vast majority occurred at the Cranberry Beds plus a small amount at Welsh Bettisfield Moss. Its associated community is dominated by mosses and vascular plants, most frequently *Aulacomnium palustre, Erica tetralix, Eriophorum vaginatum* and *Vaccinium oxycoccos*. Soil pH is highly acidic, similar to the upper water table. Electrical conductivity of the upper water table is low. Elevation of RWL relative to soil surface averaged −10.8 cm. No sporophytes were found. It was concluded that although the species was restricted to these relatively small uncut areas of peatland, they support a strong population of *Dicranum undulatum*. Far more plants than had previously been thought were encountered. Reproduction appeared limited to clonal spread via detached shoot tips

Given its very limited dispersal ability, with no sporophyte production at Whixall, Dr Callaghan proposed a trial reintroduction to nearby suitable sites using material transplanted from Whixall. Possible sites were reviewed and in November 2020 he carefully removed 15 hand-sized plugs of the moss from the Cranberry Beds, transplanting five of them to North East Fenn's (part of the Marches Mosses complex) and ten of them to Wynbunbury Moss SAC, located 26 km north-east.

The health condition and extent of translocated colonies was monitored after 15 months in February 2022 by Dr Callaghan. The five colonies translocated to North East Fenn's had not generally done as well as those translocated to Wybunbury Moss, for reasons unclear. None of the colonies at Fenn's Moss had increased in extent. Overall, the ten colonies translocated to Wybunbury Moss appeared to have done reasonably well. These early results were generally encouraging. Further monitoring in the next few years is planned.

4.3 Results and Discussion

Quadrats

The Twinspan analysis generated dendrograms for the 5 management categories - see **figures 4.3.1 - 4.3.5**. Dendrogram for category *1. Bunding with conifer removal*, shows that most of the final quadrats surveyed (with suffix Fin) are separated from the baseline quadrats (with suffix Bas) based on the vegetation present. The separation detected is what would be expected in circumstances where a management intervention had caused a significant change in the vegetation. Note that different recorders carried out the baseline and final surveys and it is not possible to determine to what extent recorder bias may have affected the results. The full set of results from the survey of 85 quadrats can be found in **Appendix 4.3.1**.

It is likely that the Twinspan analyses picked up on both a genuine change in vegetation and a change in the recorders. The surveys of categories 2-5 were completed by the same recorder so should be unbiased. Category *2. Bunding with broadleaf removal* shows a less clear difference between the baseline surveys and the final surveys when compared. The groups which are highlighted in red exclusively, include final quadrats survey results and not both.

The Twinspan groupings are notably different from each other suggesting that even when there has been a change this was not consistent across the whole category. For Category 3. *Bunding without woodland removal* group some of the quadrats are separated in the analysis into exclusive baseline and final groups, but not all of them. For Category 4. *Damming*, some of the quadrats are assigned to exclusive baseline groups but the quadrats from the final survey cannot be distinguished. It could be that the baseline surveys results were too variable and some of the restoration work for this category was ongoing at the time that the final survey took place leading to the results being inconclusive.

Category 5. *Turfing trial* results shows a distinct difference between the baseline and final quadrats. The Twinspan results separate the two based on the presence or absence of *Juncus effusus* which is a typical fen species characteristic of the areas surveyed. It is also a species that is associated with a high-water table.

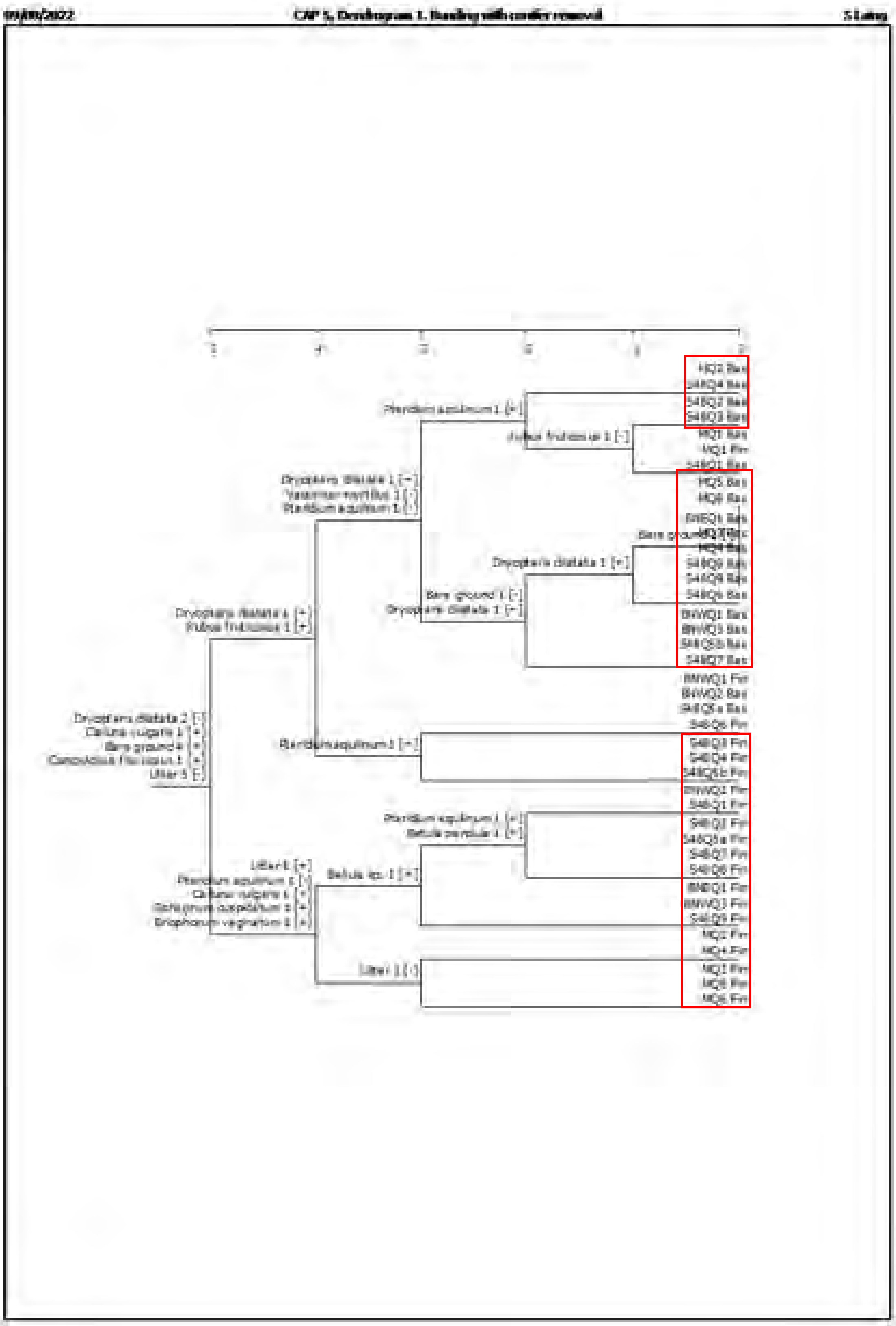

Figure 4.3.1 Dendrogram of vegetation data for areas which underwent bunding with confer removal.

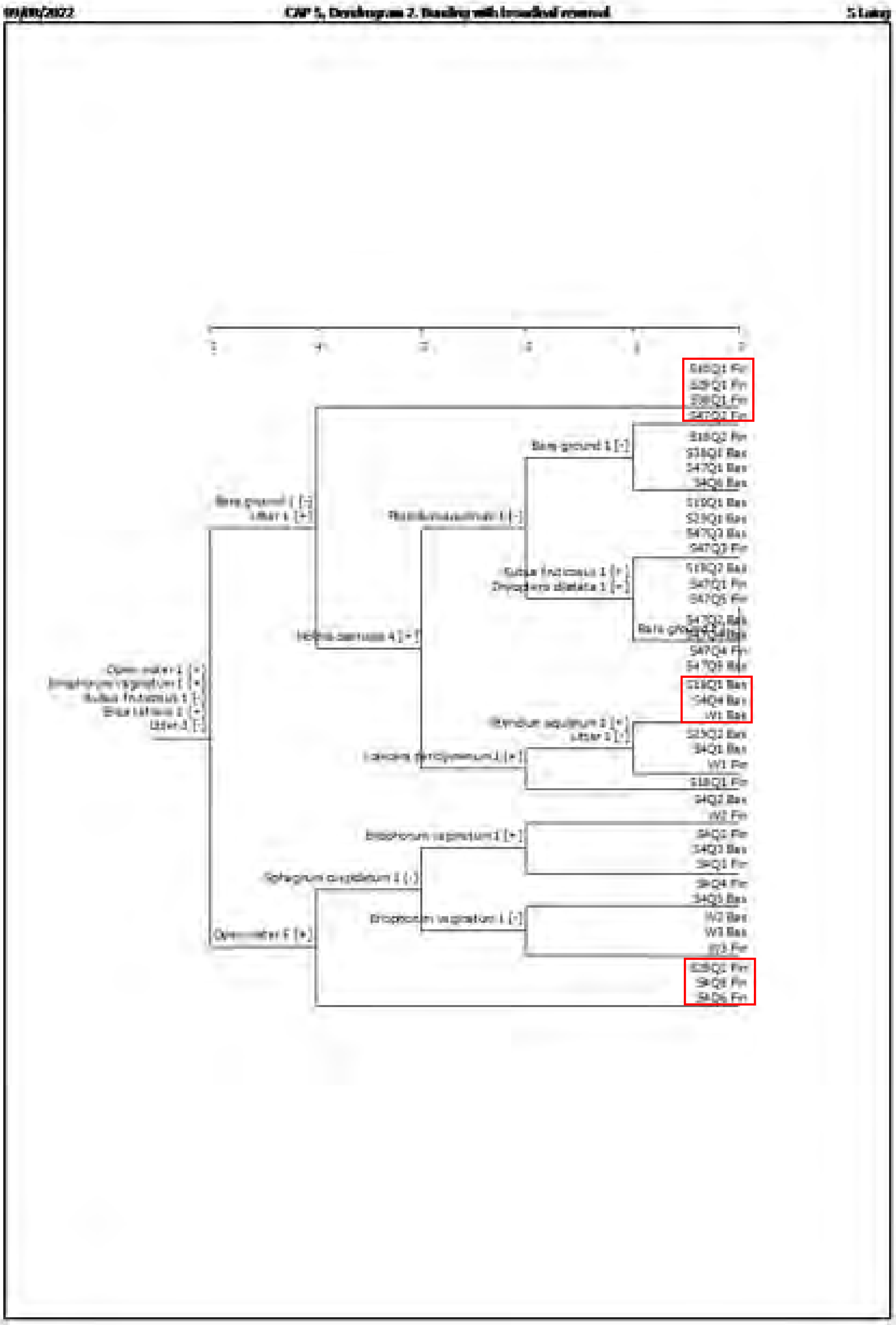

Figure 4.3.2 Dendrogram of vegetation for areas which underwent bunding with broadleaf removal.

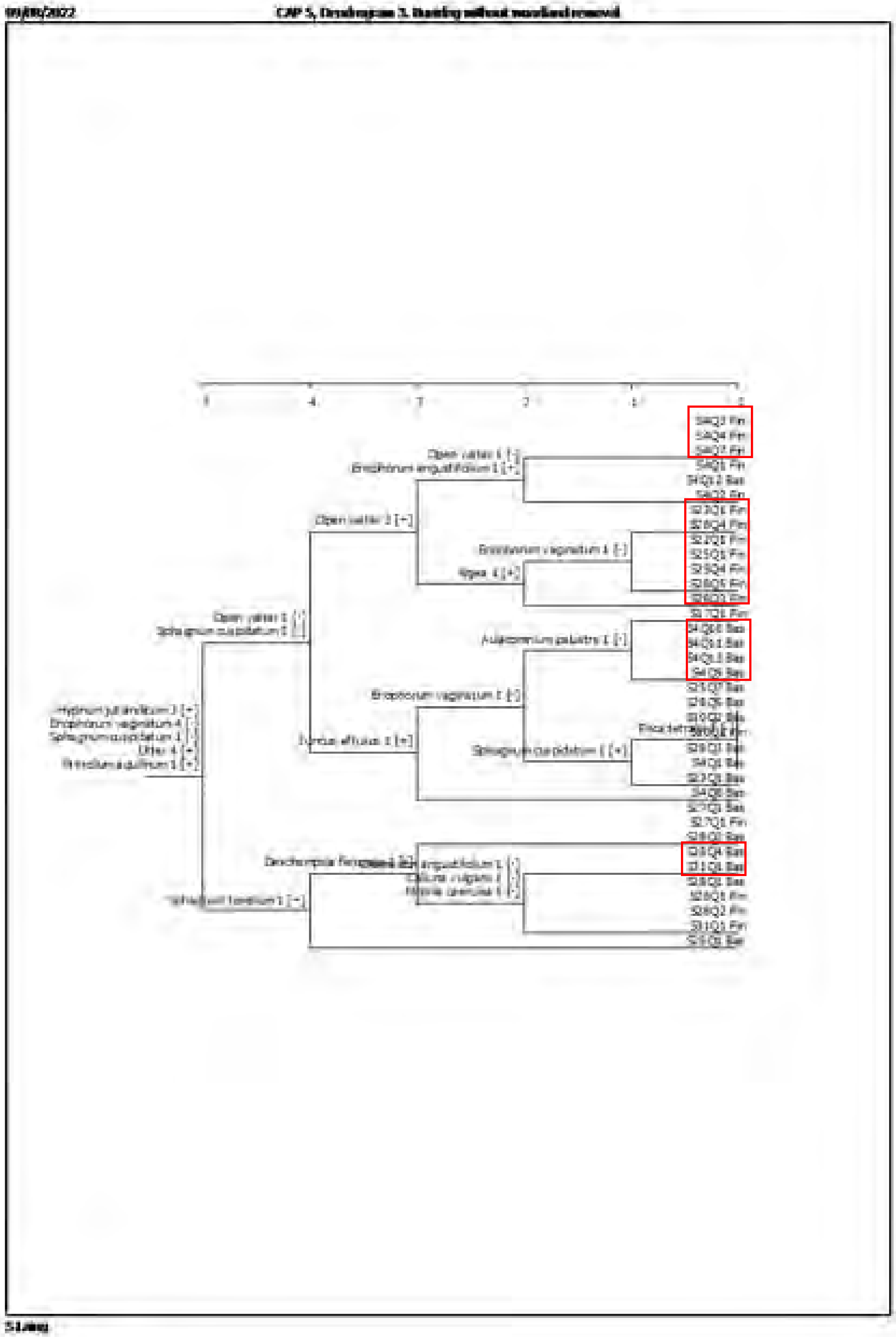

Figure 4.3.3 Dendrogram of vegetation for areas which underwent bunding without woodland removal.

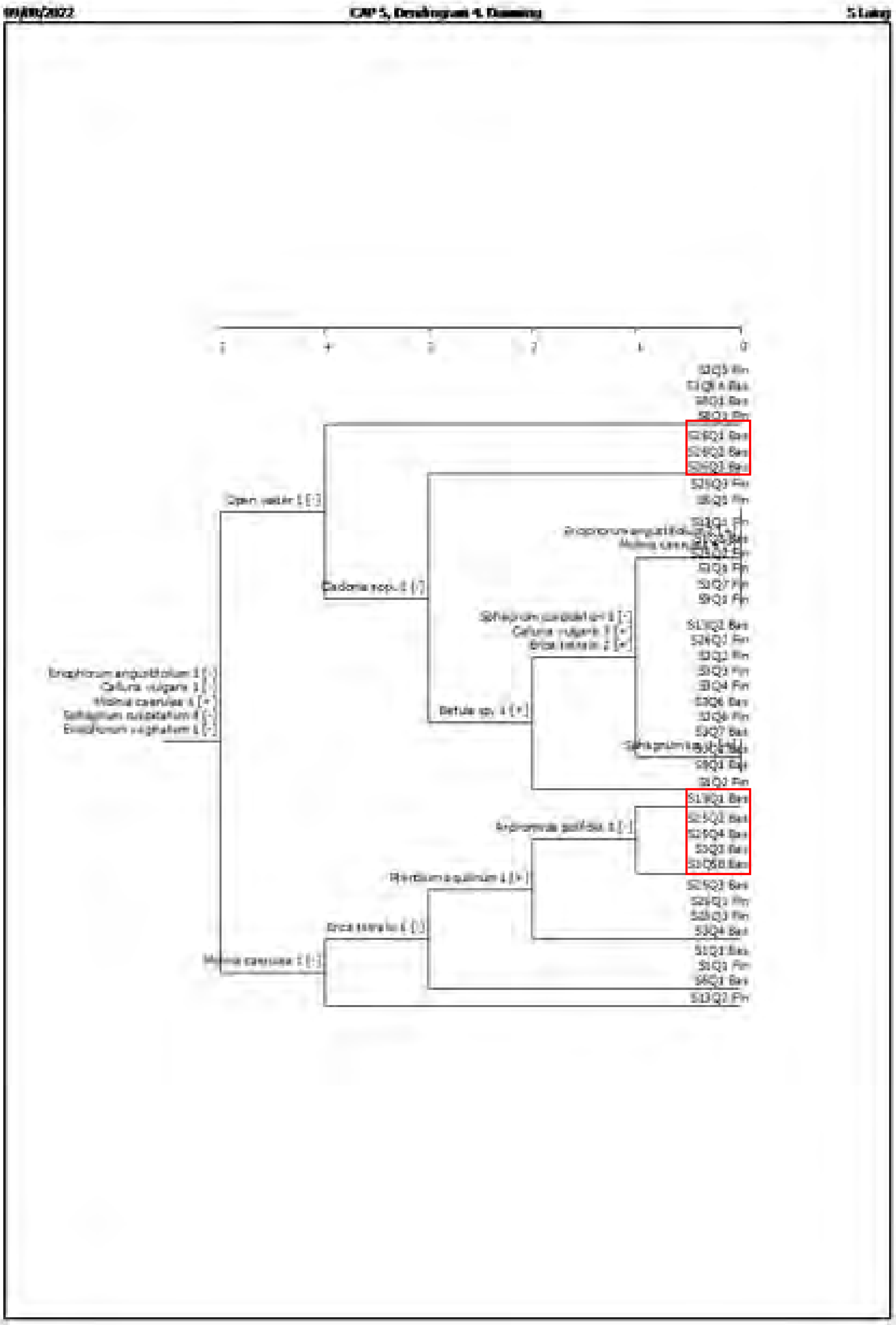

Figure 4.3.4 Dendrogram of vegetation for areas which underwent damming.

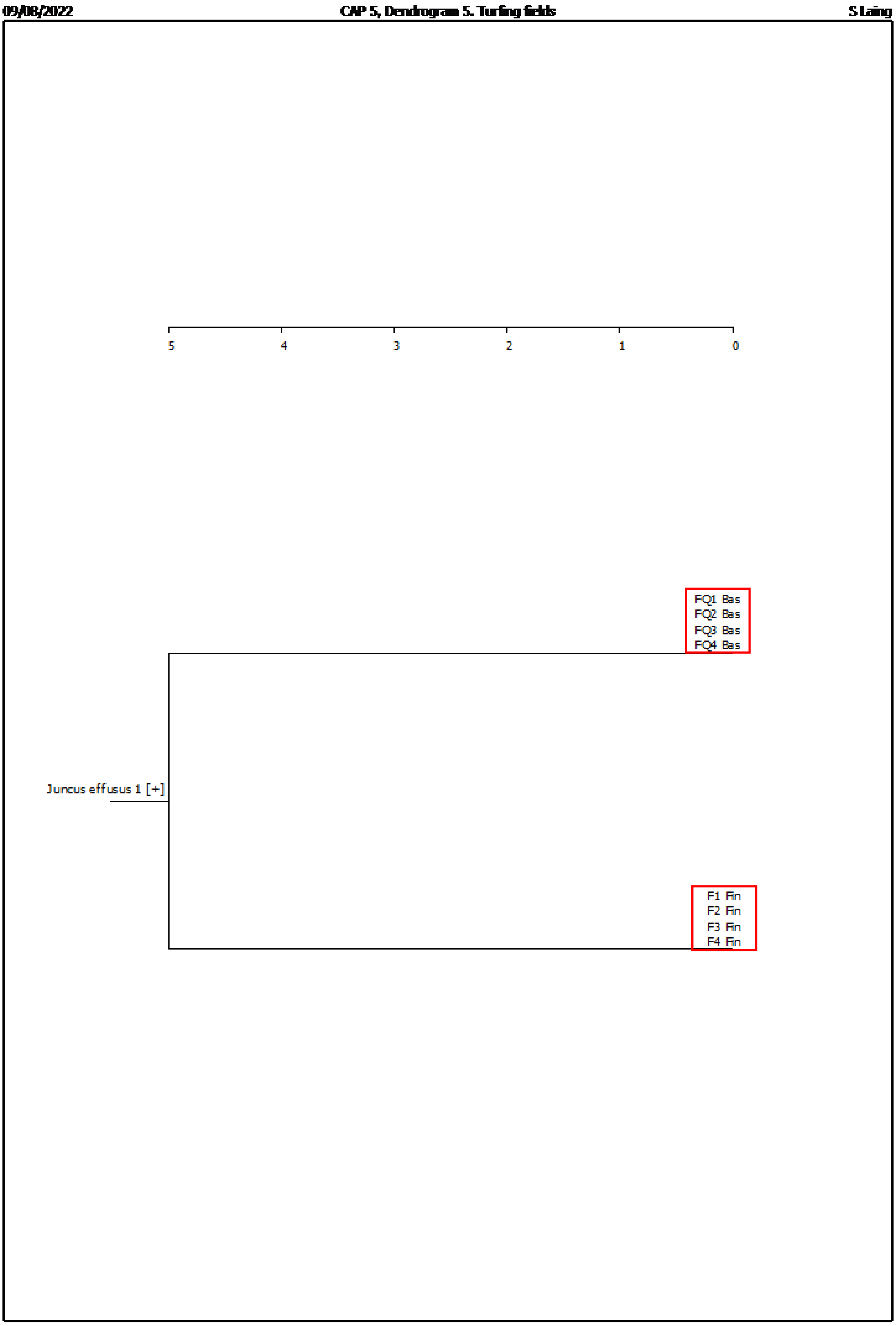

Figure 4.3.5 Dendrogram of vegetation for areas which underwent turf stripping.

Table 4.3.1 shows a comparison of the number of axiophyte species recorded pre- and post- the different management interventions. There was increase in the number of axiophytes post management for *category 1 Bunded (with conifer removal)* and *category 2 Bunding (with broadleaf tree removal)* reflecting the beneficial impact of the rewetting works. *Category 5 Turfing trials* also showed an increase in axiophyte species post management suggesting that the change that was detected by the Twinspan analyses is a positive.

The list of axiophytes (notable plants of conservation interest) was taken from the BSBI website which gives axiophyte lists by county. As there is no list for Wrexham the whole site was assessed based on the list for Shropshire (Salop). Note that the baseline survey for category 2 features a high starting value of 23 axiophytes which may explain why the Twinspan analysis was inconclusive for this management type given that many of the target species were already present at the start of the project.

Table 4.3.1 Number of axiophyte recorded in the LIFE Quadrats by survey category.

Count of Axiophytes	Baseline	Final
1. Bunding (with conifer removal)	12	26
2. Bunding (with broadleaf woodland removal)	23	31
3. Bunding (without woodland removal)	19	22
4. Damming	21	20
5. Turfing trials	7	10

Long Term monitoring Network (LTMN)

The final NVC categories were derived from MAVIS, comparing the possibilities to the tables in the Rodwell 1991, to ensure that most appropriate category was selected. MAVIS stands for Modular Analysis of Vegetation Information System. **Table 4.3.2** shows a summary of the selected National Vegetation Classification (NVC) categories along with the percentage match to each category generated by MAVIS. The maps for previous years and for the data from 2021 can be seen in **figures 4.3.6 and 4.3.7**. Data from the LTMN can be found by following the link in **Appendix 4.3.2.** The full set of results from the MAVIS analyses are contained in **Appendix 4.3.3**.

Table 4.3.2 results from NVC analyses carried out using MAVIS on LTMN quadra data.

	Year					
	2012		2016		2021	
Site	NVC	% Match	NVC	% Match	NVC	% Match
Bettisfield	M18a	55.56	M18a	56.5	M18a	54.73
Bettisfield Dome	M18a	55.38	M19a	50.92	M18a	55.59
Bettifield NW	M19a	45.08	M18a	62.6	M2b	55.17
Cowberry Beds	M16a	45.89	M2	49.36	M2	48.01
Cranberry Beds	M18a	50.2	M18a	56.5	M18a	54.11
NE Fenns	M2	59.43	M18b	50.87	M18a	49.55
Oafs Orchard	M18a	52.16	M18a	54.05	M18a	53.59
Wem Moss	M2	57.02	M18a	52.4	M19a	53.55

NVC M18 *Erica tetralix – Sphagnum papillosum raised and blanket mire* represents the vegetation community of a lowland raised bog in favourable condition. As can be seen from **figures 4.3.6 and 4.3.7** some areas were in a favourable condition prior to the project however these areas remained at risk from drying out because of the effects from drainage around them. For example, the main dome of Bettisifeld Moss transitioned from lowland raised bog communities towards wet heath communities *M19a Calluna vulgaris – Eriophorum vaginatum blanket mire (Empetrum nigrum ssp. nigrum sub-community)* between 2012 and 2016 but appeared to be reverting back to a lowland raised bog community in 2021 due possibly due to the impact of re-wetting work in 2019.

Between 2012 and 2016 Wem Moss transitioned between M2 and M18a. However, the analysis of the results of the 2021 survey indicate the vegetation community is now closer to M19a. This is considered to reflect an increase in wet heath plants rather than because of a loss or decrease lowland bog community species. Following the rewetting works it is predicted likely that the moss will transition back towards M18a in the future.

Overall, the LTMN NVC results which encompass the uncut best areas of remaining bog habitat on site are in a largely healthy and satisfactory condition. There is a reasonable likelihood the vegetation communities will continue to improve in the future as a result of the impact of the tailored contour bunding undertaken around them.

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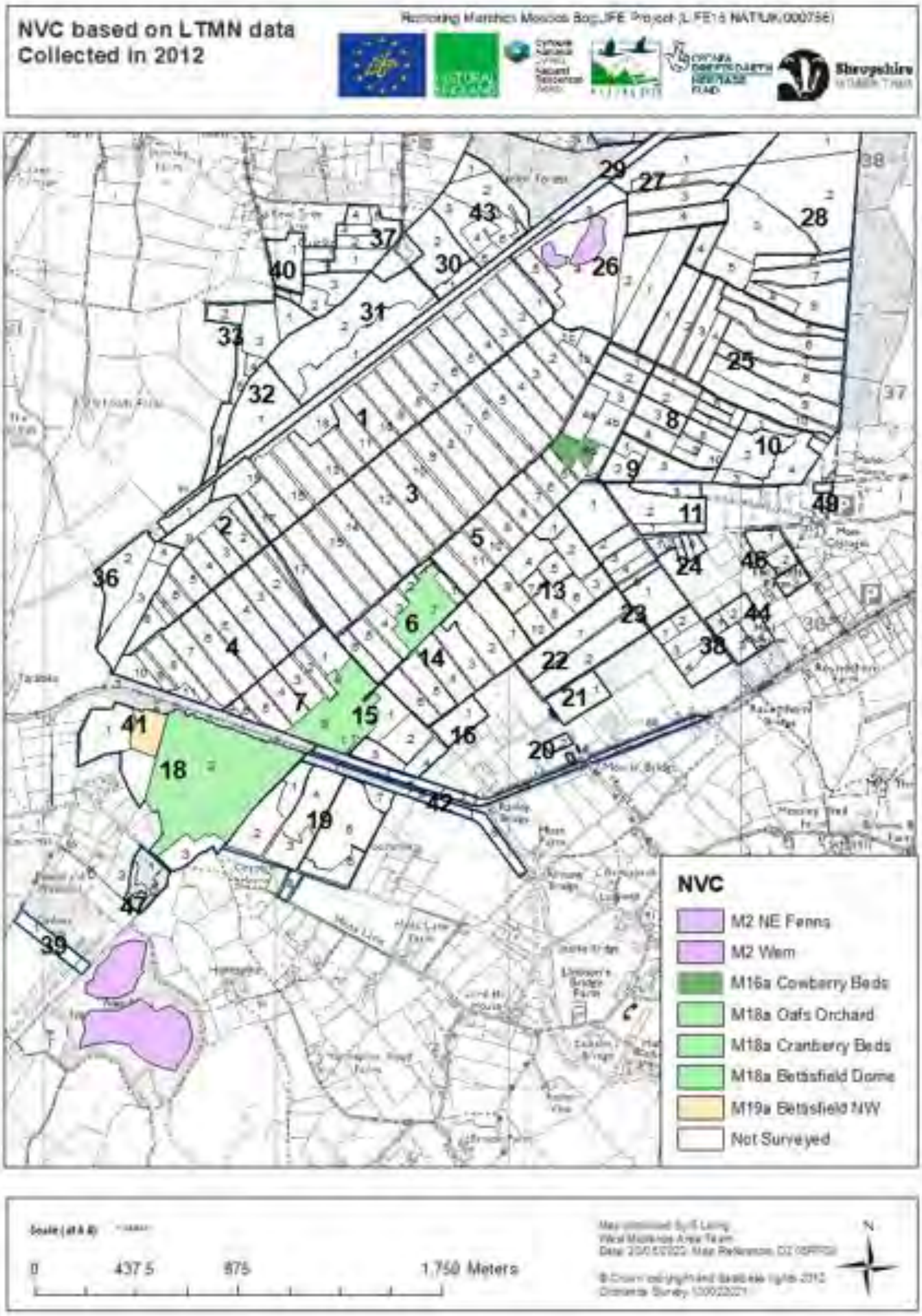

Figure 4.3.6 Map showing locations of the Long-Term Monitoring Network (LTMN) survey areas and their corresponding NVC categories for the 2012 survey.

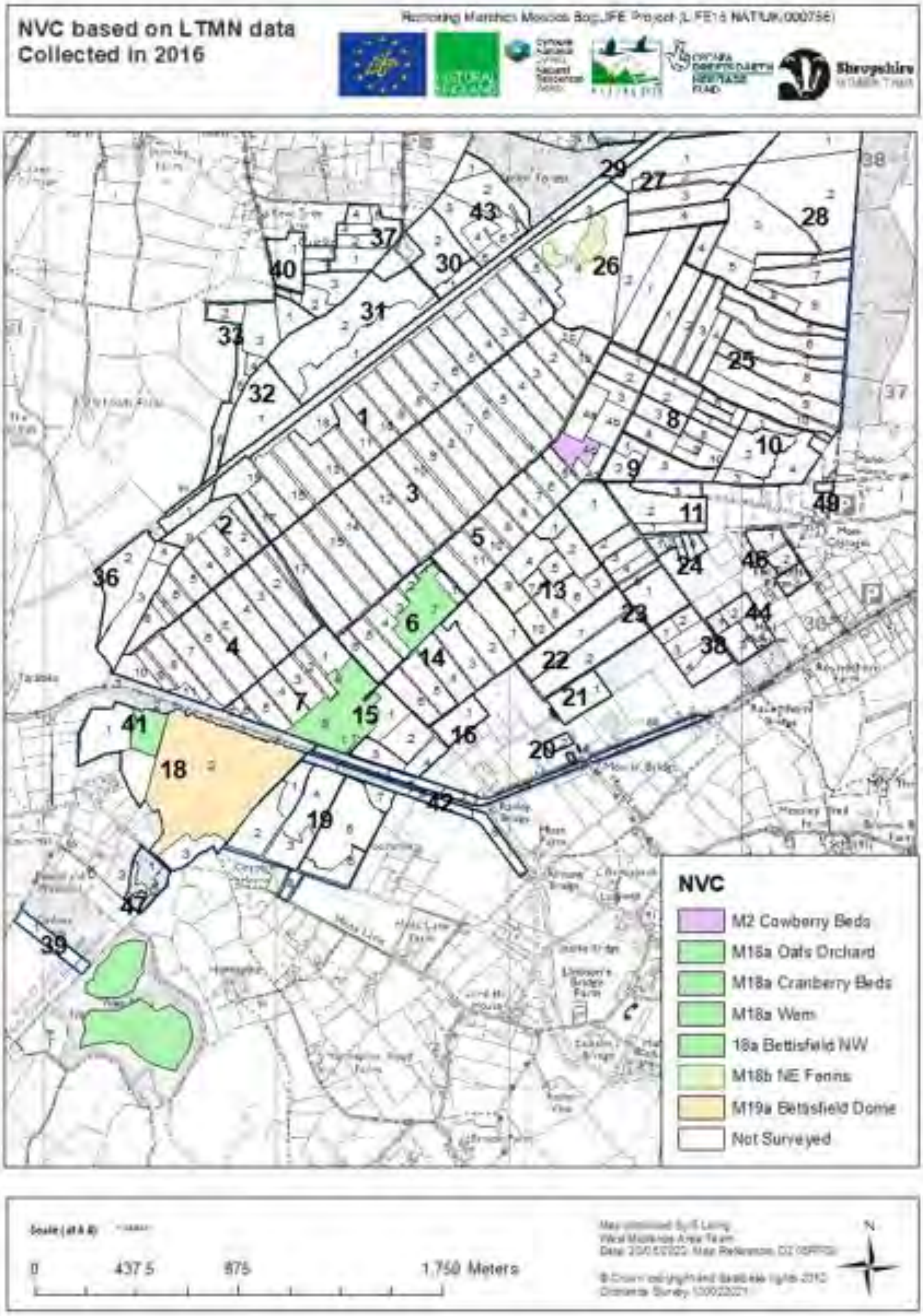

Figure 4.3.7 Map showing locations of the Long-Term Monitoring Network (LTMN) survey areas and their corresponding NVC categories for the 2016 survey.

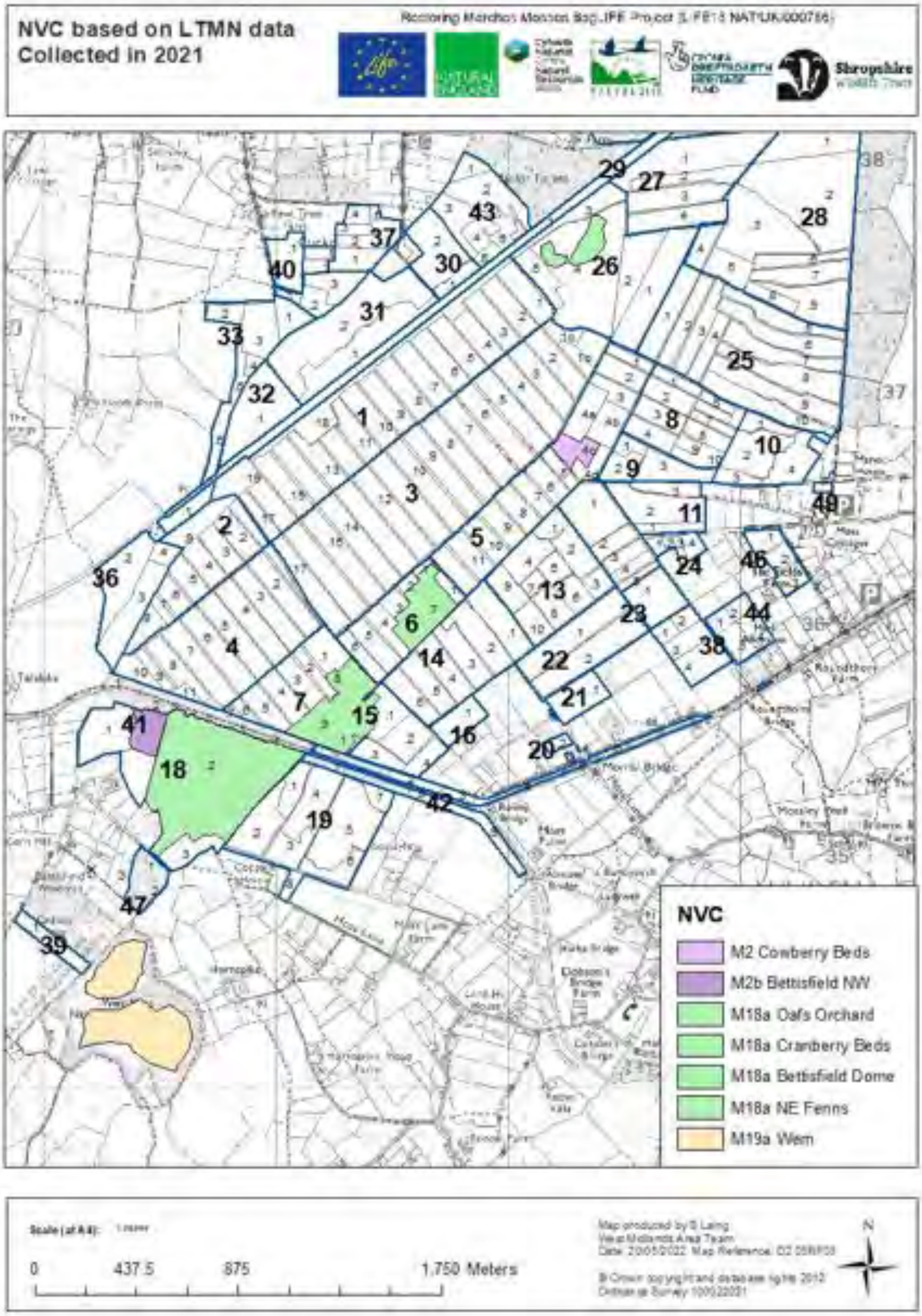

Figure 4.3.8 Map showing locations of the Long-Term Monitoring Network (LTMN) survey areas and their corresponding NVC categories for the 2021 survey.

Permanent Quadrats

Additional 1x1m permanent quadrats were resurveyed in July 2021 as part of the project. A full account of the survey and results can be found in **Appendix 4.3.4**. Key findings from this survey are displayed in **Figures 4.3.9 and 4.3.10**. Due to the nature of the survey, it was considered best to divide the results into percentage cover categories. As many of the volunteers were inexperienced with botanical surveys their individual estimates of percentage cover varied so care needs be taken when looking for changes.

The percentage cover of *Eriophorum vaginatum* (Hare's-tail Cottongrass) can be seen in **Figure 4.3.9**. *E.vaginatum* is a peatland species which is known to be a good wetness indicator so we would expect for it to increase in coverage as the site gets wetter. This is what the results appear to show. There appears to be a slight increase in cover between 2003 and 2012 which would fit with when damming was carried out on Bettisfield Moss. There is also a slight increase between 2012 and 2021 which would fit with the re-wetting carried out as part of the Life project. The differences between the 2003 data and the 2021 are considered large enough to represent an actual change and not recording error. Re-wetting works in Section 1 had only just started when the 2021 survey was carried out which would explain why there was no change detected here.

Figure 4.3.10 show changes in Sphagnum cover for the same intervals. On the part of Bettisfield examined the % cover of Sphagnum appears to have decreased between 2003 and 2012 and by 2021 had not yet increased back to its former level of cover. Section 1 data for 2012 is not available however there appears to be a small increase in sphagnum cover in 2021 compared to 2003. As Sphagna species are the main peat forming group this is a positive change.

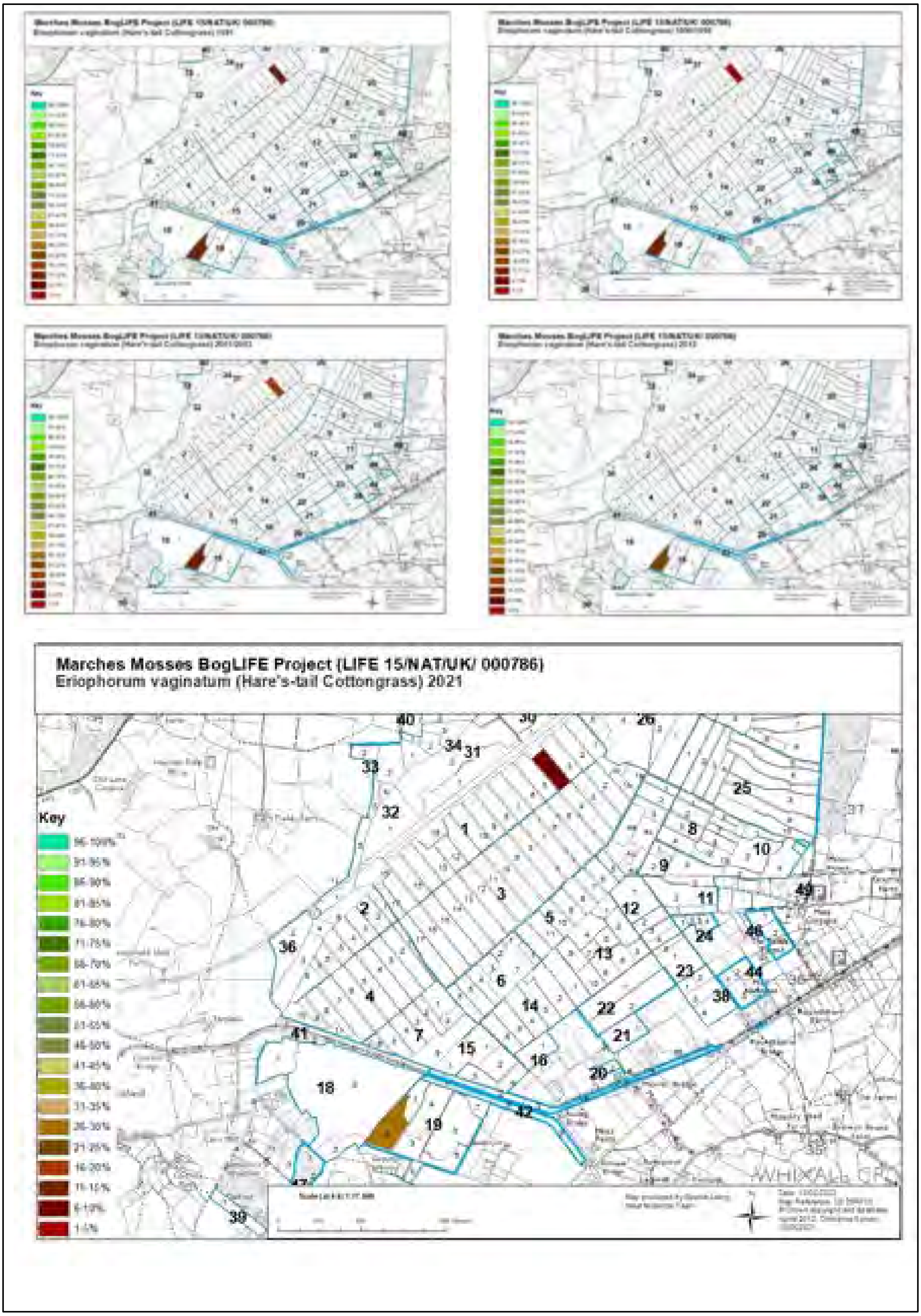

Figure 4.3.9 Changes in percentage cover of *Eriophorum vaginaum* over time.

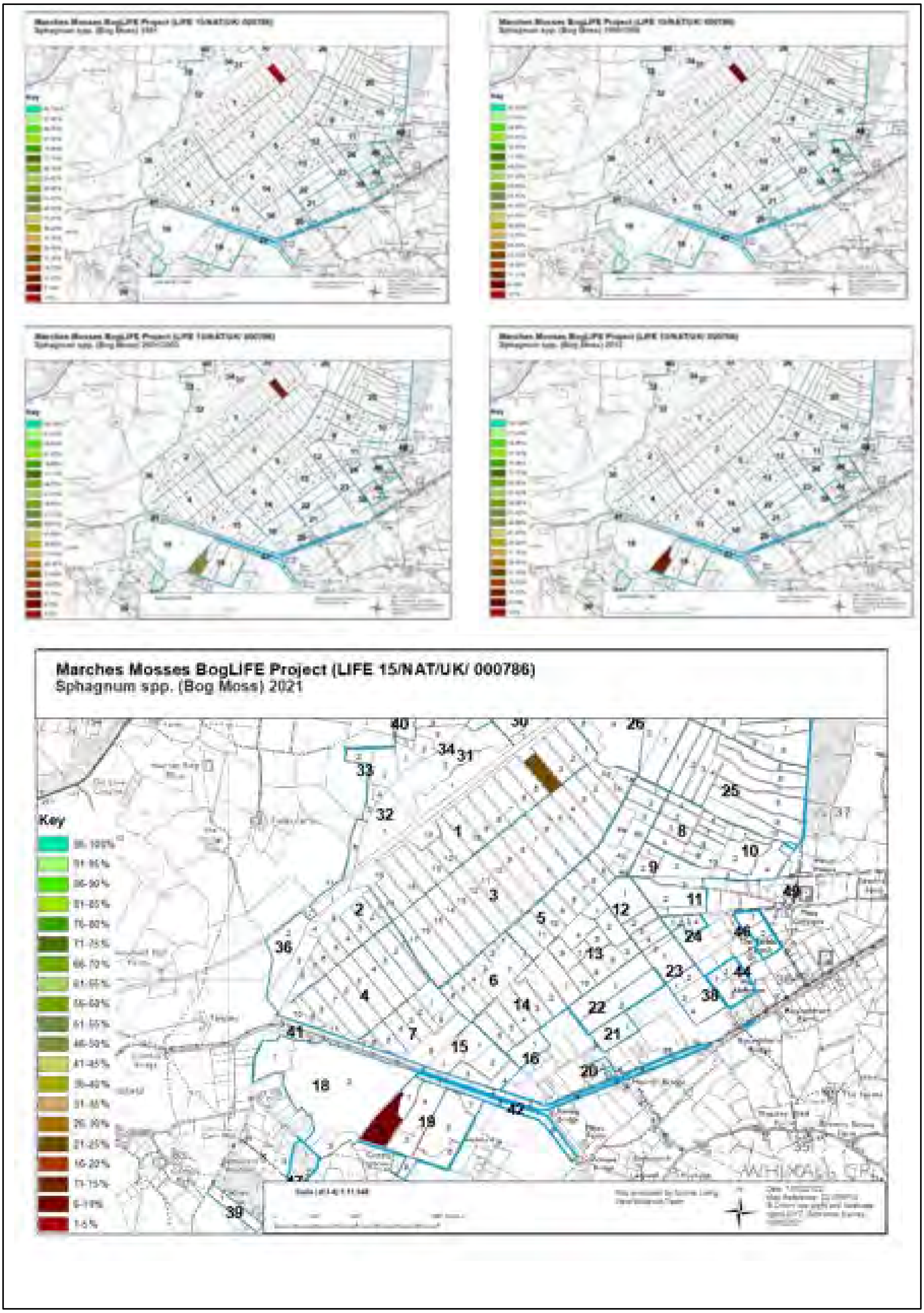

Figure 4.3.10 Changes in percentage cover for all Sphagnum species over time.

NVC Survey of the Sinker's Fields LP7

The 14 ha area of the Sinkers Fields was surveyed in September/October 2021 and classified using the National Vegetation Classification system. The plant communities were classified as mainly MG13 - *Agrostis stolonifera - Alopecurus geniculatus g*rassland, S5 - *Glyceria maxima* swamp, MG1b - *Arrhenatherum elatius* grassland, *Urtica dioica* sub community, W1 - *Salix cinerea - Galium palustre* woodland, OV30 - *Bidens tripartita – Persicaria amphibia* community, S12 - *Typha latifolia* swamp, OV26e - *Epilobium hirsutum* community, *Urtica dioica - Cirsium arvens*e sub-community and S28a - *Phalaris arundinacea* tall-herb fen, *Phalaris arundinacea* sub-community (Appendix 4.3.4.a)

Molinia Control Trials

The results from the analysis of the Molinia trial vegetation data using Twinspan is noisy and no clear trends in vegetation change related to the management treatment are discernible. The Twinpsan generated dendrogram of the vegetation data can be seen in figure 4.3.11**.** If there was a significant difference between the vegetation results of the management types, it would be expected to see them as separate groups and differentiated from the control. However, most of the management categories are mixed and overlap together and cannot be differentiated. Five out of the six scraped areas however did separate into individual groups. They are split between three different groups rather than all being grouped together. The full set of data from the Molinia trials can be found in appendix 4.3.5

The turf scraping is a very labour-intensive method of removing Molinia and the experience gained through the trial showed it was not practical to use at a large scale. The scraped areas also resulted in high amounts of bare peat which were only slowly recolonised by plants. Bare peat is associated with higher greenhouse gas emissions.

Table 4.3.3 shows the number of axiophyte species recorded in each of the treatment areas. The results vary between both the areas and the different management types. The number of axiophyte species recorded remained low across all the areas.

Table 4.3.3 Number of axiophytes recorded by management category for the Molinia trials.

Count of Axiophytes	Oafs Orchard	Section 10	Section 15	Section 17	Section 3	Section 32
Control	5	4	8	1	5	5
Mow	2	4	4	5	9	5
Scrape	4	0	4	3	9	5
Wipe	7	2	5	4	4	3

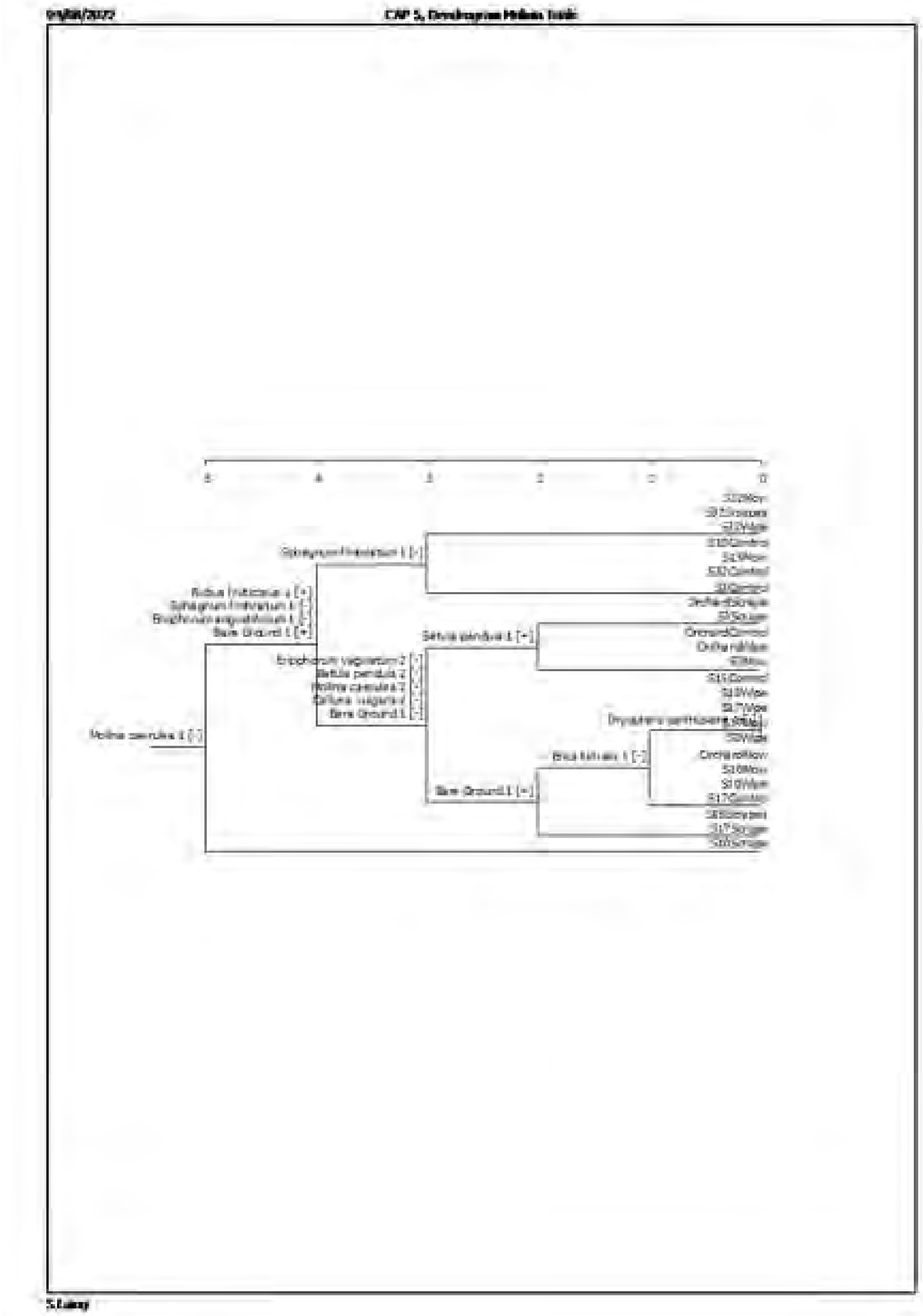

Figure 4.3.11 Dendrogram of vegetation surveyed as part of the Molinia trials.

Assisted Dispersal

The full set of results for the assisted dispersal of *Dicranum undulatum* can be found in the report by Des Callaghan which is included in **appendix 4.3.6.** The initial results are overall positive, but it is still too early to make any assessments over whether the species will spread in the sections it has been transplanted too so further monitoring is needed.

Sphagnum Planting and Turfing Fields

A detailed account of the monitoring carried out can be found in **appendix 4.3.7**. At this stage it is too early to assess if sphagnum planting is an effective method for developing characteristic bog or fen vegetation community on former pasture fields in conjunction with rewetting by bunding. It is recommended that the areas are monitored on a 5 yearly basis to assess the long-term changes. Initial observations indicate that the variable water levels (too high in winter and too low in summer) seem to be a critical factor in determining the success of sphagnum plug plants in spreading.

Habitat Map

Aerial photographic images dated July 2021 were used to produce a map of the broadscale vegetation types. The % cover by broad habitat category is given in **figure 4.3.12.A**. The target habitats of Heath and Cotton Grass represented by the purple and yellow areas respectfully (**Figure 4.3.12.B**) cover much of the site (37%). It is likely that the areas of Mixed vegetation and water (7.7%), represented by turquoise, will transition into these target habitats. Molinia, one of the species which the project aimed to control, continues to dominate 22% of the project area according to this method of classification.

The 2021 map below provide a baseline against which future changes can be assessed against. However, it was not possible to produce a comparable analysis using the 2015 drone imagery although visual comparison is possible.

Figure 4.3.12.A Table of Habitat cover - Fenn's, Whixall and Bettisfield and Wem Mosses

Habitat	Area of habitat (Ha)	% cover of habitat
Artificial Surfaces	3.30	0.42
Bare Ground	22.21	2.80
Bracken	106.81	13.45
Broadleaved Woodland	46.98	5.92
Cotton Grass	184.04	23.18
Heath	115.16	14.51
Mixed water and vegetation	61.45	7.74
Open Water	9.42	1.19
Other Grassland	44.19	5.57
Purple Moor Grass	175.58	22.12
Scrub	24.74	3.12
Sum	**793.88**	**100.00**

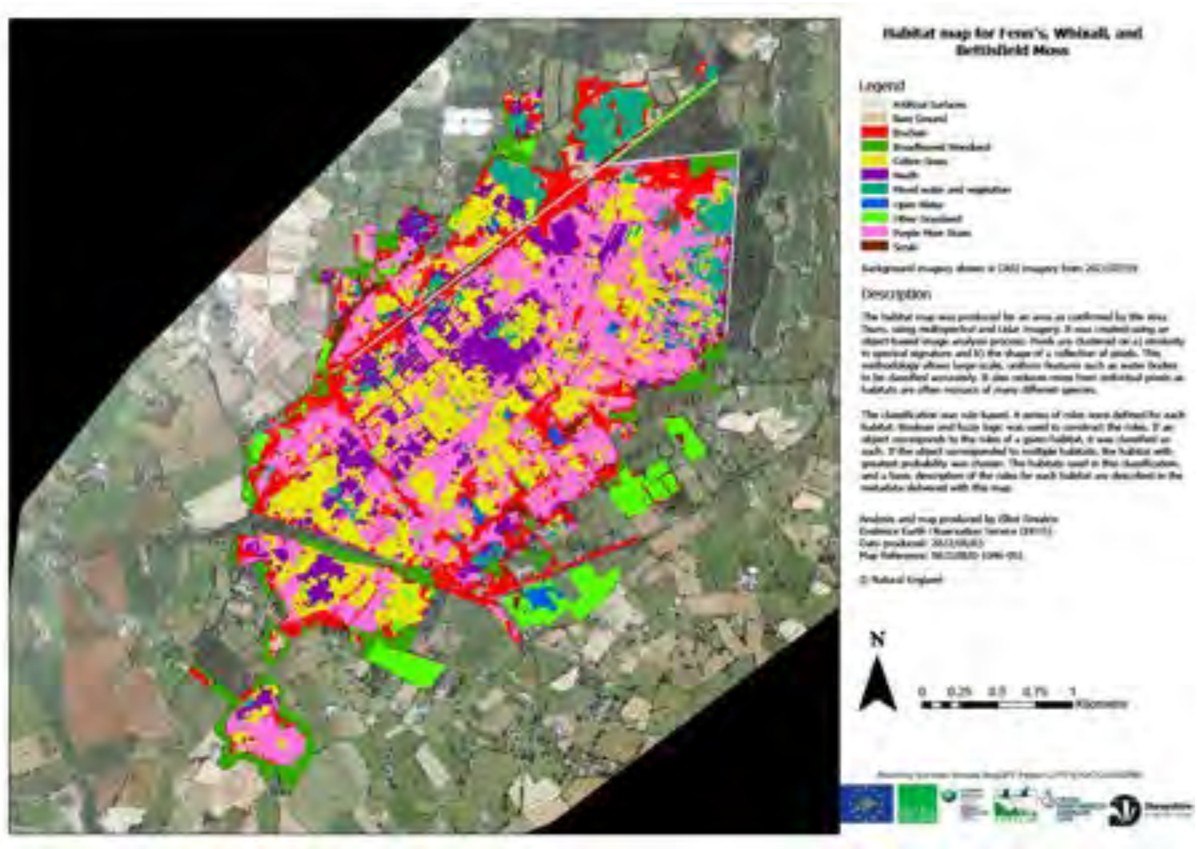

Figure 4.3.12 Habitat map of Fenn's, Whixall, Bettisfield and Wem Mosses.

4.4 Conclusion

Overall field visits, habitat and aerial image analysis indicate there have been marked changes and significant improvements to the vegetation communities. It is therefore considered more likely that the inconclusive results of some of the fine-scale analyses are reflective of the methods chosen and not necessarily that the restoration has not benefitted the site.

The habitat map and the long-term monitoring data show that significant parts of the site are in a good or improving condition in terms of lowland raised bog communities.

The fine scale vegetation monitoring did not provide the quality of information that was expected i.e. representative of the gross change in vegetation communities in response to the various project actions. The methodology and location of some of the vegetation monitoring was not the optimal and did not sufficiently reflect the site's complex microtopography and fine-scale heterogeneity. Much of the baseline data is quite variable making changes that have taken place during the project difficult to clearly discriminate. Overtime repeat surveys may show up clearer trends.

5.0 Efficacy and Extent of Works Monitoring

5.1 Aims and Objectives

- D1.4 & D2.4: Efficacy and Extent of Works Monitoring: a combination of high resolution, colour aerial photography and fixed-point photographs will be used to compare before and after works undertaken.

5.2 Methodology

Hydrological and vegetation response monitoring only provides a limited snapshot of how the project areas have responded to restoration. This is because the data only comes from point locations, at a certain snapshot in time. The broad-scale vegetation surveys using drone photography (as outlined under "Vegetation Monitoring") allow the efficacy of works on a broader scale to be evaluated. However, to effectively assess the impact of project works, a record of concrete conservation actions is also required.

The extent of works were recorded in a variety of way. Aerial and Drone photography was employed to capture a record of the Woodland Removal (C2) and Raising Water Levels through Bunding and adjusting dams (C3 and C4). Comparison of drone photography taken at the start of the project with aerial photography taken in July 2021 to show changes in woodland cover by tree removal and areas bunded up to that date. In addition, Dinsdales Moorland Specialists provided drone photographic coverage of bunded (C3 and C4 areas) in March 2022. Moreover, the WMP Ltd captured drone footage of the construction phases of the Bronington Manor Drain diversion (C6), and the wetland restoration schemes at World's End and the Sinker's Fields (C3). Drone images were also captured of various stages of the clean-up and remediation (C5) of the former scrap yard (LP4). The fields subject to turf removal (C7) are also evidenced on drone and aerial images.

The Molinia trial locations were recorded by GPS coordinates, fixed point photography and are shown on aerial photography sourced from the web.

Fixed-point photography was also used to show broad scale changes across the site. Locations were randomly selected at the start of the project in areas where works were planned. The initial photographs were taken in October 2018, and this was repeated at the same locations in October 2020. At each of the selected points using an easily repeatable method a photograph was taken facing in the direction of each of the four compass points to provide a nearly 360-degree visual record of that location. Easily locatable marker posts were installed to ensure the accuracy of repeat photographs.

Where relevant, photography and GPS references were also be taken of specific works before, during and after they occurred.

5.3 Results and discussion

The full set of fixed-point photography is contained in **Appendix 5.3.1**. In some locations little change is discernible because some works had only recently taken place. The drone photography, photos and maps evidencing key works can be found in the Efficacy and Extent of Works Monitoring report in **Appendix 5.3.2**.

5.4 Conclusion

Broad-scale changes as a result of the works carried out can be clearly seen from the aerial and drone photography and GPS based mapping of the bunds. The fixed-point photographs were limited in the changes that they showed due to their locations and the timings of when the repeat surveys were carried out. Now established they should however provide a useful baseline for monitoring longer term trends. Other photos taken of specific key works such as those included in the Efficacy and Extent of Works Monitoring report, have proven to be a more effective way of documenting project works.

6.0 Invasive Species Monitoring

6.1 Aims and Objectives

- D1.5, D2.5 & D3: Invasive Species Monitoring: monitoring of areas where invasive species have been removed will be undertaken to assess success of the actions and highlight areas of re-growth for further treatment.

6.2 Methodology

At the start of the project the known distribution of Non-Native Invasive Species (NNIS) at the site was mapped (**Figure 6.2.1**) based on existing records and knowledge.

Based on this a targeted field survey to further assess the extent of non-native invasive species was carried out in 2017. Prior to the project Himalayan Balsam, New Zealand Pigmyweed (AKA Australian Swamp Stonecrop), Rhododendron, Pitcher Plant and Japanese Knotweed were known to be present. Hybrids of Spanish bluebell have since been recorded. The effectiveness of NNIS control management action and the need for follow up treatment was assessed throughout the project.

Because the area occupied by non-native invasive plants on the NNR are typically very localised and scattered, monitoring using quadrats was not considered to be a suitable method to use to assess the efficacy of removal work. Instead, field visits by the project staff and volunteers were made to known non-native invasive species locations at intervals during the project. Incidental sightings were also recorded. Control management measures undertaken were recorded and the requirement for follow up management assessed.

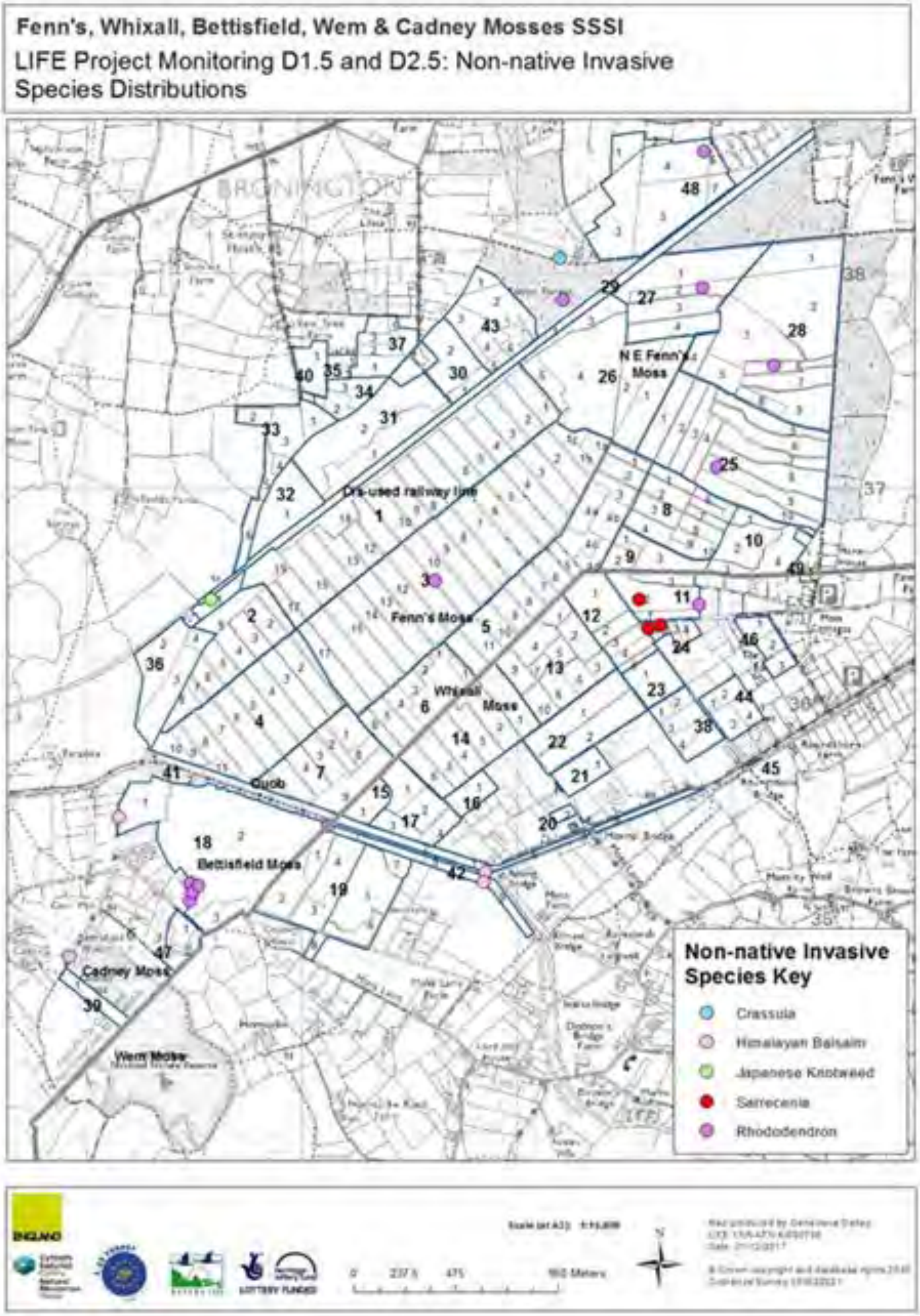

Figure 6.2.1 Map showing the known distribution of NNIS at the start of the LIFE project.

6.3 Results and Discussion

Below Table 6.3.1 shows the number of localities each NNIS species was recorded at, both at the start and end of the project:

Table 6.3.1: Number of surveyed NNIS locations at the start of the project (2017) and end of the project (2022)

Species	Start of Project		End of Project	
	On NNR Land	On Adjacent Land	On NNR Land	On Adjacent Land
Himalayan Balsam	4	0	1	0
Japanese Knotweed	2	0	0	1
Rhododendron	11	0	7	0
Pitcher Plant (*Sarrecenia*)	3	0	0	0
New Zealand Pigmyweed (*Crassula*)	0	1	0	0*
Spanish Bluebell Hybrid	0	0	1	0
Totals	**20**	**1**	**9**	**1**
**The New Zealand Pigmyweed was only monitored from NNR land because at the time of the 2022 field visit no permission was granted to undergo a closer inspection of the pool*				

In response to the findings of the 2017 field survey, targeted efforts to remove the NNIS from each location was undertaken. Himalayan Balsam was hand-pulled and removed from site and disposed of; Japanese Knotweed was treated with herbicide with any cuttings stored securely until dry enough to burn; Rhododendron stems were cut low with the stumps and then treated with herbicide; and Pitcher Plants encountered were dug up and removed from the site and disposed of appropriately. No management to remove New Zealand pigmyweed was undertaken because the location of plant could not be re-found. As result of these efforts there was a reduction from 20 known NNIS plant locations in 2017 down to just 9 in 2022.

Between 2017 and 2022 seven Rhododendron plants were also identified and treated located on management sections: 31.1, 1.18, 4.2, and 4.5 as shown on **figure 6.3.1** (2018 progress update map). Japanese knotweed plants were removed on management section 18.1 (see **figure 6.3.1**).

Before and after photographs of NNIS are found in **Appendix 6.3.1**: NNIS Monitoring Pictures.

With the low level of frequency and scattered occurrence of NNIS, re-locating individual plants could sometimes be a challenge. Accordingly, the identified locations of NNIS will continue to be monitored, regardless of whether they were treated, to ensure that the plants have not regenerated or that other plants in the vicinity have not been overlooked. Some of the identified NNIS occur adjacent to or on privately owned land and so further work may need to be undertaken with the landowners concerned to reduce the NNIS and help prevent them spreading. The distribution of NNIS at the end of the LIFE Project is shown in **figure 6.3.2.**

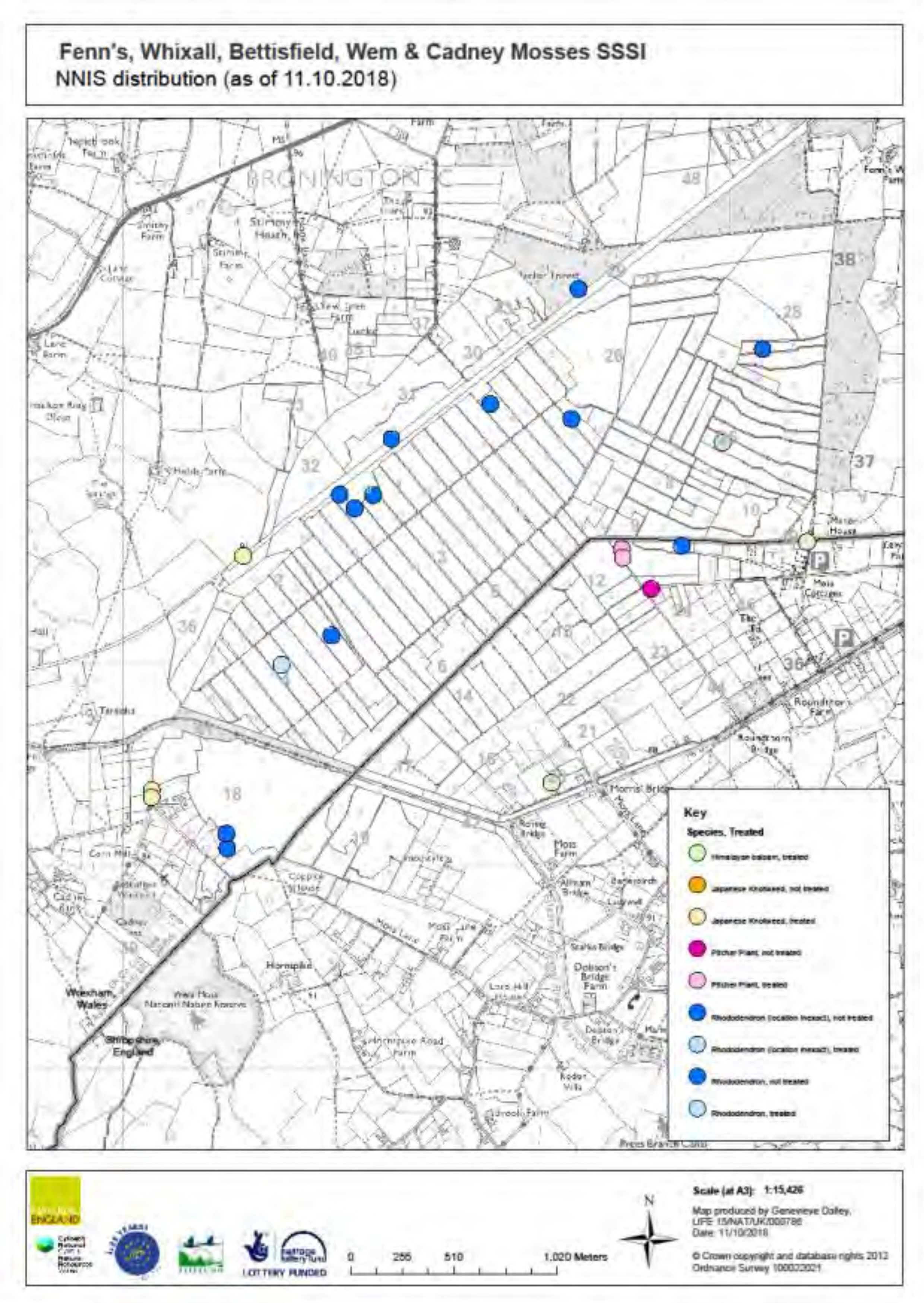

Figure 6.3.1: Map showing the distribution of NNIS and treatment progress in November 2018.

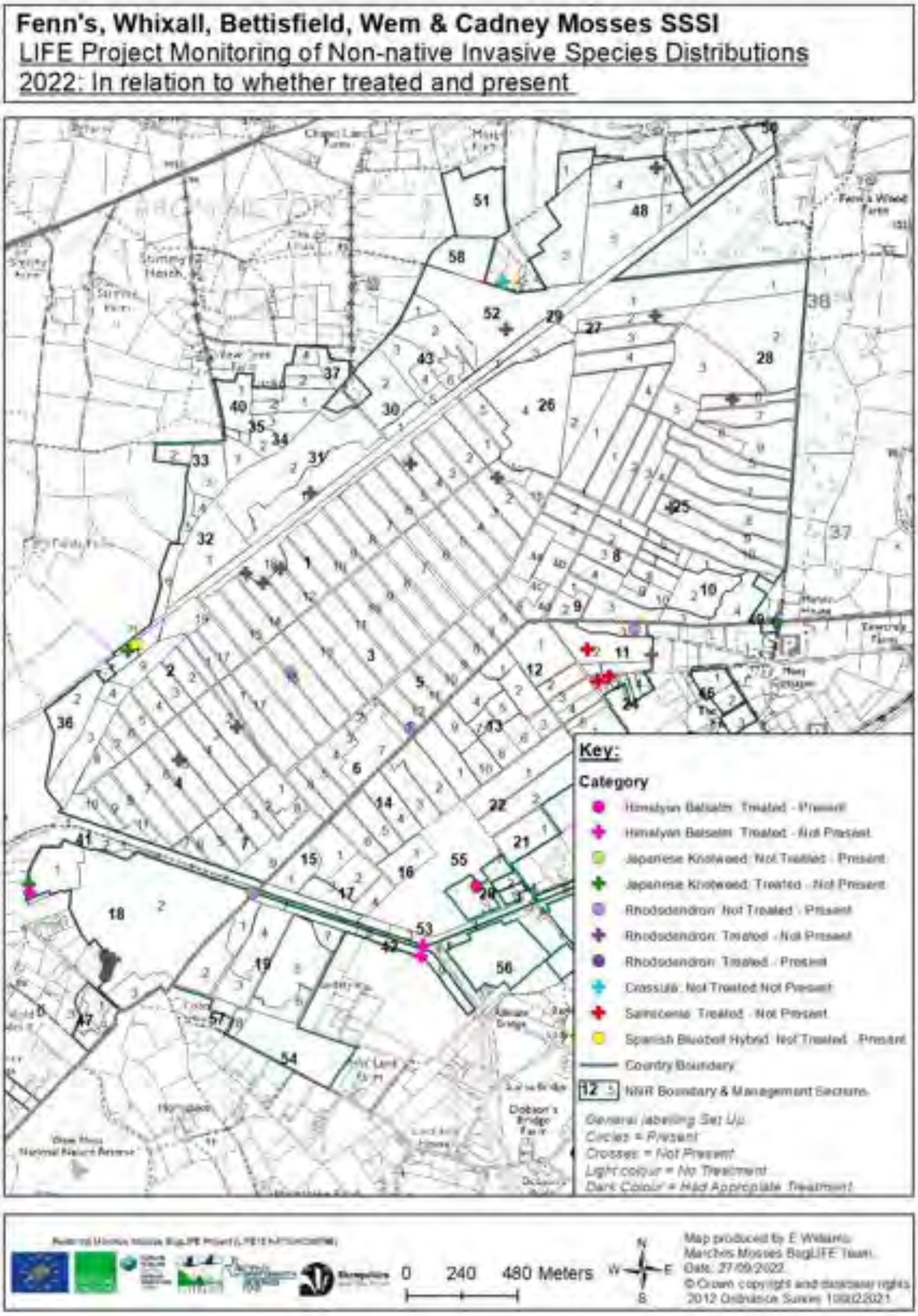

Figure 6.3.2 Map showing the distribution of NNIS and treatment progress at the end of the LIFE project (Sept 2022).

6.4 Conclusions

The occurrence of NNIS on site is fortunately at a low and manageable level. During the project targeted efforts to remove plants were undertaken at known locations. This has been effective at reducing the number of locations from 20 in 2017 down to 9 in 2022. This approach should continue in the future in order to reduce the risk posed by plant NNIS to a de minimis level.

7.0 Overall Conclusions

Overall, there are positive signs that the bog restoration undertaken as part of the Marches Mosses BogLIFE project has had a major effect on the condition of the lowland raised bog habitat, particularly in respect of its hydrology but because of the complex nature of the site it is too early to fully assess the degree of the recovery response. Further monitoring is needed to establish the area over which favourable water levels have been achieved able to support optimal bog habitat regeneration. Many areas currently feature vegetation communities which are undergoing significant dynamic transitions in response to the restoration works.

Because the timing of works has necessarily been phased, those carried out in the latter stages of the project such as the 2nd fix bunding (C4) or the Worlds End Wetland restoration scheme (C3) have not fully taken effect and it is not yet possible to assess their impact on water levels and vegetation. These areas will benefit from a further period of monitoring.

The diversion of the Bronington Manor Drain (C6) has succeeded, creating water quality conditions along original part of the drain, more in line with those of characteristic of bog habitat. Over time this is expected to aid the restoration of the peatland areas either side.

For the pasture to bog trials on the turfing fields it is too early to say if suitably favourable environmental conditions have been provided for the sphagnum and cotton grass planting to succeed in spreading and speeding up the transition to a fen or bog vegetation community. The water levels are too variable between the winter and summer seasons but there has been some improvements in Section 21 in terms of reduced variability.

Areas of land and water pollution and nutrient enrichment on the site are localised and either reducing over time or remaining stable. There is no indication of the problems spreading and water pollution is not impacting the site as a whole. Aerial nitrogen pollution remains a major intractable cause of ecosystem degradation. There is a now a good understanding of the issue based on site monitoring however marked improvement relies on changes in policy and agricultural practice.

The prevalence of non-native invasive species have been significantly reduced and the risk they pose is considered minimal even though they have not been completely eradicated from the site. Due to their very low level of occurrence and slow speed of spread a strategy of ongoing monitoring and periodic removal with the goal of elimination is deemed adequate for managing the threat effectively in the future.

8.0 Bibliography

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9.0 Appendices

Available as separate documents.