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Post-Restoration Nutrient Monitoring: Felbrigg Lake
Final report to the National Trust

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Ben Goldsmith & Carl Sayer

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Post-Restoration Nutrient Monitoring: Felbrigg Lake

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Authors:
Ben Goldsmith & Carl Sayer

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Ensis Ltd.
Environmental Change Research Centre
University College London
Pearson Building, Gower St.
London, WC1E 6BT

Tel: +44 (0)20 7679 9248

info@ensis.org.uk
www.ensis.org.uk

Cover photo: Felbrigg wetland, January 2015. B. Goldsmith

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1. Background

Combined limnological and palaeolimnological studies show Felbrigg Lake to have been negatively affected by eutrophication over at least the last century (Sayer *et al.*, 2010a,b; Rawcliffe *et al.*, 2010). In particular, since the 1960s-1970s, the lake has possessed an impoverished macrophyte community and charophytes (which were abundant prior to 1900) have been sparse-absent.

To guide future lake-catchment works Luckes & Sayer (2002) undertook a study of nutrient sources to Felbrigg Lake. This included a quarterly survey of nutrient concentrations within the lake, its two inflows and the outflow (over 2001-2002). Similar to an earlier study (1999-2000 – see Sayer *et al.*, 2010a) they showed high concentrations of total phosphorus (TP) and nitrate nitrogen (NO_3^- -N) in the lake ($189 \mu\text{g l}^{-1}$ and 5.9 mg l^{-1} respectively) and consequently advocated a range of nutrient reduction measures. These measures included fencing of the north-eastern bank, desilting of the northern stream on National Trust land, stream buffering, creation of silt traps and diversion of the northern stream through the *Phragmites* bed at the top of the lake (see Figure 1).

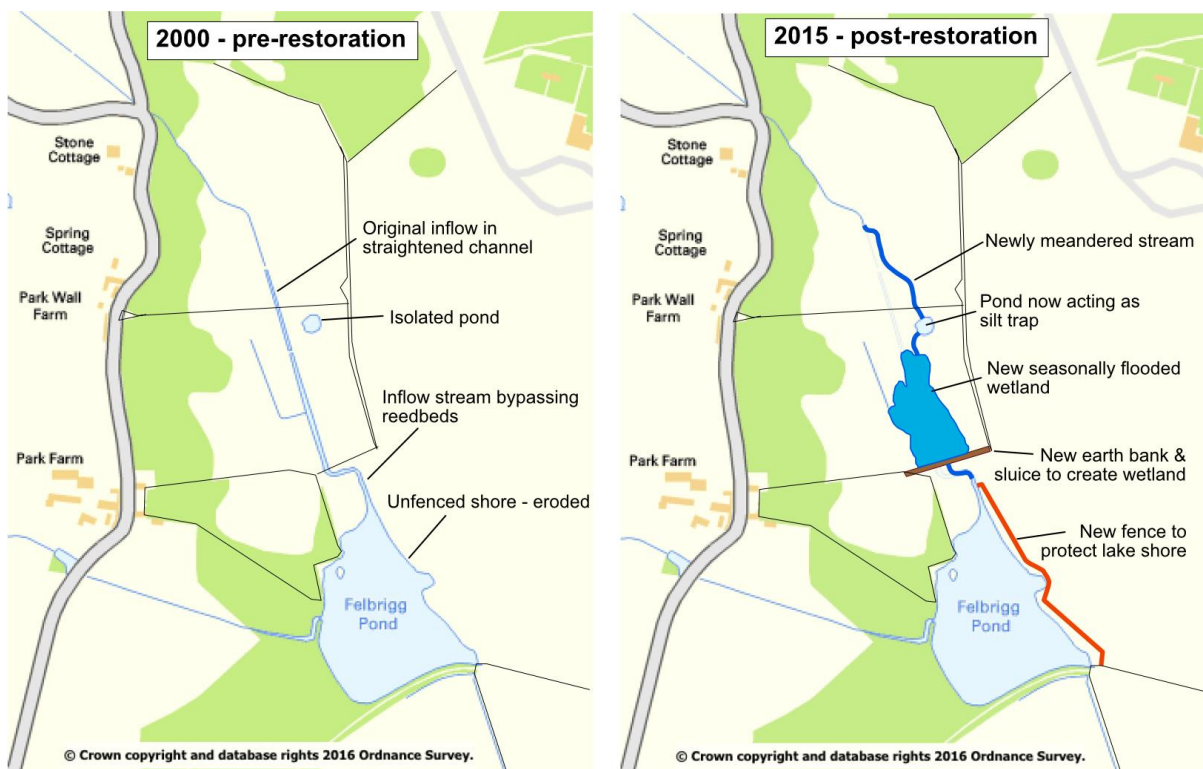


Figure 1. Pre- and post-restoration maps of Felbrigg Lake

In 2003-2004 the lake was fenced from cattle with the immediate effect of reducing littoral erosion. Further, over winter-spring 2012 a range of measures were introduced to facilitate nutrient reduction to the lake and help prevent the in-wash of sediments from the catchment. First the stream to the north of the lake was re-meandered (on National Trust land) and connected to a small pond at TG 1895 3920. In so doing, the pond now acts to trap sediment that would otherwise enter the lake. Secondly an earth bank and simple sluice was constructed just up-stream of the lake. This has

created a shallow wetland on the meadows and provides a control on water levels. Finally the Northern stream was diverted through the *Phragmites* bed at the top of the lake in an effort to slow sediments transport to the lake and potentially strip nutrients from the water. The overall aim of the restoration work was to reduce nutrient and sediment delivery to the lake hopefully leading to improvements in its conservation value.

1.1. Project aims

Monitoring restoration projects is vital to understand their impact and success. In this case, there is the added advantage of having high quality, pre-restoration data as well as excellent palaeolimnological evidence against which to make comparisons.

ENSIS was engaged by the National Trust to undertake a programme of monitoring to determine the function and success of the recent restoration works. In addition it was anticipated that the outcome of the monitoring would inform the necessity for any future restoration work (especially sediment removal). The study has the following aims:

- to determine changes in nutrient dynamics in the Felbrigg Lake catchment;
- to determine current nutrient concentrations and algal biomass in the lake;
- to assess extent to which the restoration work has changed the nutrient dynamics of the lake.

By utilising local NT staff to undertake the water sampling, a relatively high intensity sampling regime was proposed in order to give an indication of where and when nutrients are washing in from the lake catchment. Furthermore, it was recommended that additional samples were taken from the streams and lake during storm events to capture periods of peak run-off.

2. Methods

2.1. Water quality samples

With the focus of this project being on the restoration work, water sampling was confined to within the proximity of the lake rather than extending throughout the entire catchment. A total of six sites were chosen to best capture the impact around the wetland and to coincide with sites monitored during the 2001-2002 survey (Luckes & Sayer, 2002), thus allowing for direct comparisons between years. These sites are listed in Table 1 and shown on Figure 2.

Table 1 Water quality sampling locations within the Felbrigg Lake catchment 2015/16

Site no.	Site name	Grid ref	Corresponding sample site 2002
1	Lake outflow	TG1914838782	1
2	Weir below wetland	TG1898639032	3
3	Wetland top, below pond	TG1894439179	4
4	North Steam at woodyard	TG1875939456	5
5	Stream 2 at road	TG1868738893	12
6	Stream 2 at woodland bridge	TG1896338842	15



Figure 2. Water quality sampling sites within the Felbrigg Lake catchment

ENSIS staff conducted a site walk-over and collected the first set of samples (30th January 2015), with all subsequent sampling undertaken by NT staff following on-site training. Water samples were then collected monthly at the beginning of each month from February 2015 to February 2016. At the same time a single sample for chlorophyll-a analysis (a measure of phytoplankton biomass) was taken from the lake outflow (site 1). Samples for determination of chlorophyll-a and total phosphorus (TP) were filtered on-site under vacuum through Whatman GF/C filters (47 µm diameter). An additional set of samples was collected on 27th July 2015, following a high rainfall event.

Following collection, water samples were sent directly by overnight courier to the Environment Agency's UKAS accredited laboratories in Devon (National Laboratory Services - NLS) and all samples were subjected to nutrient analysis: soluble reactive phosphorus (SRP), TP, nitrite (NO₂⁻-N) and total oxidise nitrogen (NO₃⁻-N), with chlorophyll-a measured for on the lake outflow sample. pH and conductivity were also determined for all samples (Table 2).

Table 2 List of determinands analysed for water quality

Determinand	Unit	Limit of detection
pH	pH	0.05
Conductivity @ 20C	µS/cm	10.0
Orthophosphate, reactive as P (=SRP)	µg/l	1.0
Total Phosphorus (TP)	µg/l	3.0
Total oxidised Nitrogen as N	mg/l	0.005
Nitrite Nitrogen as N	mg/l	0.001
Nitrate nitrogen*	mg/l	0.005

*Nitrate nitrogen is derived by subtracting nitrite from TON

3. Monitoring Results

3.1. Water quality 2015/16

The monitoring results show Felbrigg Lake to be hyper-eutrophic, with a mean annual TP of 164 µg⁻¹ (see Section 3.3 below for comparative results with 2002). Within the catchment, the main inflow stream to the north of the lake had a mean annual TP of around 100 µg⁻¹, whereas the smaller stream to the west averaged 200-300 µg⁻¹ (Figure 3). Nitrogen concentrations (primarily nitrate) were on average relatively low in the lake, whereas increased levels were recorded higher in the catchment in both inflow streams (Figure 5). These results are typical of lowland areas in regions of relatively intensive agriculture.

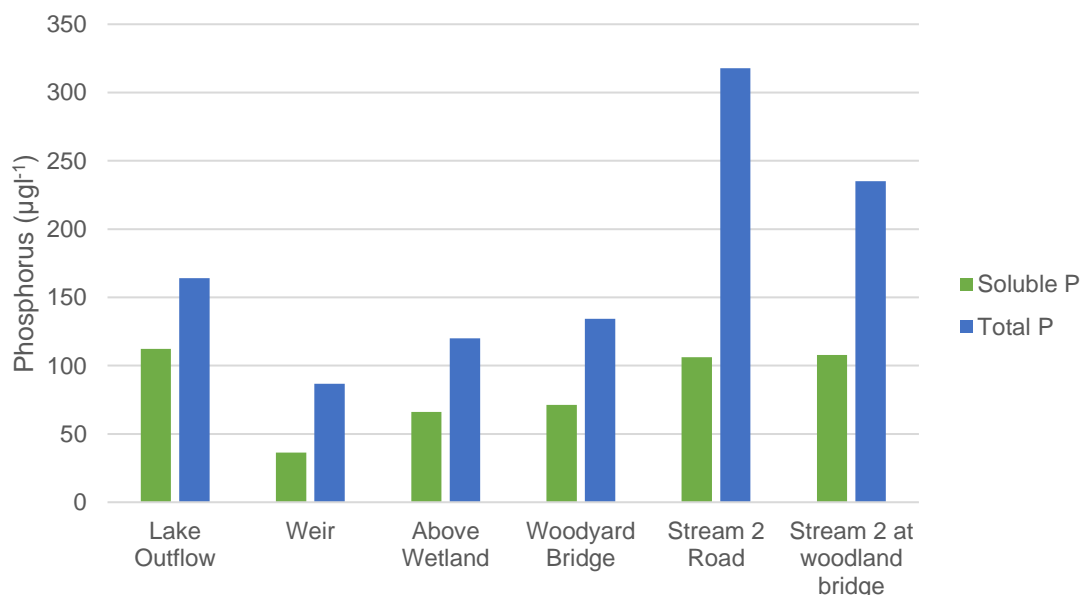


Figure 3. Mean annual phosphorus concentrations in the Felbrigg Lake catchment

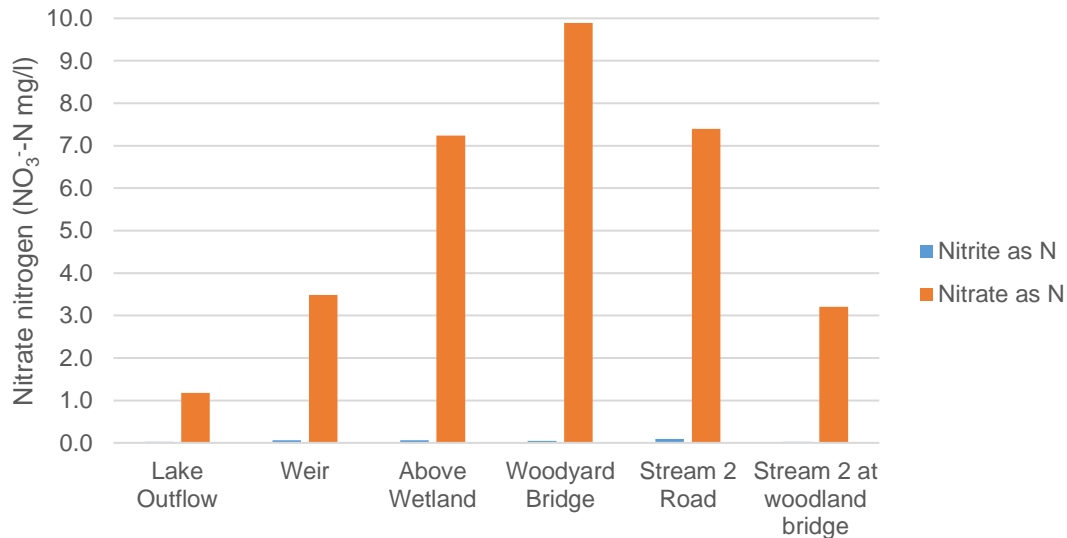


Figure 4. Mean annual nitrogen concentrations in the Felbrigg Lake catchment

3.2. Seasonal variation in water quality 2015/16

Felbrigg Lake

As a standing body of water, the lake functions somewhat differently to the streams and is therefore presented separately.

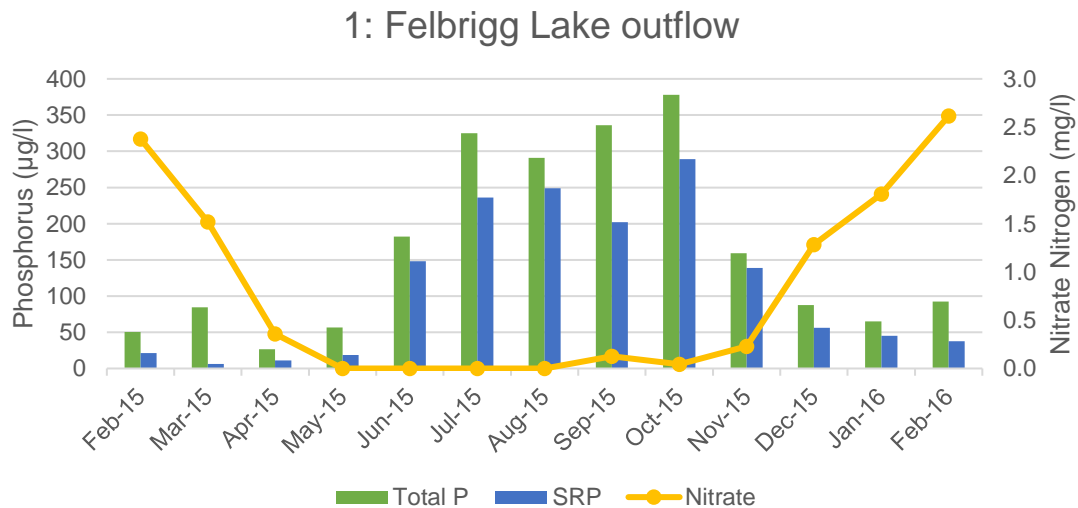


Figure 5. Seasonal nutrient concentrations in Felbrigg Lake (outflow)

In Felbrigg Lake, there is a clear seasonal pattern of nutrient concentrations (Figure 5). Phosphorus levels remain relatively low during the winter months increasing in the summer. This pattern in the phosphorus data is likely indicative of P-release from the sediments – a common phenomenon in eutrophic shallow lakes (add refs). Conversely, the levels of nitrogen are high in the winter and low during the summer growing season (May-Oct.). High levels of available phosphorus during summer combined with low levels of nitrogen strongly suggest that primary production (phytoplankton and macrophytes) in the lake is currently nitrogen limited. This is reflected in the levels of chlorophyll-a (Figure 6). Often, in eutrophic lakes where nutrients are unlimited, we see high summer values of chlorophyll-a as the

phytoplankton biomass increases with longer day length and higher summer temperatures. In Felbrigg Lake however, there appears to have been an initial increase in algal biomass in March 2015, but as nitrate availability decreased, algal biomass declines, despite high levels of SRP. In addition, over the period May-July 2015 competition by submerged macrophytes (which tend to peak in the lake at this time) likely placed a check on phytoplankton development.

1: Felbrigg Lake outflow

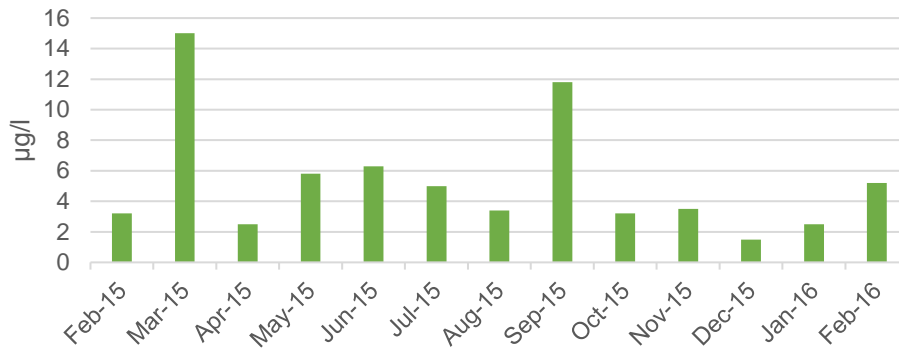


Figure 6. Seasonal concentrations of chlorophyll a in Felbrigg Lake (outflow) 2015/16.

Main inflow stream and wetland

The main inflow stream flows into the lake from the north. Prior to restoration, this was a relatively straight channel running under the road at the Woodyard, directly to the lake. Since the restoration work, the stream flows through a gently meandering channel to the in-line pond and is then held by the installation of a low earth dam and weir to form a shallow wetland area to the north of the lake (Figure 1).

Seasonal data from the stream at Woodyard Bridge show there to be high phosphorus and nitrogen within the inflow stream throughout the year (Figure 7 – Woodyard Bridge). As water moves through the system, concentrations of phosphorus and particularly nitrate fall considerably, over what is a relatively short distance (Figure 7).

In terms of phosphorus, the reduction in soluble P (that which is available for plant and algal uptake), the largest downstream reduction is during the winter months. Whereas nitrate concentration fall more rapidly as the water moves through the wetland system during the warmer summer months; in July 2015. For example, the nitrate levels were almost 50 times lower at the wetland outflow (0.28 mg l^{-1}) than at the Woodyard bridge (13.6 mg l^{-1}); a distance of only 500 m. This pattern is however disrupted during high flow events (see below).

In early September 2015, there appears to have been a spike in phosphorus (TP and SRP) above the wetland, which was not seen at the Woodyard bridge, suggesting that it came from the adjacent land. The reason for this is unclear, but was possibly related to recent rain prior to sampling. The sample was taken on September 1st, the day after 15.6 mm of rain was recorded at Sheringham (5 km from Felbrigg lake - <http://www.nr26.com/>) and therefore material from the adjacent pasture was likely washed into the stream potentially causing disturbance of the small pond just above the sampling site.

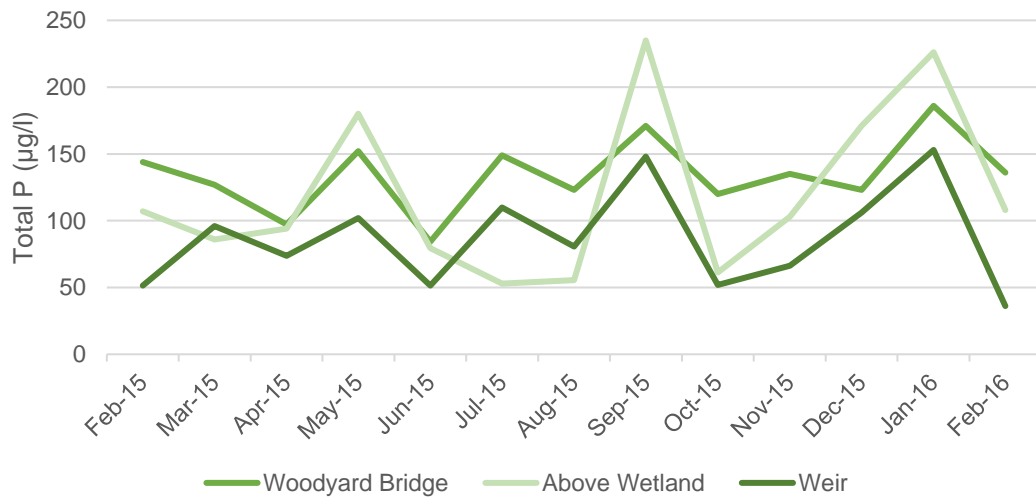
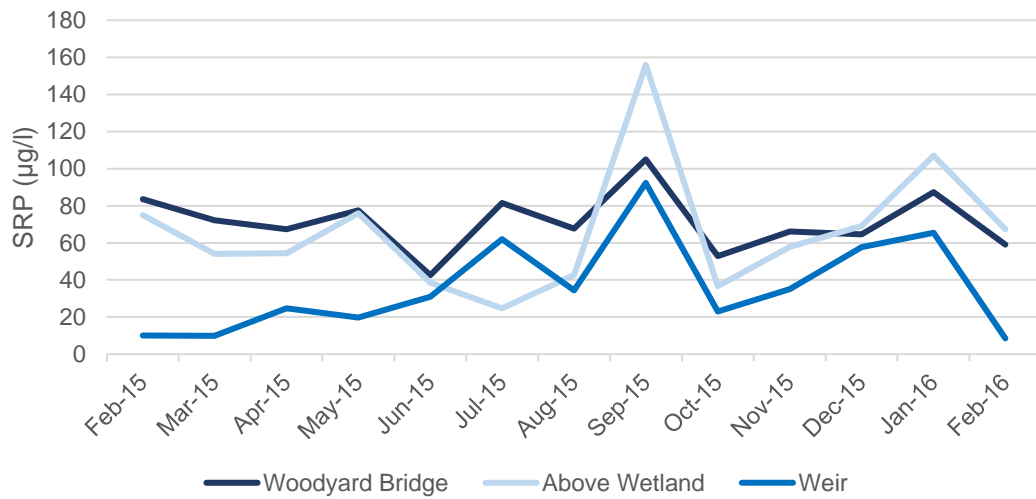
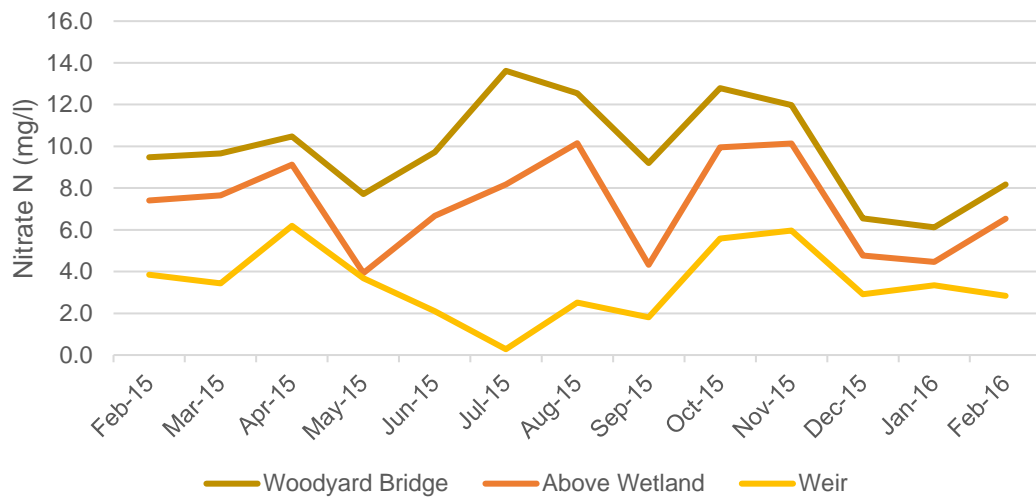


Figure 7. Seasonal nutrient concentrations in the northern stream and wetland

Woodland stream

The stream to the west of the lake drains much smaller area of catchment than the northern stream. Inputs of water and nutrients are nonetheless significant with past measurements showing high concentrations of both N and P. Unlike the northern stream, there has been no remedial work since 2002 when the last comprehensive monitoring was carried out (Luckes & Sayer, 2002).

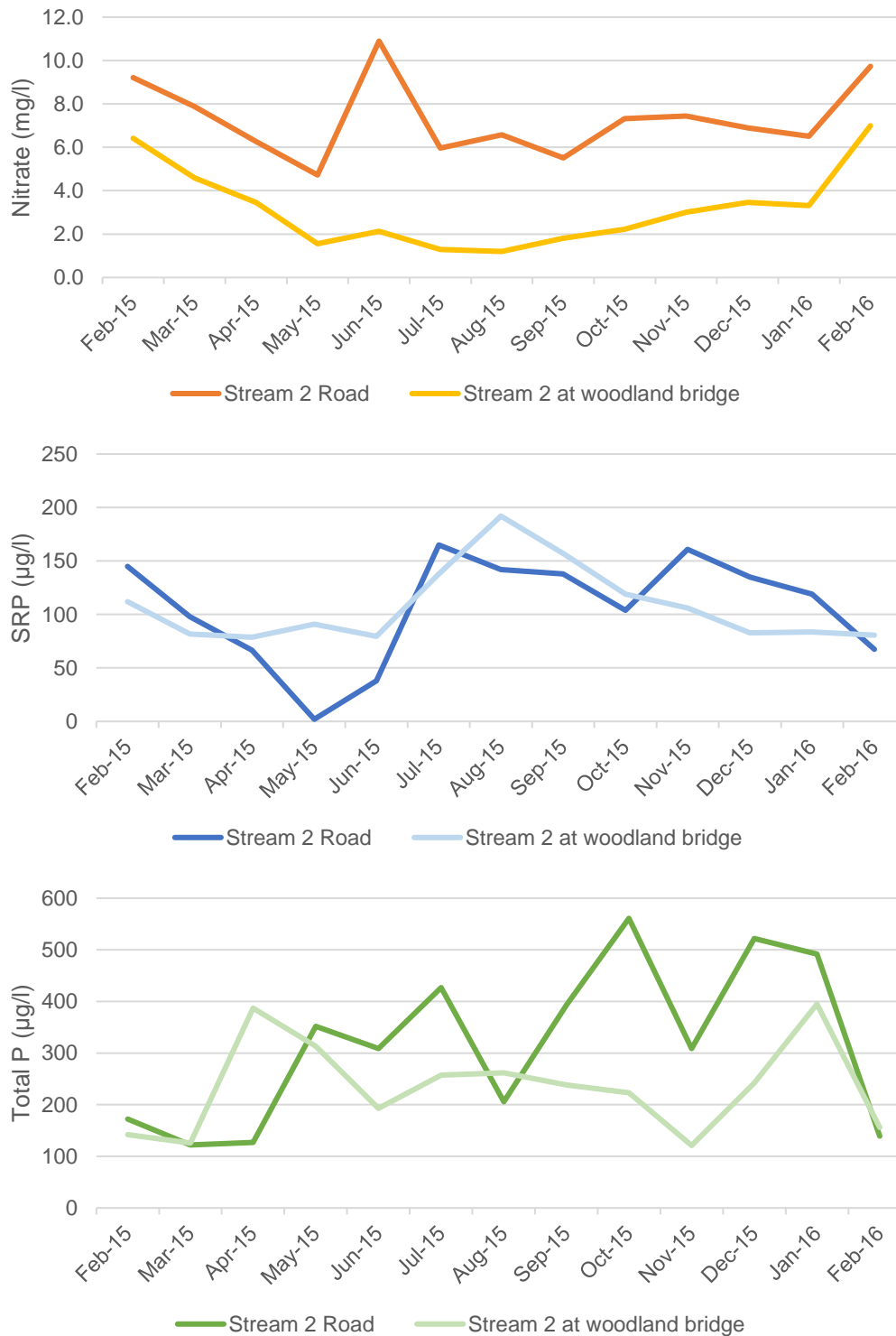


Figure 8. Seasonal nutrient concentrations in the woodland stream

Similar to the northern stream, concentrations of nitrogen were higher in the winter months and there was a reduction in nitrate from the up-stream to down-stream site throughout the year of, on average, approximately 50 % (Figure 8).

Phosphorus concentrations were rather variable, but it is worthy of note that TP was significantly higher in the woodland stream (at both sites) than in the northern stream (Figure 8), with average values being approximately double (Figure 9).

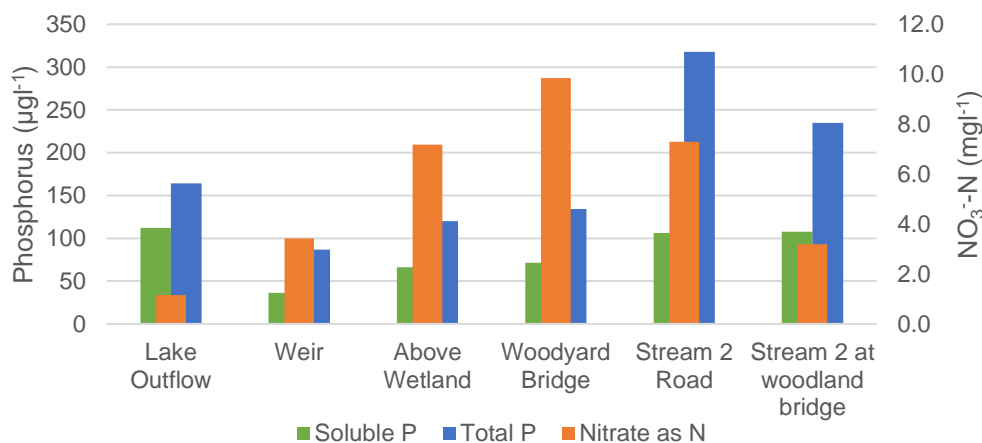


Figure 9. Annual mean nutrient concentrations in the Felbrigg catchment 2015/16

3.3. Comparative water quality: 2002 to 2015/16

In order to assess the impact of the restoration work it is necessary to compare the recent results with water quality collected prior to the restoration. Luckes and Sayer (2002) undertook quarterly chemistry at eight sites, inclusive of five of the same sites used in this study¹. There is only very limited comparative data from the Stream 2 site at the woodland bridge.

It should be noted here that the catchment nitrogen figures quoted by Luckes & Sayer (2002) are significantly higher than those recorded in this study. The reason for this appears to be due to the way the data are expressed rather than a dramatic reduction of nitrogen within the catchment. In Section 3.2 of Luckes & Sayer (2002), it suggests nitrate was measured as elemental nitrogen (referred to as nitrate nitrogen - NO₃⁻-N) rather than nitrate ions (NO₃⁻), yet it gives a conversion between these two forms, which does not appear to have been used. Furthermore, the figures for N derived in the 2002 report are well above the expected values for elemental nitrogen, and it is therefore assumed the report used nitrate ion concentrations (NO₃⁻) and incorrectly expressed the data as NO₃⁻-N. When the 2001-2002 nitrate figures are converted to elemental nitrogen, they are directly comparable with those in this report (Figure 10) and with figures from the lake collected in 1999 and 2000 (presented in Luckes & Sayer, 2002).

All Luckes & Sayer nitrogen data presented in this report have been converted to nitrate nitrogen concentrations using the formula: NO₃⁻-N = NO₃⁻ x 0.226

¹ Site 2, the Weir in this study, is located slightly up-stream of the sites used by Luckes & Sayer

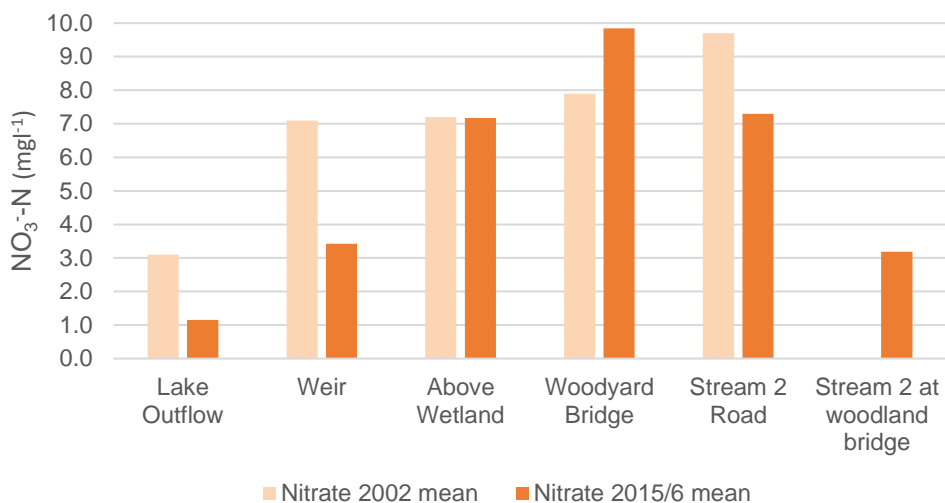


Figure 10. Annual mean nitrate (as N) concentrations in the Felbrigg catchment during 2001-2002

Within the main stream, nitrogen concentrations are very similar above the wetland and were slightly higher in 2015 at the Woodyard bridge site (Figure 10). Below the wetland however, mean nitrate in 2015-16 was half that reported in 2002, prior to the wetland being present. Similarly, in the lake, the mean nitrate in 2015 has dropped to almost a third of the concentration seen in 2001-2. In the woodland stream, mean nitrate was slightly higher at the road site in 2001-2. Only a single value for nitrate was recorded at the woodland bridge site in April 2002; 1.78 mg l⁻¹, compared to 3.5 mg l⁻¹ April 2015.

These results appear to show a positive impact of the wetland for removing nitrogen from the stream water; the overall reduction in nitrate N flowing into the lake being greater following the creation of the wetland. These figures are consistent with the seasonal data from 2015, which show a significant decrease in N downstream of the wetland, particularly in the summer (see Figure 7).

Phosphorus concentration show a markedly different pattern (Figure 11). Within the lake, mean TP is very similar to that recorded in 2001-2002. Available phosphorus (SRP) however is almost double that recorded in 2001-2. At first sight, this looks to be a problem; phosphorus is a major driver of eutrophication and therefore we hope to see a reduction, particularly in this biologically available form of P. When viewed in conjunction with the Nitrate data however, it is clear that the site becomes limited by N during the summer months and therefore the uptake of P is limited and hence the available P remains unused and is hopefully being flushed from the lake.

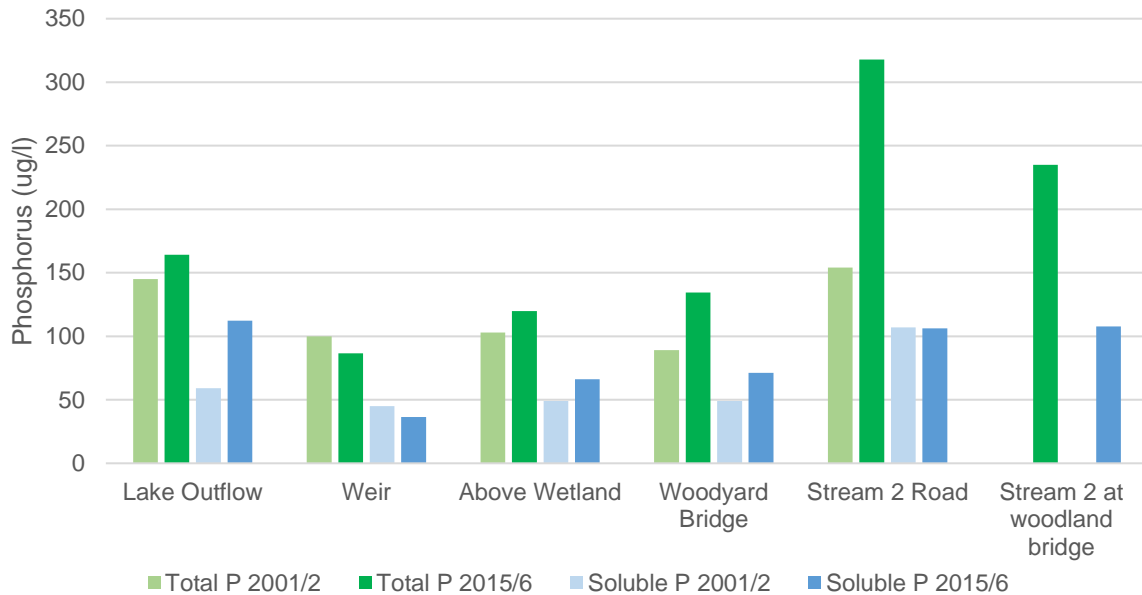


Figure 11. Annual mean Phosphorus concentrations in the Felbrigg catchment for 2001-2002 and 2015-2016

Within the streams there is less variation between the two sampling periods. A slight reduction in TP below the wetland, but generally TP was higher within the catchment, and significantly so in the upper part of the Woodland Stream catchment which suggests there to have been an increased problem of P from within the catchment since 2002; something that requires further assessment and where possible, intervention.

Unlike nitrogen, there is very little decline in P as a result of the wetland creation.

4. Comments and Recommendations

There is great value to the periodic monitoring of catchment lake catchment, particularly where management and restoration is implemented. Furthermore, for the assessment of impact and success of restoration works, it is essential to collection high quality environmental data prior to any management work. At Felbrigg Lake, the collection of water quality data from the catchment prior to the work on the northern stream and wetland creation provides just such an opportunity to determine the impact of the works.

4.1. Catchment nutrients

The two main inputs to the Felbrigg Lakes are the streams running in from the north and west of the lake. Samples taken from the Woodyard Bridge and at the road on Stream 2, show, rather disappointingly, that the nutrient inputs from the upper catchment have changed very little over a period of 12 years. Mean annual total phosphorus concentrations in the northern stream have increased from 89 $\mu\text{g l}^{-1}$ in 2002 to 134 $\mu\text{g l}^{-1}$ in 2015, and in the western stream, they have doubled from 154 $\mu\text{g l}^{-1}$ to 317 $\mu\text{g l}^{-1}$ over the same period.

The changes in nitrate nitrogen concentrations are less dramatic, but nonetheless nitrate remains very high within the catchment. Concentrations of nitrate in 2015 have increased slightly in the northern stream, and now regularly exceed the threshold value for Nitrate Vulnerable Zones (NVZ's) of $11.29 \text{ mg l}^{-1} \text{ -N}$ ($50 \text{ mg l}^{-1} \text{ NO}_3$) between July and October. There is a strong recommendation therefore that farmers within the catchment adhere to best practice in terms of nutrient applications and methods as specified within NVZ's to prevent leaching to freshwaters (DEFRA, 2013).

4.2. Impact of restoration work

Despite the higher nitrogen concentrations within the upper catchment, the amount of nitrate reaching the lake from the northern stream has decreased significantly since 2002. There are two main areas where this appears to have happened. The first reduction is below the re-meandered stream and settlement pond; a region where almost no reduction in N was seen by Luckes & Sayer (2002). There is then another significant reduction in nitrate N between the top and bottom of the wetland; again, a region where Luckes and Sayer (2002) found no difference.

We can therefore say that it appears that both the new stream layout and the wetland are having a positive effect on nitrogen concentrations within the lake, which has now become N limited in summer. Hence the restoration work, it seems, has been a success.

The reasons for the reduction in nitrogen through the new stream and wetland system are most likely a result of the complex interactions between biological and chemical processes within the nitrogen cycle. By increasing the retention of water within the stream and wetland, the process of nitrification/denitrification is greatly increased such that a significant proportion of the nitrate entering the system can be removed (Van Cleemput 2007). The process by which this happens is dependent on the oxidation state of the soil or sediment. In the saturate anaerobic layers that often occur within waterlogged ground, organic nitrogen may be converted to inorganic ammonium, and taken up by plants and microbes, or become bound to soil particles. Under aerobic conditions some plants and microorganisms can assimilate nitrate through denitrification processes to produce gaseous nitrogen which is lost to the atmosphere. With both processes facilitated by reduced flow and the holding of water in the wetland, nitrogen is held up within the system or lost completely.

This process appears also to be happening within the wet woodlands of stream 2 where N concentrations can be seen to be reduced by over half between the road and the lake. Management of this stream should therefore focus on holding water within the woodland rather than letting it flow directly to the lake. Fallen trees and natural blockages help to reduce direct flow and keep the stream connected with the woodland floor.

The extent to which the nitrogen cycle occurs in wetlands is effected by many factors, including temperature, light, pH, soil structure, mineral content, flow rates (to name only a few), but overall, at Felbrigg, the initial monitoring data suggests the restoration is working to reduce N from reaching the lake.

This is not the case for Phosphorus. Phosphorus also has the capacity to be used by plants and microbes within streams and wetlands, and therefore uptake of SRP is often seen. Phosphorus also binds to soil and clay particles, but its capacity to do this is often limited (dependent on mineral composition) and therefore in wetland systems where the rate of supply of P is high, the soils very quickly become saturated with P and the capacity for further uptake diminishes. Wetlands are therefore generally considered to be poor at long-term phosphorus removal (Richardson *et al.* 1997). Again, this fits well with the observations in this study, with minimal reductions of P evident through the wetland system.

Overall, the impact of the wetland on the lake appears to have been positive. Very low nitrate concentrations within the lake, appear to have reduced phytoplankton biomass (chlorophyll-a), thereby improved conditions for macrophyte growth. Indeed in this respect, for the first time in at least 18 years the lake is currently (2016 observations of C. Sayer) supporting good sized macrophyte beds into late summer including *Chara* spp. and *Ceratophyllum demersum*; two species that were present in the palaeo-record from Felbrigg Lake prior to the recent eutrophication phase (Sayer *et al.* 2010b), but have not been seen in the lake during the last 20+ or so years.

4.3. Recommendations

With the restoration measures now in place and apparently reducing nitrogen inputs to the lake, the focus should be turned back to the upper catchment. Agricultural and domestic inputs of nutrients within the catchment remain a problem. Water entering the wetland and the woodland area is heavily laden with nutrients, and hence the restorative measures can only limit inputs to the lake to an extent.

Addressing any specific problems within the catchment, such as poor agricultural practice, areas of high field run-off, poorly managed agricultural building (slurry / manure), poor domestic drainage (sewage outfalls, cesspits, misconnections), can have a major impact on reducing pollution. This requires working together with landowners, communities and stakeholders within the catchment, to both identify and mitigate any such problems.

Future monitoring (catchment and lake) is recommended to ensure improvements occurred not only with water quality, but also with the ecological health of the lake. A survey of the fish population is also highly recommended in order to determine the current species composition within the lake. Recent anecdotal evidence from anglers indicates that perch has become established and that the once abundant rudd and tench population have undergone a dramatic decline. Fish are a key component of shallow lake ecology, and additional knowledge of their populations in the lake will be essential in understanding how the lake functions and for informing future management.

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