River Wye Management Catchment Integrated Data Analysis Report

Data Cut-Off: 31st October 2021

Report Date: January 2022

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About this Report

The River Wye SAC (Special Area of Conservation) is failing to meet phosphate targets in some reaches and very close to the threshold in others. There have been reports of algal blooms in the river and accounts of ecological decline over the past few years.

The scale of data being captured in the Wye Management Catchment is increasing exponentially as more continuous monitoring sondes, autosamplers, remote sensing and citizen scientists are deployed.

All this data contributes differently to the overall picture of what is happening in the catchment.

The Environment Agency West Midlands Area Analysis and Reporting Team and Integrated Environment Planning Team are bringing this data together with existing datasets four times a year to answer the following questions to contribute to a shared understanding and ownership among all stakeholders of the issues and actions required:

1. What are the main variables contributing to algal blooms in the Wye?
2. What other ecological and water quality issues does the data show?
    a. When did these occur?
    b. Where did these occur?
3. Which locations, sectors and activities were responsible for the ecological and water quality issues identified in the data?
4. What recommendations can be made for regulatory, partnership and industry sector actions to prevent the reoccurrence of ecological and water quality issues identified in the data?

If the available data does not allow us to answer a question, we describe what data is needed to be able to answer it.

Citizen science data has not been analysed for this report as the Environment Agency received the data after the data-cut-off date for this report. It will be included in future reports.

If you have any feedback on this report or additional information to contribute to future reports, please contact Enquiries_WestMids@environment-agency.gov.uk

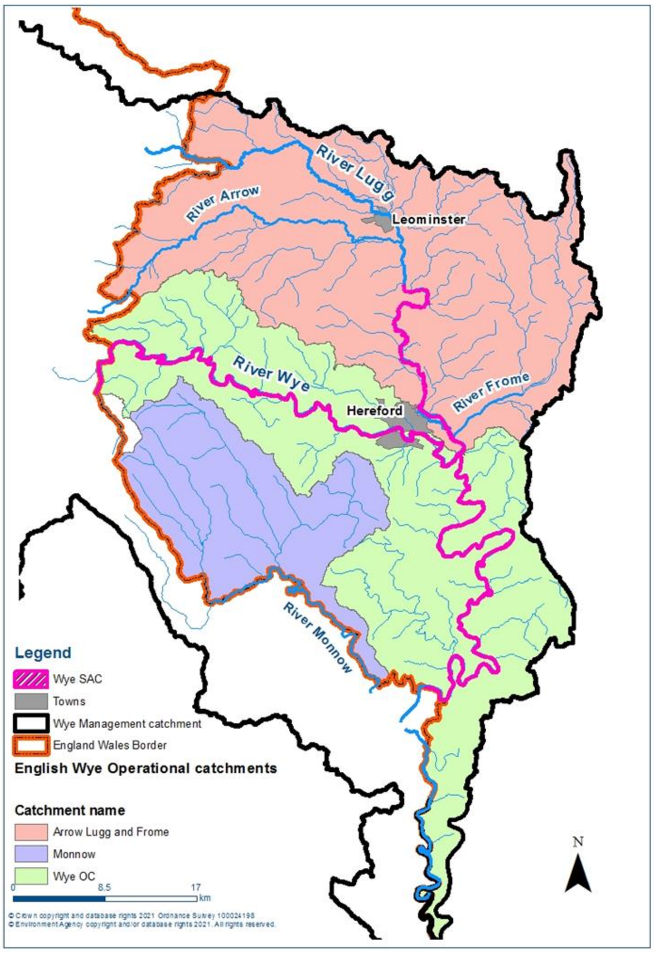


Figure 1: River Wye Management Catchment within England and associated Operational Catchments and major tributaries.

Summary of Conclusions

We can currently conclude, based on the latest available data, that:

1. What are the main variables contributing to algal blooms in the Wye?

Significant algal growth occurs on the main River Wye during the summer. A large amount is filamentous algae and diatoms covering the riverbed. The relative proportion of riverbed to free floating algal growth is currently unknown.

Excessively high summer water temperatures on the main river Wye are a major contributing factor to this algal growth.

Water column phosphate concentrations are low where the algal blooms have been recorded. More frequent and widespread orthophosphate, total phosphorus, and sediment nutrient data is required in partnership, to test whether this means other factors are more important triggers of algal blooms.

Water column nitrogen concentrations are too high everywhere in the catchment but would not trigger algal blooms if phosphate availability to aquatic plants were low enough to limit growth.

2. What other ecological and water quality issues does the data show?

Salmonid fish populations have declined over the last 10 years, and there has been a shift to the headwaters of the Lugg for the main Atlantic Salmon population in the English sections of the Wye.

Invertebrate populations currently appear to be healthy, although additional metrics need to be explored.

Macrophyte communities sampled in 2021 show evidence of eutrophication across the whole catchment.

Nutrients within the water column are a bigger problem in tributaries than the main Wye. Sediment analysis is needed to build a more complete understanding. Since 2010, there has been an increasing trend in orthophosphate on tributaries of the Wye and an increasing trend in nitrogen across most of the catchment.

3. Which locations, sectors and activities were responsible for the ecological and water quality issues identified in the data?

Arable agriculture, particularly maize and autumn sown crops like winter wheat on permeable soils contribute significantly to orthophosphate concentrations.

There has been an extreme increase in the proportion of land managed as arable since 2016, particularly maize and potato crops, which are more susceptible to soil loss.

Sewage treatment works (STW) and combined sewer overflow (CSO) discharge rates are significant contributing factors to orthophosphate concentrations. STW phosphorus limits are effective in reducing the contribution to orthophosphate concentrations, however, CSOs and agriculture appear to contribute towards target exceedance where p limits are in place.

The number of poultry units in a catchment does not show a clear correlation with orthophosphate levels but does appear show a link with nitrogen levels and total phosphorus. Total phosphorus data is currently too sparse to demonstrate a causal relationship and this analysis does not account for pathways of impact outside the unit such as spreading of manure or digestate on fields outside the catchment where the poultry units themselves are located. Further investigation is needed to demonstrate that this is a cause and confirm the pathways.

Sewage discharge and agriculture account for the largest share of environmental incidents reported to the Environment Agency in the Wye Management Catchment between 01/11/2020 and 31/10/2021.

4. What recommendations can be made for regulatory, partnership and industry sector actions to prevent the reoccurrence of ecological and water quality issues identified in the data?

Efforts to increase shade by tree planting and better management of riparian trees could help mitigate high temperatures.

Extreme reduction in nutrient input from all sources is required across the whole catchment to contribute to the recovery

Taking a catchment-based approach all contributing partners in the Wye Management Catchment could target key focus catchments based on criteria identified in this report

Data Sources

Continuous Data Loggers (sondes)

Four sondes, deployed between May and October 2021 on the Rivers Wye, Arrow and Frome to monitor evidence of algal blooms and associated environmental conditions, were analysed (Figure 2). Several water quality parameters were recorded at 30-minute intervals at each site. Dissolved oxygen, temperature and chlorophyll have been examined in detail.

Data from an additional sonde on the Lugg deployed at Mortimer's Cross as part of a separate project has also been examined, although this sonde did not measure chlorophyll.

Sondes are remote water quality measuring units, which are comprised of a probe placed in a waterbody and a unit that collects and transmits data in real time. Data is cleaned prior to analysis by omitting erroneous measurements caused by probe fouling or sensor malfunctions.

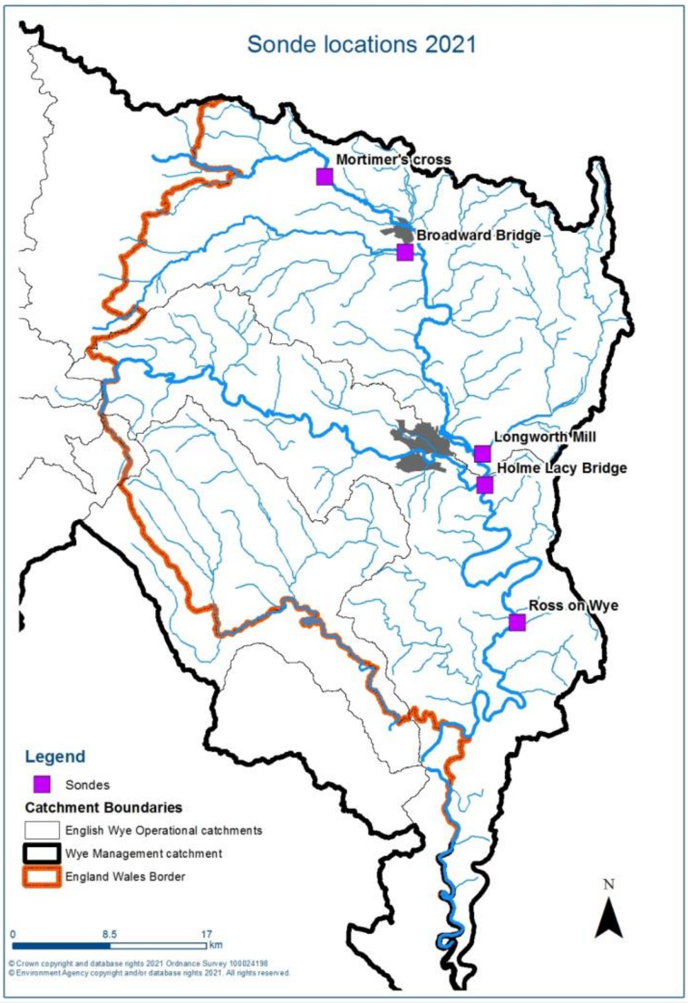


Figure 2: Locations of sondes deployed in 2021 that were used in this analysis.

Algal samples

A limited number of river water samples and riverbed algal samples were collected at the same time during periods of high algal growth on the River Wye at Holme Lacy. These were subsequently analysed to determine the species of algae present.

Macrophyte Surveys

During 2021, 13 macrophyte surveys were conducted (Figure 3) and 8 Weight of Evidence of Eutrophication (WoE) surveys were attempted.

The Environment Agency’s macrophyte data is available as open data on the EA Ecology & Fish Data Explorer

Macrophytes are plants and algae visible to the naked eye. The macrophyte community in a section of river (100m of channel length for a standard survey) provides information about physical and water quality, with a particular emphasis on eutrophication.

Weight of Evidence surveys are used to target point source discharges of phosphate suspected to be polluting a river and determine whether an impact on the ecological quality is associated with them. Ideally, WoE surveys consist of paired macrophyte surveys upstream and downstream of a phosphate discharge to provide a direct comparison. However, this isn’t always possible, and other methods such as Rapid Assessment of PeriPhyton Ecology in Rivers (RAPPER) surveys or expert observation of the ecological condition are carried out instead. Macrophyte and RAPPER surveys require largely unshaded sites. Heavily shaded sites are not suitable for demonstrating the impact of eutrophication.

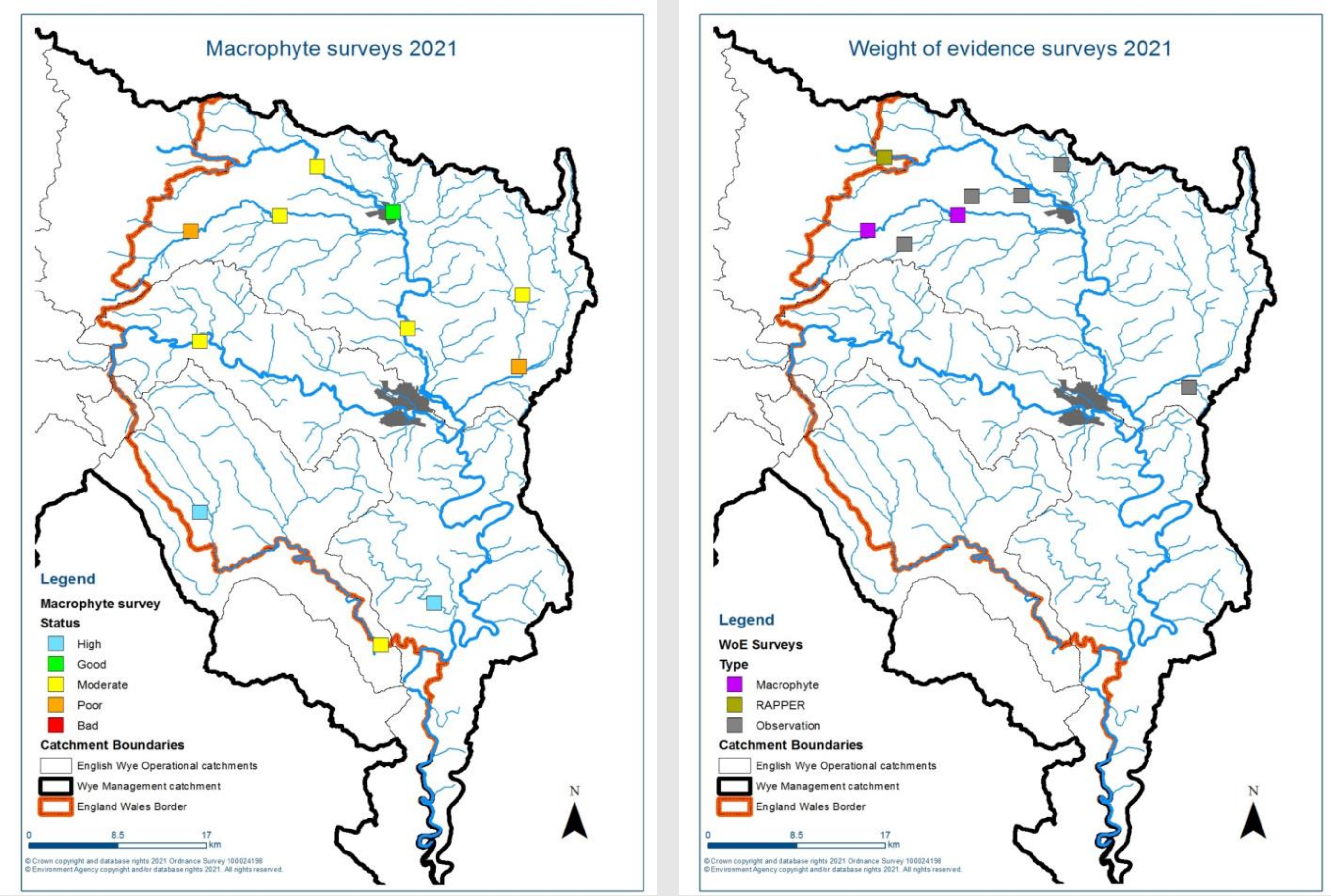


Figure 3: 2021 Macrophyte and Weight of Evidence Surveys

Routine Water Quality Sampling

The Environment Agency's water quality data is available as open data on the Water Quality Data Archive.

The water quality parameters analysed for this the report were orthophosphate (also known as soluble reactive phosphate), ammonia, dissolved oxygen and total oxidised nitrogen (TON).

Fish Surveys

The Environment Agency's fish data is available as open data on the EA Ecology & Fish Data Explorer

Three types of electric fishing surveys have been undertaken in the Wye catchment during 2021, as follows:

- Quantitative surveys
    - Catch-depletion sampling. A formula is applied to the catches from a multiple removal survey to calculate a population estimate for each species caught

- Qualitative surveys
    - Single catch survey that will produce observed fish densities but not population estimates
- Catch Per Unit Effort/Timed (CPUE/T)
    - Where results obtained are expressed as numbers or weights of fish caught per minute. Surveys are carried out in habitat suitable for juvenile salmon (i.e. shallow riffles). Timed surveys can be used to obtain qualitative abundance data on fish populations.

Thirty sites were surveyed in 2021 (Figure 4).

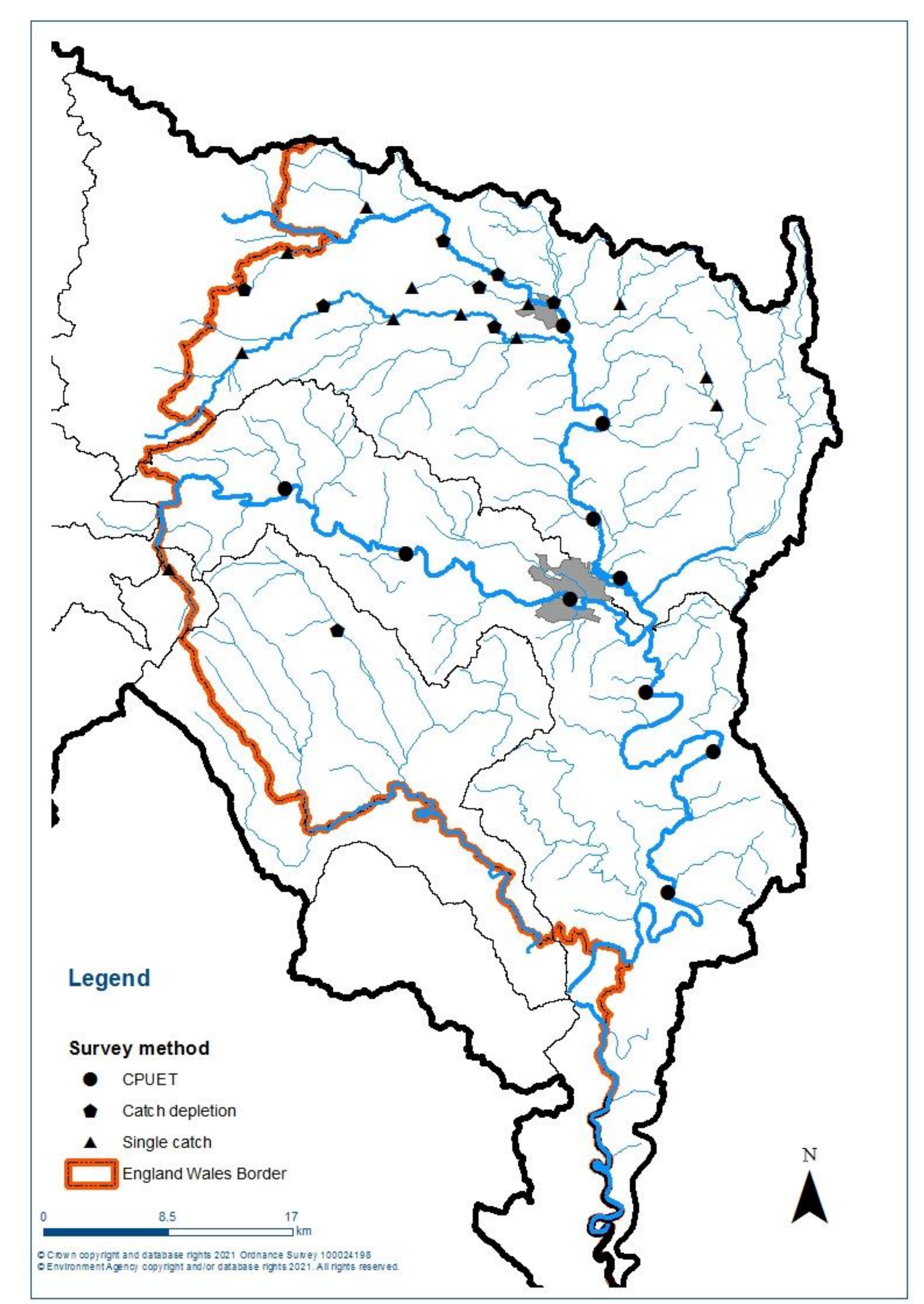


Figure 4: Environment Agency fish surveys undertaken in 2021.

Invertebrates

The Environment Agency's macroinvertebrate data is available as open data on gov.uk

EA Ecology & Fish Data Explorer

Crop Map of England

Since 2016 the Rural Payments Agency has been using satellite imagery collected by the European Space Agency's Sentinel network to annually classify agricultural land use in England. The project is known as CROME (Crop Map of England) and assigns crop types using a machine learning approach called Random Forest Classification. Large validation efforts were undertaken to ensure reasonable accurate classification of crop types, with approximately 18300 field visits conducted to validate the crop assignments generated by the classification system.

To generate crop cover area England has been divided into approximately 32 million equally sized hexagonal tiles, each 4156 square meters (0.42 hectares) in area. The English portion of the Wye catchment contains approximately 452,000 tiles, each individually assigned a cover type.

Although CROME classifies arable land by individual crop, with the exceptions of maize and potato, crops have been aggregated into mixed arable for this report to account for crop rotation cycles and to simplify analysing changes in land use. The cover of permanent grassland, woody plants (trees, shrubs and hedgerows), non-agricultural/sparsely vegetated land, and open water were also classified. This had made it possible to compare changes in rural land cover between 2016 and 2020. There are some caveats around overall accuracy of the classification, with it predicted to be 84% accurate in 2016 and 70% accurate in 2020. However, due to the large number of classification tiles, this still makes it possible to observe overall changes in land use with reasonable confidence.

UKCEH (UK Centre for Ecology & Hydrology) Land Cover Map 2019

The UKCEH Land Cover Maps show land cover across Great Britain using UKCEH Land Cover Classes. These are based on UK Biodiversity Action Plan broad habitats.

The 2019 dataset (Morton, et al., 2020) was developed by the UK Centre for Ecology & Hydrology by classifying satellite images from 2019.

National Soil Map

The National Soil Map is produced by Cranfield University (National Soil Resources Institute, 2001) and was last updated in 2013. It details soil associations across England and Wales and includes typical characteristics of soil series in each association.

Environment Agency remote sensing analysis of poultry units

During 2021 the Environment Agency analysed current and historic LIDAR data alongside available permit data to identify possible poultry units and assess change. This analysis is exploratory and subject to change so is not currently available as open data.

Environment Agency permitted discharge outlets

These data provide details of all permit details as required under the Environmental Permit Regulation. Information is held for all permit holders and covers all substances that are controlled.

The dataset is available as open data on the Defra Data Services Platform.

Natural Resources Wales permitted discharge outlets

These data provide details of all permit details as required under the Environmental Permit Regulation. Information is held for all permit holders and covers all substances that are controlled.

The dataset is available as open data on the Lle Geo-Portal for Wales.

Welsh Water combined sewer overflows

Welsh Water/ Dwr Cymru monitor their combined sewer overflows and report spills as Event Duration Monitoring. These reports include the site, number of spill incidents per year, number of hours spilled and percentage outage in the monitoring.

Analysis Methods

We have used the following exploratory, statistical, and spatial methods in this analysis.

Time series analysis

Parameters associated with algal blooms were combined on single time series plots, where each parameter was available; particularly, temperature, dissolved oxygen, chlorophyll, orthophosphate as P, total oxidised nitrogen as N and daily mean flow. The flow gauging station, monthly sampling point and sonde location were matched based on proximity and how representative the sites were.

River Macrophyte Nutrient Index

Macrophyte surveys are classified using the River Macrophyte Nutrient Index (RMNI) to determine observed condition of the plant community compared to that predicted to be present if no human impacts were occurring. Phosphate is a key plant nutrient and elevations in phosphate levels are the primary cause of eutrophication in freshwater. This index forms part of the WFD classification methodology for macrophytes.

Indicative Water Framework Directive (WFD) Classifications

Where sufficient data has been collected in 2021 for quality elements that are assessed under WFD, indicative WFD classifications have been produced using this recent data. These are not formal classifications but allow comparisons with the 2019 formal classification. An update to the formal classifications is scheduled for 2022 and the next full classification is scheduled for 2025.

Rapid Assessment of PeriPhyton Ecology in Rivers (RAPPER)

RAPPER surveys (Kelly, et al., 2016) involve identification of macroalgae to genus level and classification of taxa based on their preference for low or high nutrient concentrations. This gives an indication of whether a location is at risk from eutrophication.

Spatial Mapping

Plotting each data source on a map of the River Wye Management Catchment allows a comparison of the results for each Operational Catchment or Waterbody. This helps locate the sources and pathways of ecological and water quality problems identified.

Watershed analysis

The potential sources of nutrients for each sampling point have been analysed. A watershed analysis was carried out to determine the area that drains to each sampling point, which was overlaid with the following datasets to obtain summary statistics:

- RPA Crop Map of England 2018-2020
- UKCEH Land Cover Map 2019
- Environment Agency remote sensing analysis of poultry units in 2021
- Environment Agency permitted discharge outlets
- Natural Resources Wales permitted discharge outlets
- Welsh Water combined sewer overflows
- National Soil Map

These summary statistics were plotted against the measurements for reactive orthophosphate as P, total phosphorus as P and total oxidised nitrogen as N.

Fish survey analysis

Data for the period 2010-2021 have been reviewed where available and comparable. The target guild for the English Wye management catchment surveys over this time period are salmonid species, typically Atlantic salmon and brown trout.

When analysing data from previous years the following issues are of note:

- Survey length in 2010 was less than 50m for the catch depletion sites that were surveyed. Surveys since then have usually been 100m in length. Whilst this should not affect the population density estimates directly, specific juvenile habitat has been targeted (i.e., shallow riffles). Where a larger area is surveyed it is unlikely to contain the same riffle habitat throughout and consequently the presence of salmonid species may be reduced through a change in habitat type. This will then impact on the estimated densities
- It is only possible to compare sites that have been surveyed using the same methodology i.e., catch depletion surveys (quantitative) can only be compared to other catch depletion surveys. In this instance, due to the different purposes that have required a fish survey at a site since 2010 this has resulted in limited quantitative surveys in the Wye catchment.

Invertebrate analysis

The macroinvertebrate indices reviewed in this report are based on the WHPT Average Score Per Taxon (ASPT) and Number of Taxon (NTaxa). These indices are compared to predicted scores for each site to produce a WFD classification using the River Invertebrate Classification Tool (RICT).

Results

The results section of this report is divided into three sections to answer the questions posed at the start of this analysis.

1. What are the main variables contributing to algal blooms in the Wye?
2. What other ecological and water quality issues does the data show?
3. Which locations, sectors and activities were responsible for the ecological and water quality issues identified in the data?

1. What are the main variables contributing to algal blooms in the Wye?

Increases in chlorophyll and dissolved oxygen (DO) levels detected by sondes at Holme Lacy (Figure 5) and Ross on Wye (Figure 6) indicate two periods of increased photosynthesis on the River Wye during the summer. This signals periods of increased algal growth. The combination of sustained peaks in chlorophyll and highly elevated DO levels (>120% saturation) was not observed in the data collected by sondes in the Arrow, Lugg and Frome catchments.

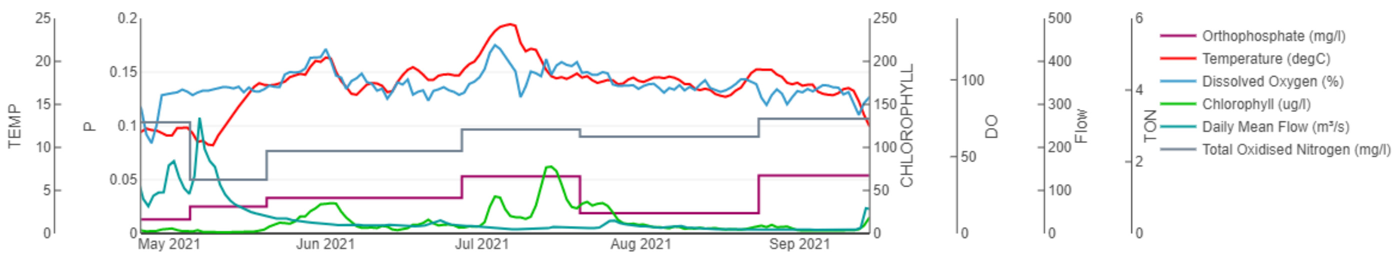


Figure 5: Holme Lacy daily mean sonde data, Holme Lacy Bridge monthly orthophosphate and total oxidised nitrogen measurements and Redbrook daily mean flow data.

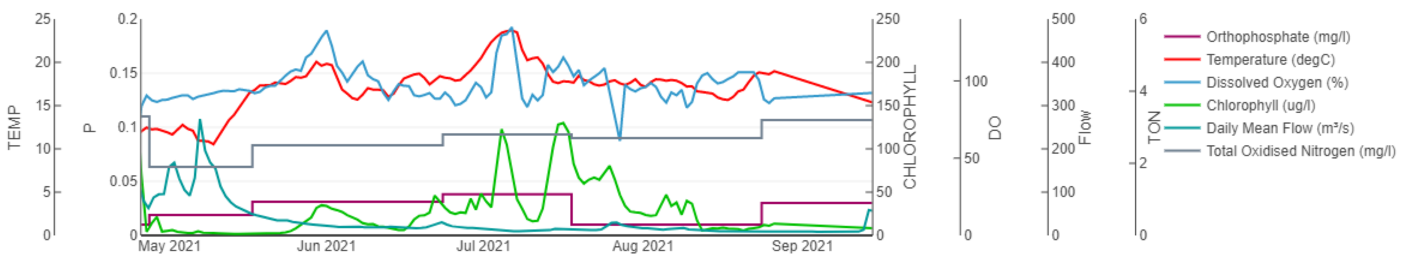


Figure 6: Ross on Wye daily mean sonde data, Wilton Bridge monthly orthophosphate and total oxidised nitrogen measurements and Redbrook daily mean flow data.

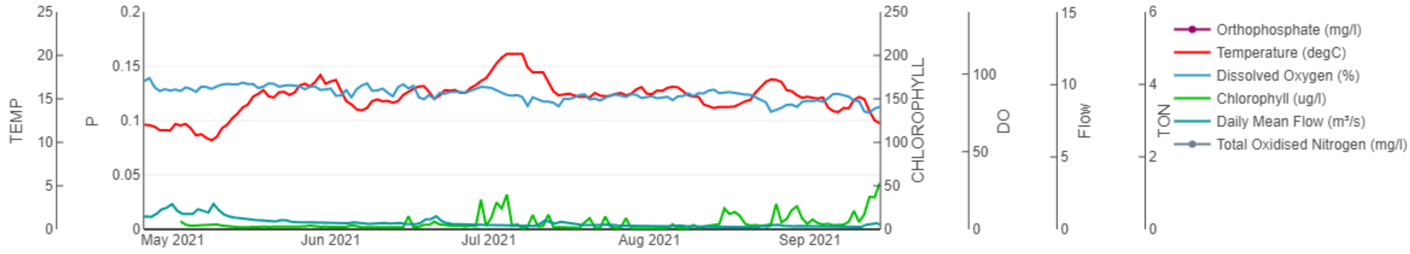


Figure 7: Frome Longworth Mill daily mean sonde data and Yarkhill daily mean flow data. Representative monthly orthophosphate and total oxidised nitrogen measurements were not available for this site over this time period.

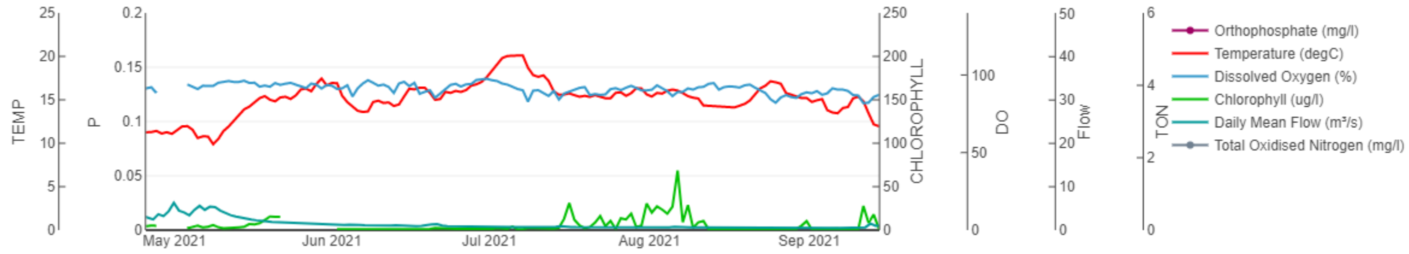


Figure 8: Arrow Broadward Bridge daily mean sonde data and Titley Mill daily mean flow data. Representative monthly orthophosphate and total oxidised nitrogen measurements were not available for this site over this time period.

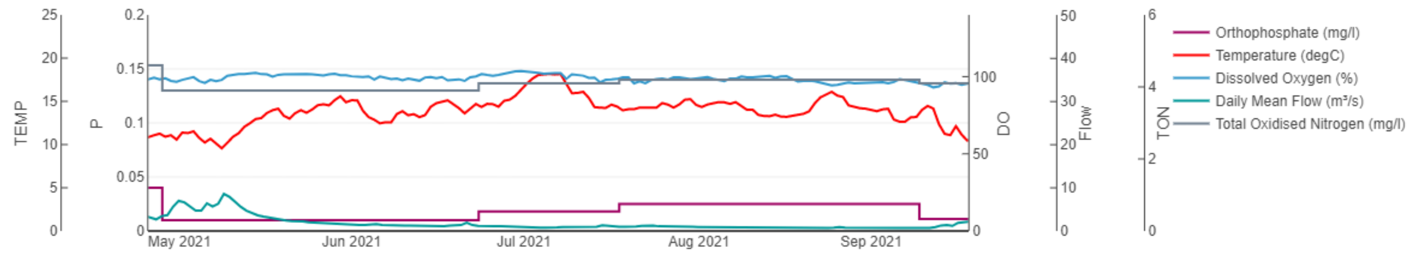


Figure 9: Lugg Mortimers Cross daily mean sonde data, monthly orthophosphate and total oxidised nitrogen measurements and Yarkhill daily mean flow data. There was no chlorophyll sensor on this sonde.

During regular maintenance visits and other survey work in the Wye catchment, a variety of filamentous algal taxa were observed (Figure 10) as was the colonial diatom *Melosira*, which forms slimy chains of individual cells embedded in mucilage, effectively growing as a filamentous species. River water samples were collected at the same time as algae were collected from the channel bed, and little or no planktonic (free floating) species of algae were found to be present in the water samples. The filamentous algae growing on the channel bed gave the water a green appearance but the water column itself was relatively clear when inspected closely (Figure 11). The proximity of the sonde probes to the riverbed mean that the chlorophyll peaks could have been caused by benthic (riverbed) filamentous algal growth, but it is not possible to definitively identify the relative contribution of benthic vs planktonic algae to the chlorophyll readings. Additional targeted sampling of planktonic algae is required to understand this.

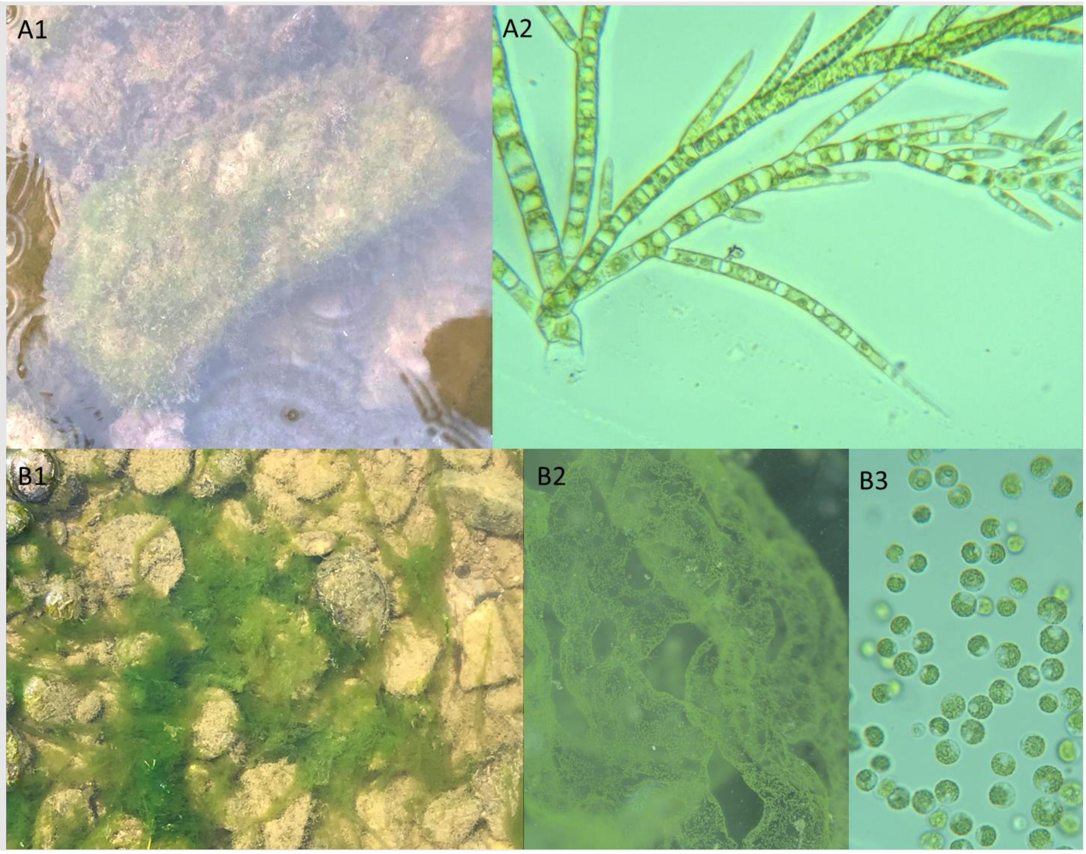


Figure 10: A: Stigeoclonium sp. present at Hoarwithy Bridge, River Wye, 29/04/2021; A1: in situ, A2 400x magnification. B: palmella forming alga, possibly Chlamydomonas sp. Present near Holme Lacy Bridge, River Wye 21/07/2021; B1: in situ, B2 10x magnification, B3 400x magnification.

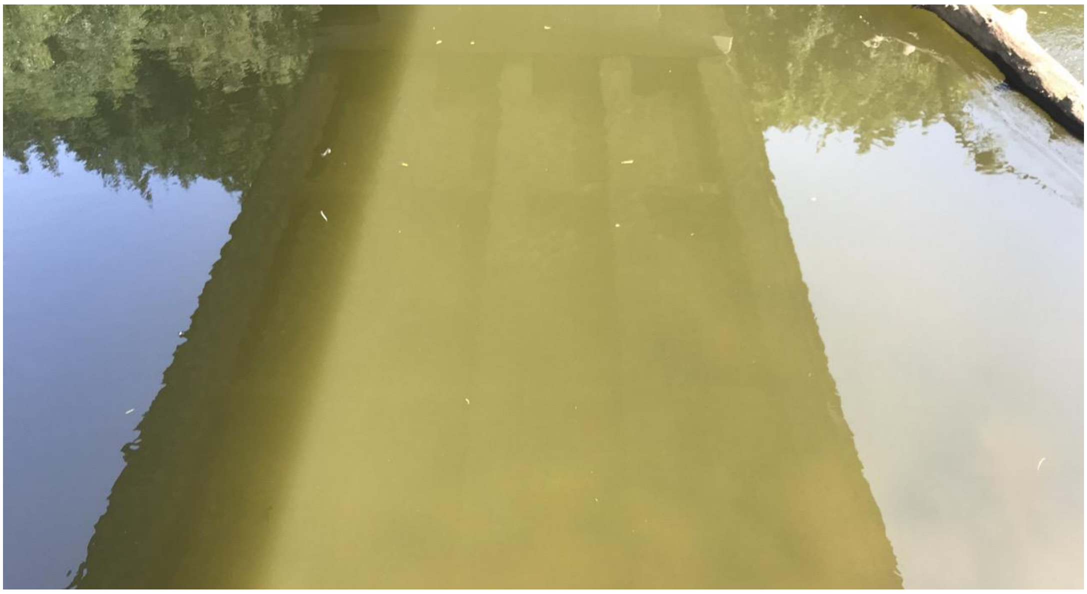


Figure 11: Benthic growth giving the appearance of green coloured water near Holme Lacy Bridge, River Wye, 21/07/2021. The water itself was actually relatively clear upon inspection.

There is a relationship between chlorophyll, DO and temperature levels present on the River Wye, which is either absent or inconclusive on the sondes present on the tributaries. When daytime peaks in temperature approach or exceed 20^{o}C, DO supersaturation and chlorophyll peaks are at their highest.

This suggests that high summer temperatures on the Rive Wye are one of the key drivers of prolific algal growth. Recorded temperatures in the tributaries were consistently lower than those recorded on the Wye, and no periods of DO supersaturation exceeding 120% or sustained periods of increased chlorophyll levels were recorded on the tributaries. Much of the English section of the River Wye is wide, relatively shallow and largely unshaded, which makes it susceptible to temperature increases.

Both phosphorus and nitrogen play a role in river eutrophication, although the main limiting nutrient in freshwater river systems is usually phosphorus. This is most likely the case for the River Wye, as all sampling points fall within the zones where phosphate is typically the limiting nutrient (Mainstone & Parr, 2002) (Figure 12).

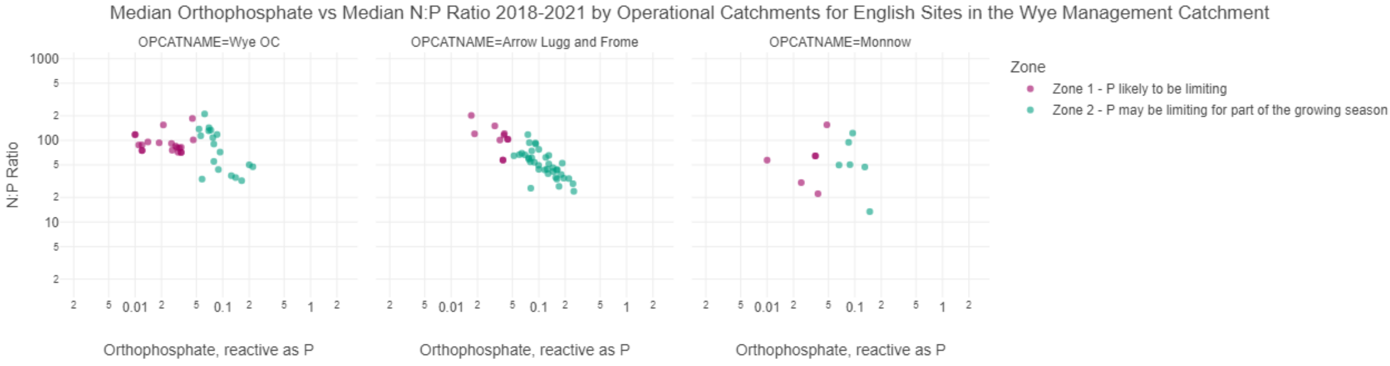


Figure 12: Median orthophosphate as P plotted against median N:P ratio (Total Inorganic Nitrogen as N:Orthophosphate as P) by Operational Catchment for Environment Agency sampling points in the Wye Management Catchment. Colours by zone of typical nutrient limitation (Mainstone & Parr, 2002). Note log scales.

Available monthly phosphate and nitrogen data for 2021 for Ross on Wye and Holme Lacy generally fall into the zone where phosphate would usually limit plant growth (orthophosphate <0.05mg/l and N:P ratio >8 (Mainstone & Parr, 2002)). None of the sampling points fall into zones where nitrogen would typically limit plant growth. Excess nutrients in the water column do not therefore appear to be the most important trigger for the algal growth. Additional forms of nutrient monitoring such as sediment analysis are needed to explore the role that other sources of nutrient uptake play.

July and September monthly orthophosphate measurements at Holme Lacy Bridge do exceed the 0.05mg/l threshold by a small amount, so higher time resolution phosphate monitoring could also contribute to an improved understanding of the role of nutrients in this algal growth.

2. What other ecological and water quality issues does the data show?

Macrophyte indicators of eutrophication

The majority of macrophyte sites surveyed in 2021 were classified at less than Good indicative status, suggesting that eutrophication is adversely impacting most sites surveyed within the Wye Management Catchment, despite a lack of algal bloom signals detected by the sondes outside the main River Wye. All the sites that achieved Good or High status were located in shaded sections of channel (Figure 3), which is likely to have mitigated against eutrophication. It is possible that sediments in the channel bed are providing a source of phosphate leading to eutrophication that it isn't detected via water sampling. Sediment sampling should be explored to fill this gap in understanding.

The WoE macrophyte surveys on the River Arrow both displayed clear evidence of ecological impact from sewage treatment works' effluent, with the upstream survey sites achieving Good and the downstream Moderate or Poor ecological status. Water crowfoot (*Ranunculus* subgenus *Batrachium*), a characteristic species group of fast-flowing unpolluted rivers, was observed smothered in *Melosira,* an alga considered indicative of eutrophic conditions downstream of the discharges. Whereas upstream, largely clean stands of crowfoot were observed (Figure 13).

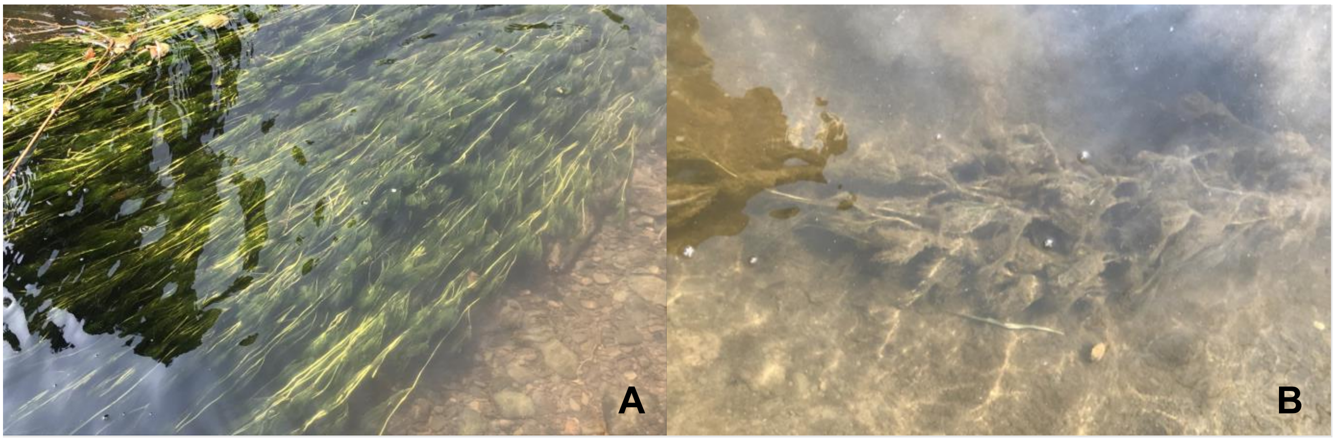


Figure 13: A, water crowfoot from WoE survey upstream of a discharge on the River Arrow; B, water crowfoot downstream of the same discharge, 21/07/2021.

In conclusion, there is evidence of eutrophication impacting the macrophyte communities present at most sites surveyed.

Trends in water quality

Figure 14 shows the individual sampling point status for phosphate in the formal 2019 WFD classification and the indicative status using the most recent data (01/01/2019 to 31/10/21). While sites along the main River Wye continue to pass for phosphates for WFD or show a potential improvement and continue to comply with the SAC targets, several tributaries in the wider catchment continue to fail WFD objectives or show a potential deterioration. Most of these are tributaries of the Arrow, Lugg or Frome.

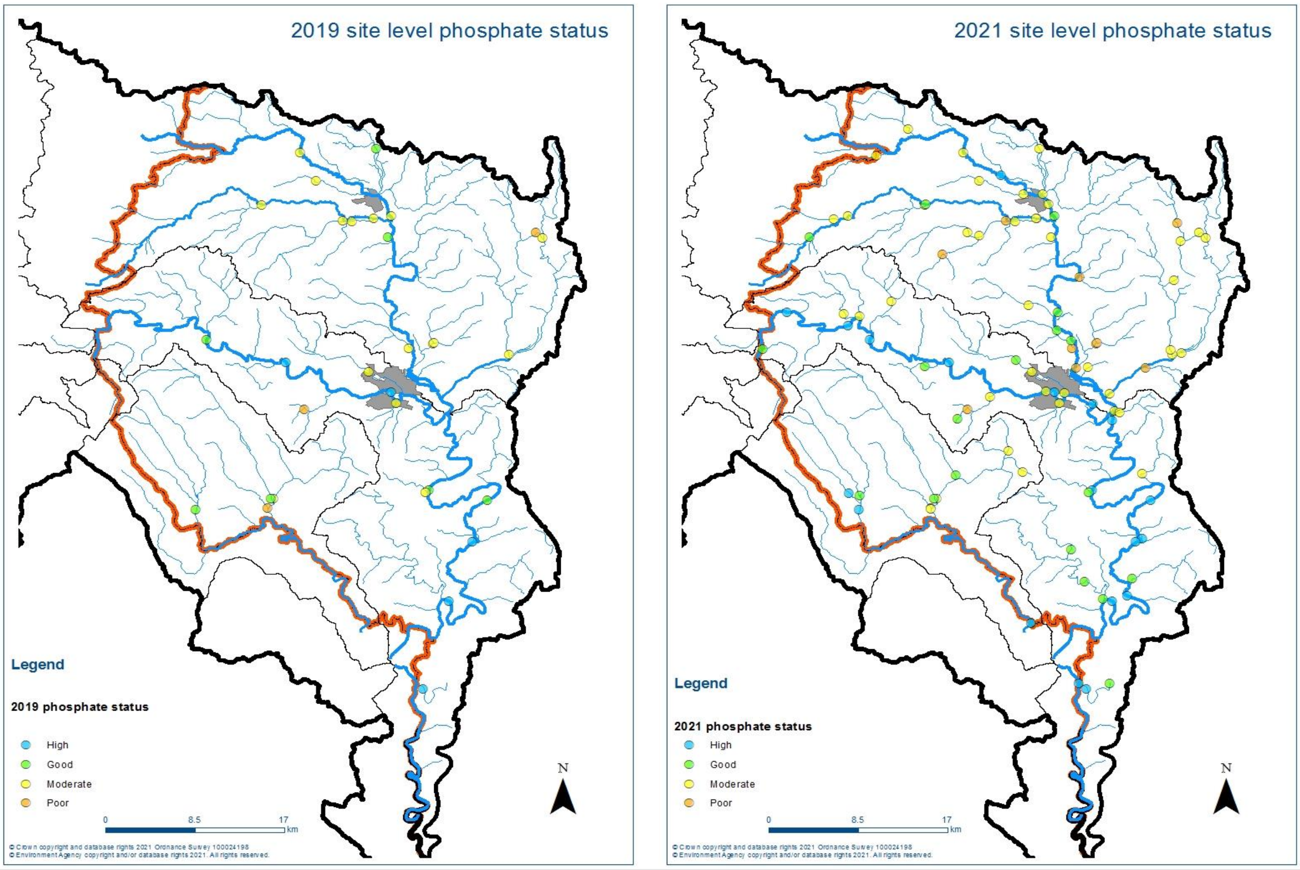


Figure 14: Most recent indicative status for phosphate calculated for sites within the Wye catchment compared to 2019 WFD waterbody classification for phosphate.

Trend analysis indicates that there are a number of sites that have seen a significant statistical increase in phosphates in the monitoring period of 2010 to 2021, in particular the Arrow, Lugg and Frome catchments. Other sites have shown a significant decrease in the levels of phosphate, mainly on the main Wye. The locations of significant increasing trends in orthophosphate do not correspond exactly to the locations where significant algal growth has been detected. The increasing trends in the Arrow, Lugg and Frome Catchments do contribute to the orthophosphate concentrations on the main Wye but there is no similar statistically significant increase over time in the water column of the larger river.

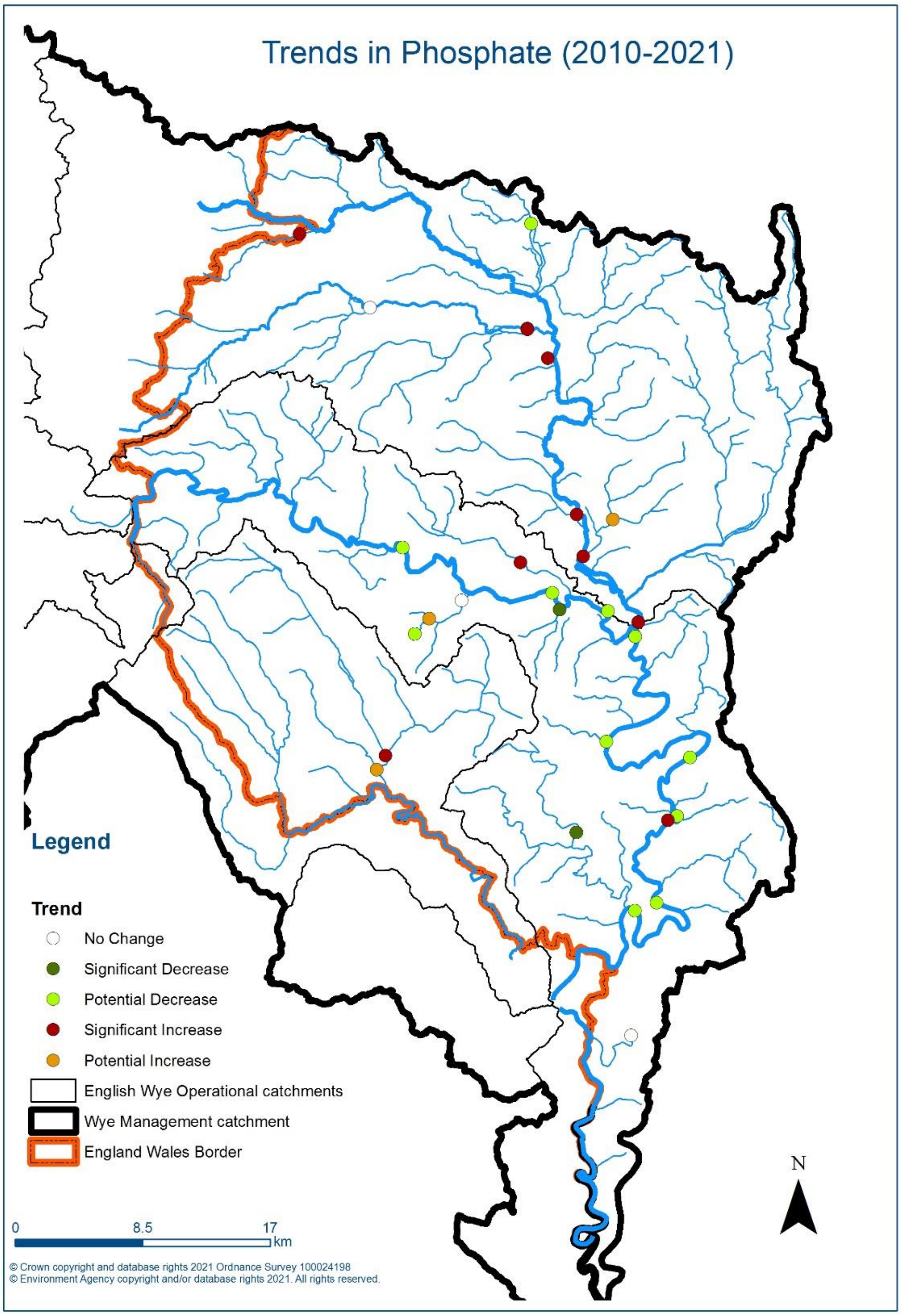


Figure 15: Trends in orthophosphate as P in the Wye Management Catchment 2010-2021

Maps showing indicative WFD status for dissolved oxygen (Figure 16) and ammonia (Figure 17) are displayed below. The majority of sites are indicative of High status for both dissolved oxygen and ammonia. At present there are no WFD or SAC targets for nitrogen. Mean values for total oxidised nitrogen for sites in the Wye catchment are shown in Figure 18

For dissolved oxygen, twelve sites were indicatively classified at less than Good status, nearly all of which fall within small tributaries of the Arrow, Lugg or Frome.

For ammonia, only one site on the Bodenham Brook was at less than Good indicative status using the most recent data. The vast majority of sites were indicatively classified as High status.

Trend analysis shows that lot of sites across the whole catchment have seen a statistically significant increase in total oxidised nitrogen between 2010-2021 (Figure 18).

Total oxidised nitrogen concentrations in the Wye Management Catchment tend not to show a seasonal trend, in contrast to orthophosphate, which results in the N:P ratio decreasing during the summer as orthophosphate concentrations increase.

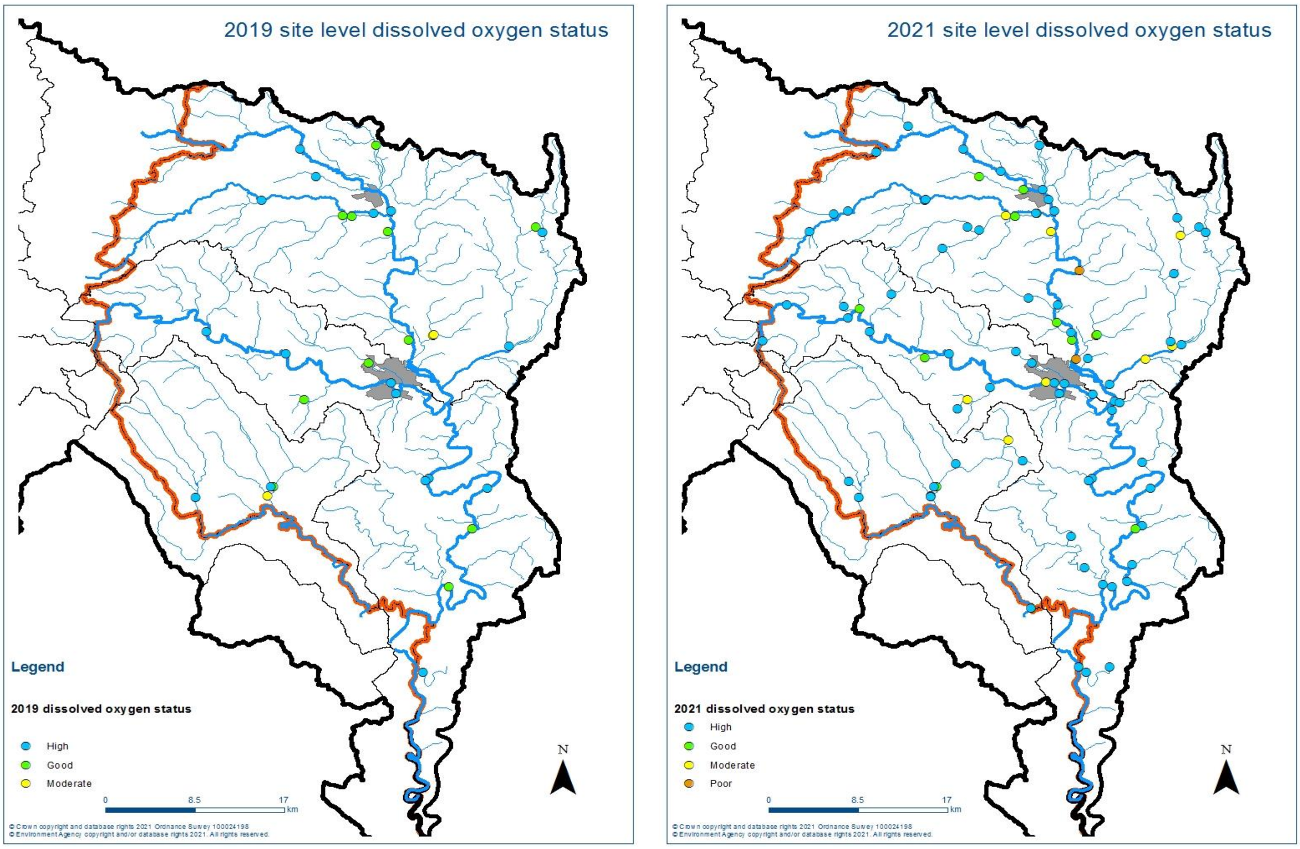


Figure 16: Most recent indicative status for dissolved oxygen calculated for sites within the Wye catchment compared to 2019 WFD waterbody classification for dissolved oxygen.

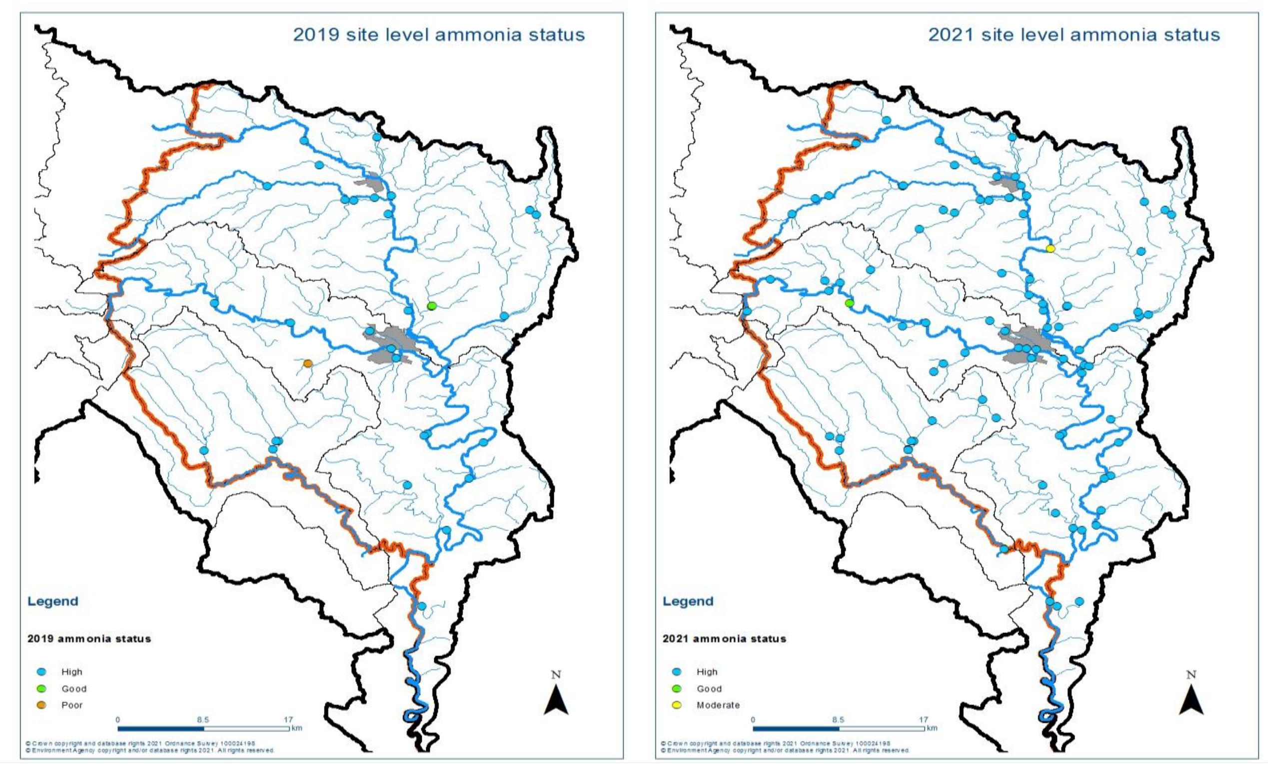


Figure 17: Most recent indicative status for ammonia calculated for sites within the Wye catchment compared to 2019 WFD waterbody classification for ammonia.

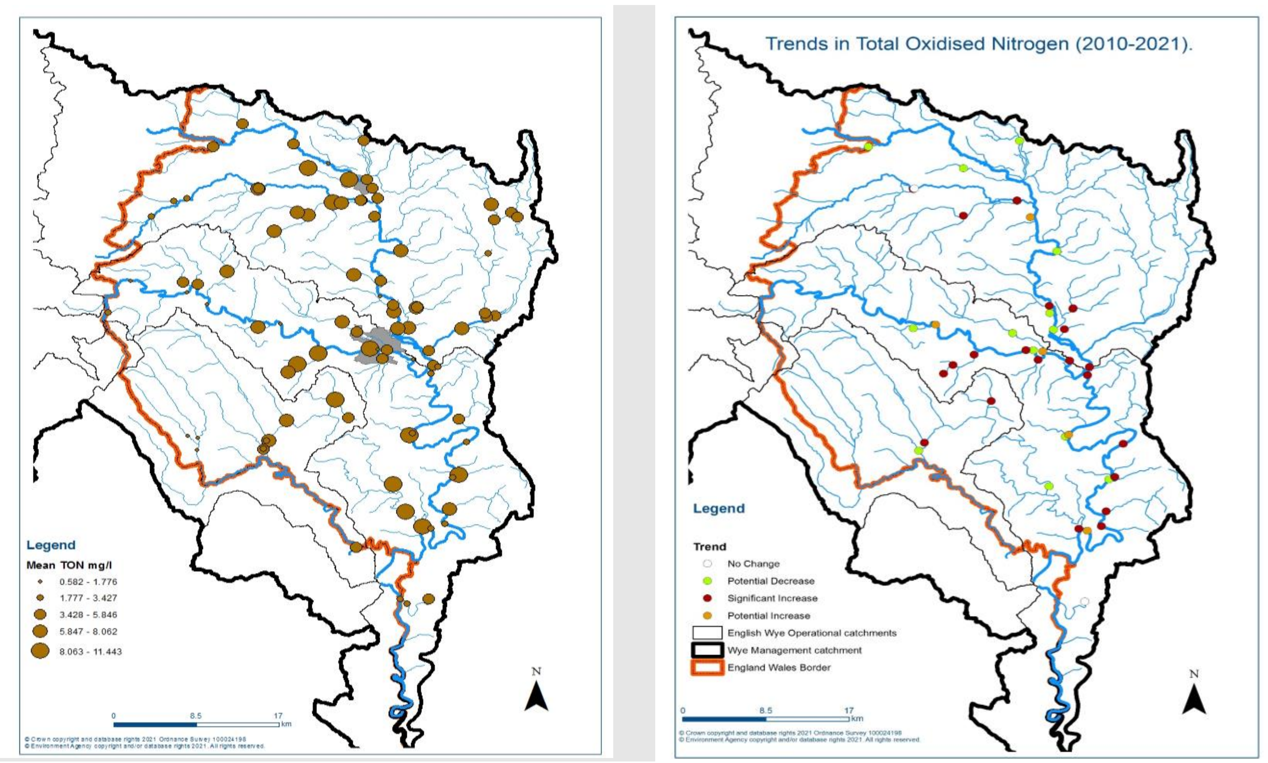


Figure 18: Mean total oxidised nitrogen in the Wye Management Catchment between 2019-2021 and trends between 2010-2021.

Salmonid fish populations

Extreme DO supersaturation can be indicative of nightly crashes of DO levels that are sufficient to harm aquatic life such as salmon and trout. It is clear from the Wye datasets (Figure 5, Figure 6, Figure 7, Figure 8, Figure 9 & Figure 19) that this was not an issue where the sondes were deployed, with readings only once falling below 60% saturation and generally remaining above 80%, which is more than adequate for salmonid fish.

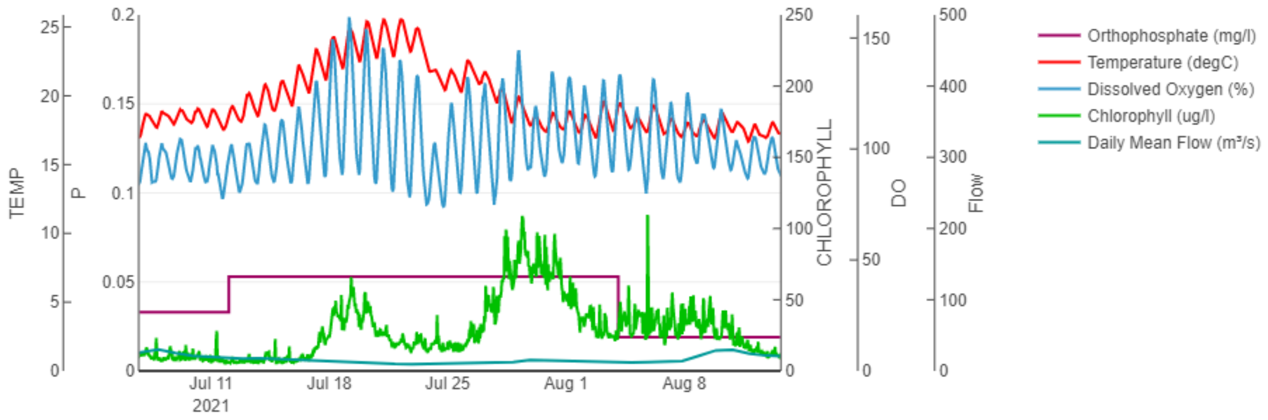


Figure 19: 30-minute data from sonde at Holme Lacy showing excessively high temperatures and dissolved oxygen supersaturation but not the typical nightly crashes in dissolved oxygen to harmful levels.

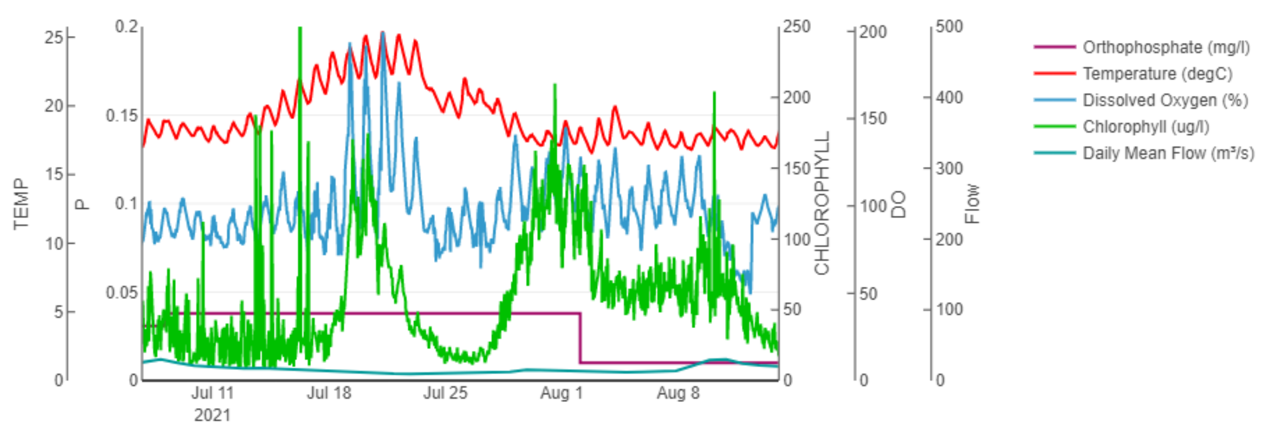


Figure 20: 30-minute data from sonde at Ross-on-Wye showing excessively high temperatures and dissolved oxygen supersaturation but not the typical nightly crashes in dissolved oxygen to harmful levels.

However, temperatures exceeding 20-21^{oC} cause heat stress in salmon and trout and several reports and observations of distressed and dying salmon were made during the summer of 2021, including a lethargic female salmon showing visible signs of secondary fungal infections and general poor condition believed to be caused by heat stress near Kinnersly in July (Figure 21).

Figure 21: Lethargic female salmon with fungal infections in River Wye, 26/07/2021.

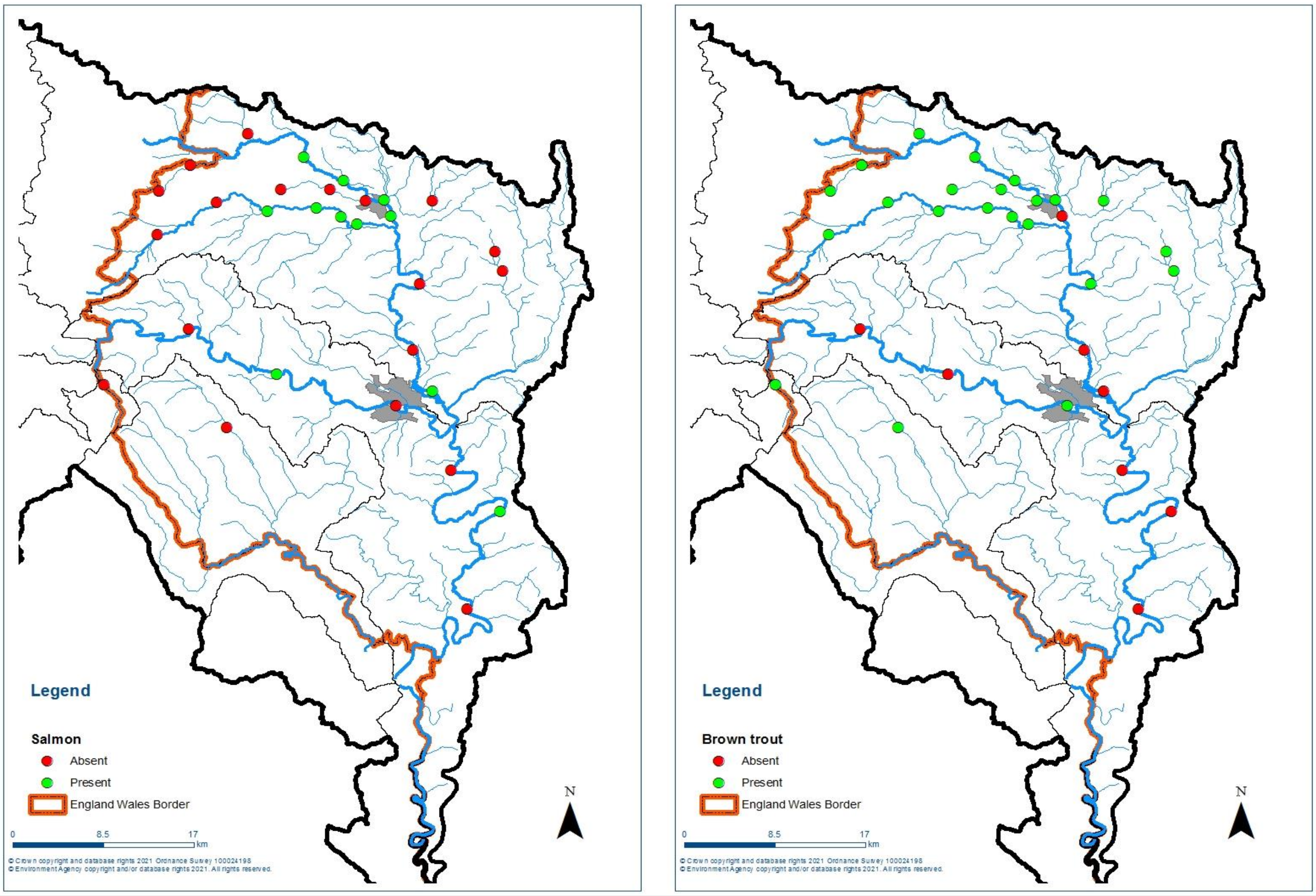


Figure 22: Distribution of Atlantic salmon and Brown trout in the Wye catchment in 2021

Brown trout were caught at 22 of the 30 survey sites in 2021 whilst Atlantic salmon were caught at 11 sites. Figure 22 presents the distribution of Atlantic salmon and brown trout for the surveys conducted in the English Wye operational catchments in 2021.

Brown trout density varied across the catchments, with the smaller tributaries seeing the highest densities recorded. Age classes were well represented overall.

The highest Atlantic salmon density (5.12 fish/100m²) was recorded at the River Lugg - Mortimers Cross survey site and evidently the river supports a breeding population. The species was also observed in the River Arrow at four of the five sites surveyed however densities of Atlantic salmon at all other sites were below 1 fish/100m² or absent.

The National Fisheries Classification Scheme is used by Natural Resources Wales and Natural England to evaluate juvenile salmonid populations in a consistent manner to compare sites in England and Wales. Figure 23 and Figure 24 map out the grades from A to F for surveys undertaken in 2021 within the Wye catchment (catch depletion and single run surveys only). All the Atlantic salmon results within the Wye are either E (Poor) or F (Fishless). There are slightly better results for brown trout with three sites classed at C (Fair) for 0+ brown trout (Hindwell, Lime Brook and Dulas Brook).

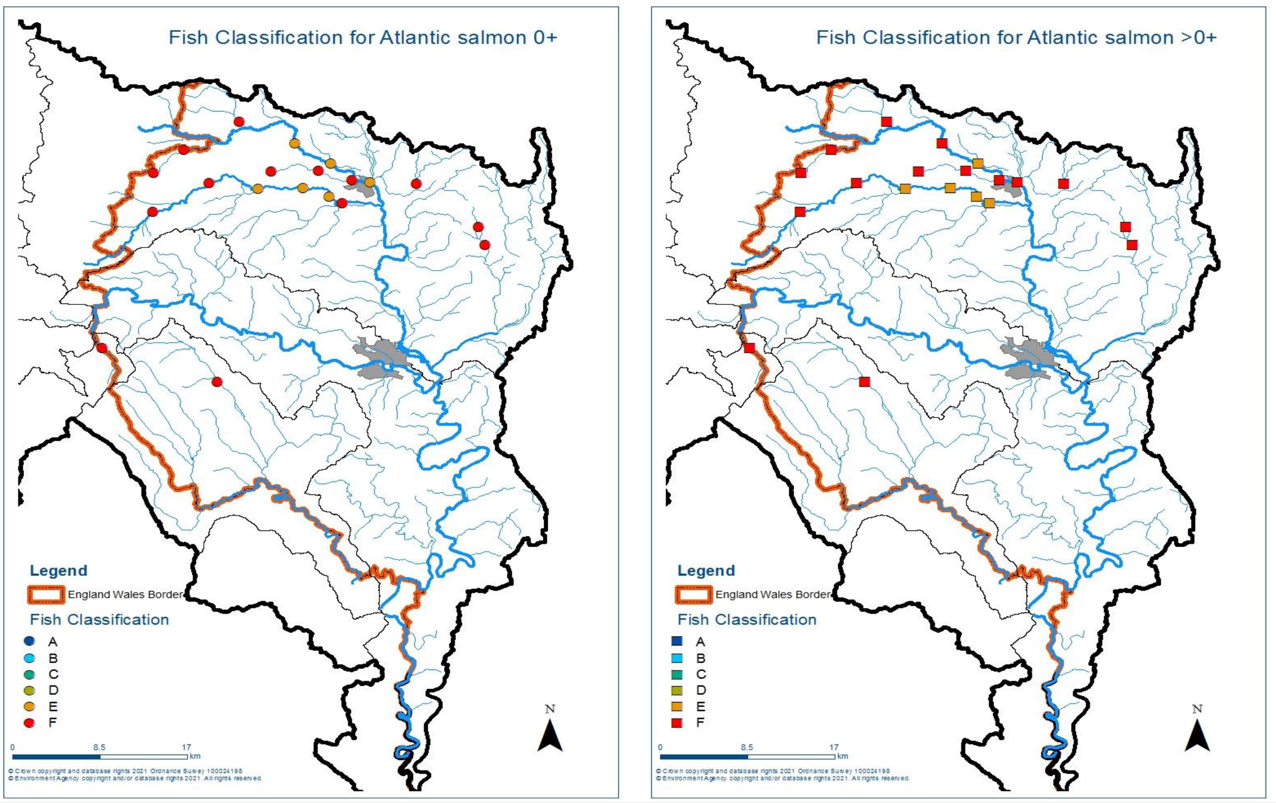


Figure 23: National Fish Classification grades for Atlantic salmon caught during catch depletion and single run surveys undertaken in 2021

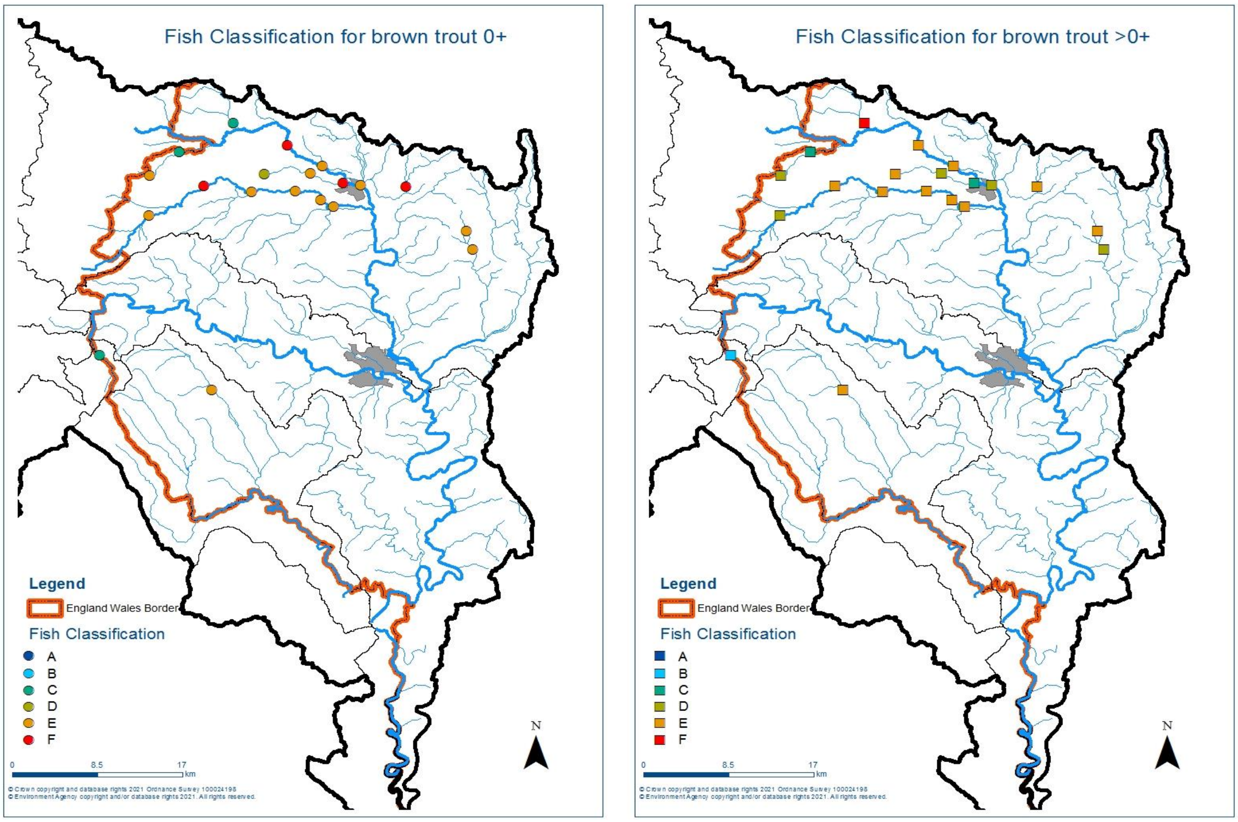


Figure 24: National Fish Classification grades for brown trout caught during catch depletion and single run surveys undertaken in 2021

Results for surveys undertaken since 2010 are varied for brown trout and Atlantic salmon (Figure 25, Figure 26 & Figure 27). Both species have seen a decrease in density observed over time. The exceptions being the River Lugg - Leominster Market and Dulas Brook - W110j (for brown trout), and the River Lugg at Mortimers Cross and Leominster Market (for Atlantic salmon). Pinsley Brook at Cobnash has recorded the most substantial drop in brown trout density over the time period whilst the most significant decrease in Atlantic salmon density is observed at Dulas Brook – W110j, where 2014 data (Figure 28) shows the species represented at the same density as brown trout, and none were captured in 2021 (Figure 29).

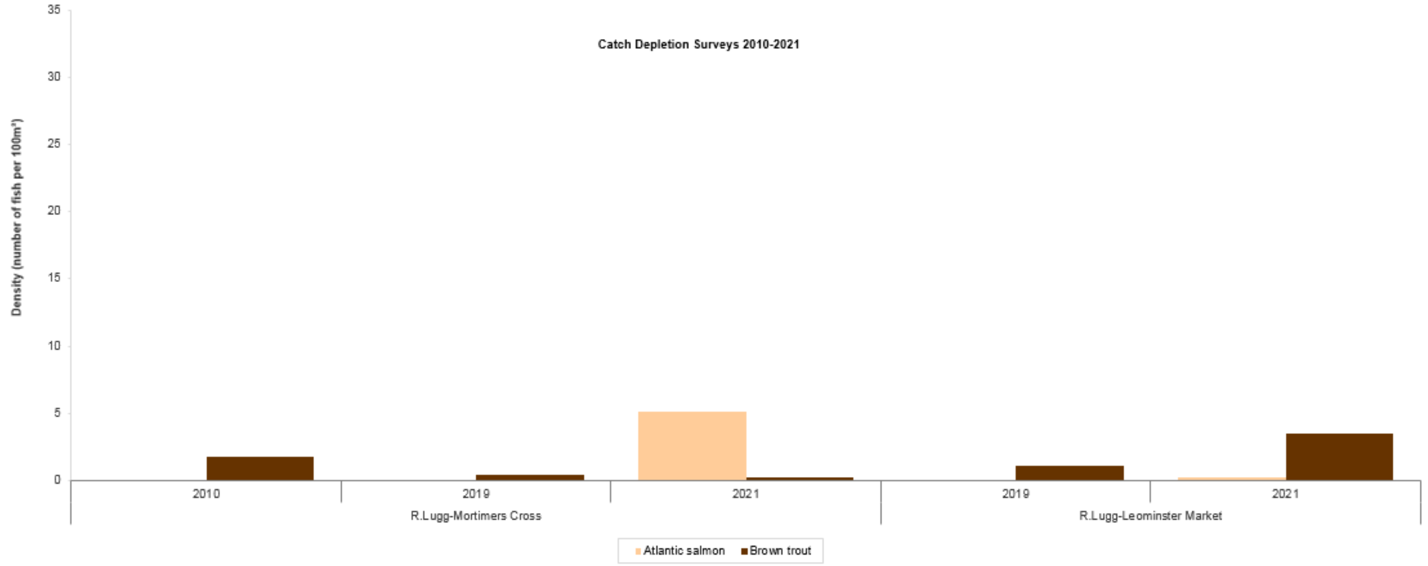


Figure 25: Population density estimates (number of fish per 100m²) between 2010 and 2021, River Lugg.

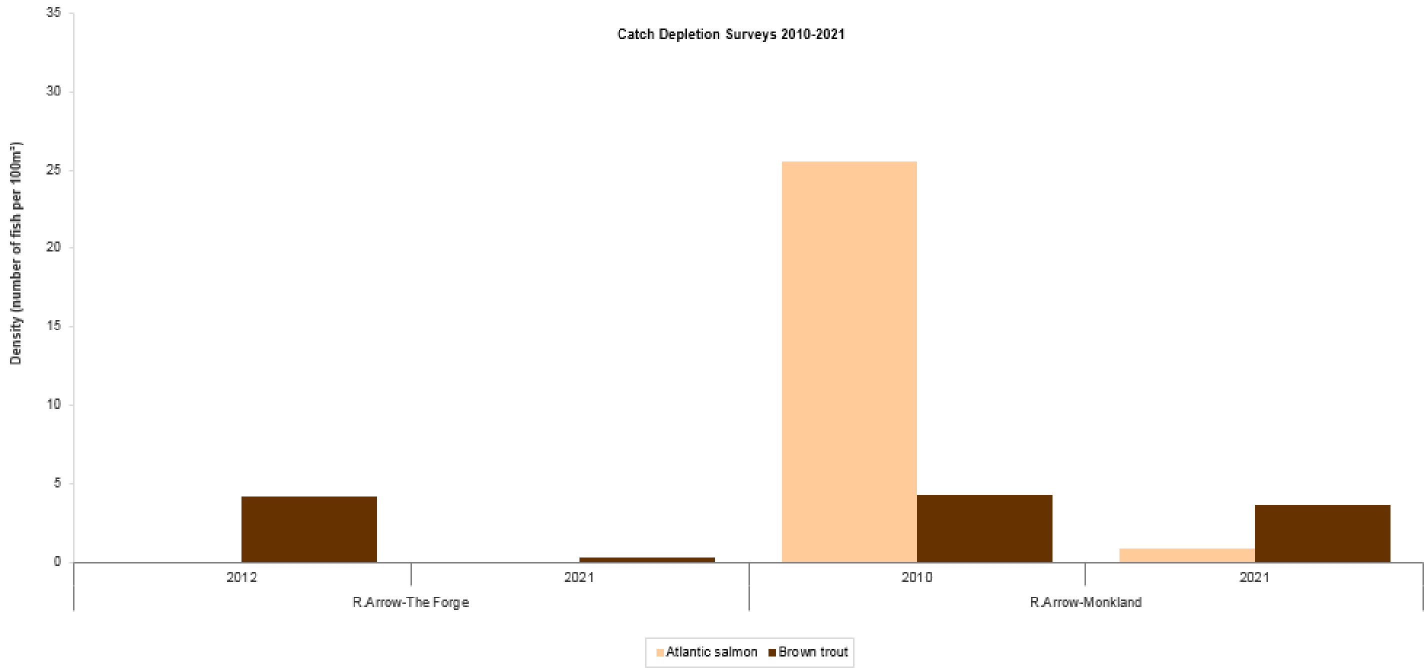


Figure 26: Population density estimates (number of fish per 100m²) between 2010 and 2021, River Arrow.

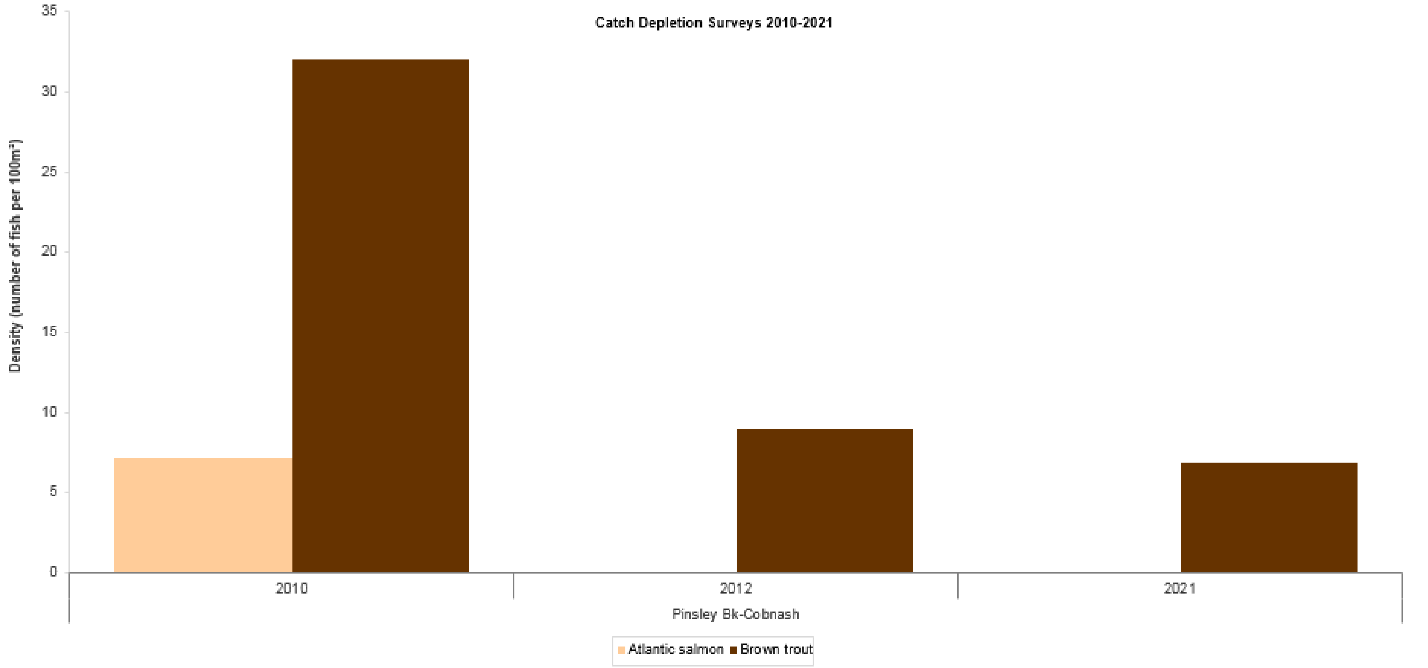


Figure 27: Population density estimates (number of fish per 100m²) between 2010 and 2021, Pinsley Bk.

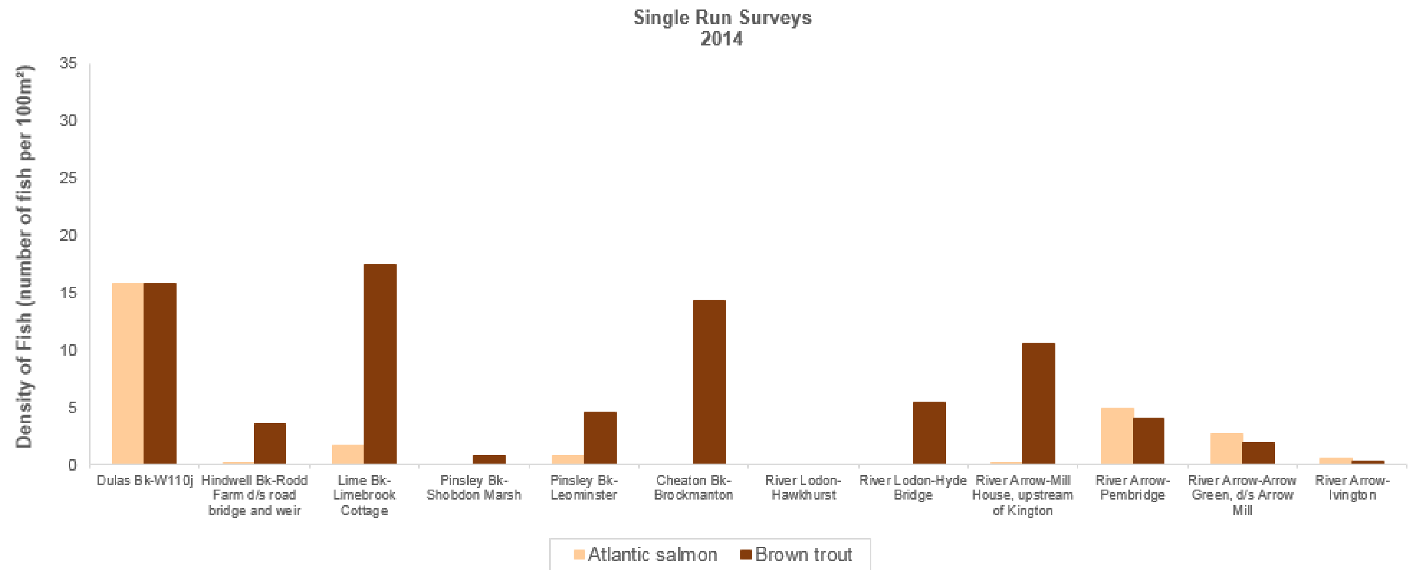


Figure 28: Observed densities (number of fish per 100m²) in 2014 across all single run surveys sites.

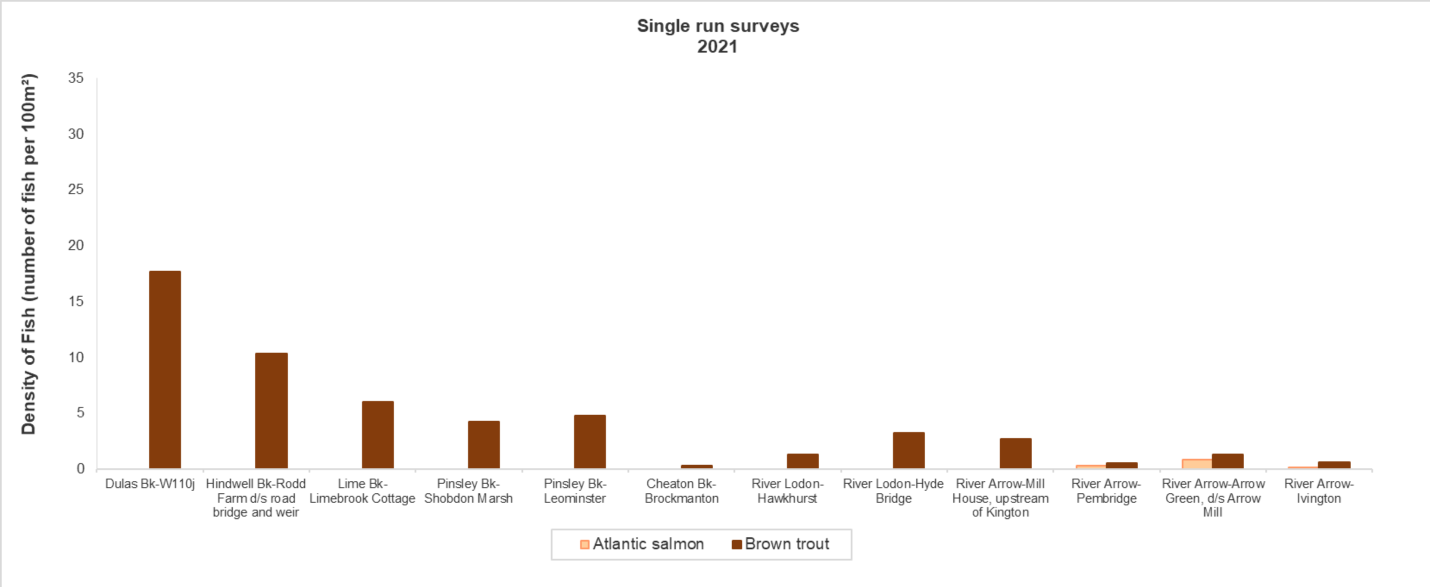


Figure 29: Observed densities (number of fish per 100m²) in 2021 across all single run surveys sites.

Additional work is needed to explore the interplay between the habitat, physical conditions and fish communities. River habitat surveys and Habscore surveys would contribute to understanding the impacts of climate change on habitat availability too.

River Invertebrates

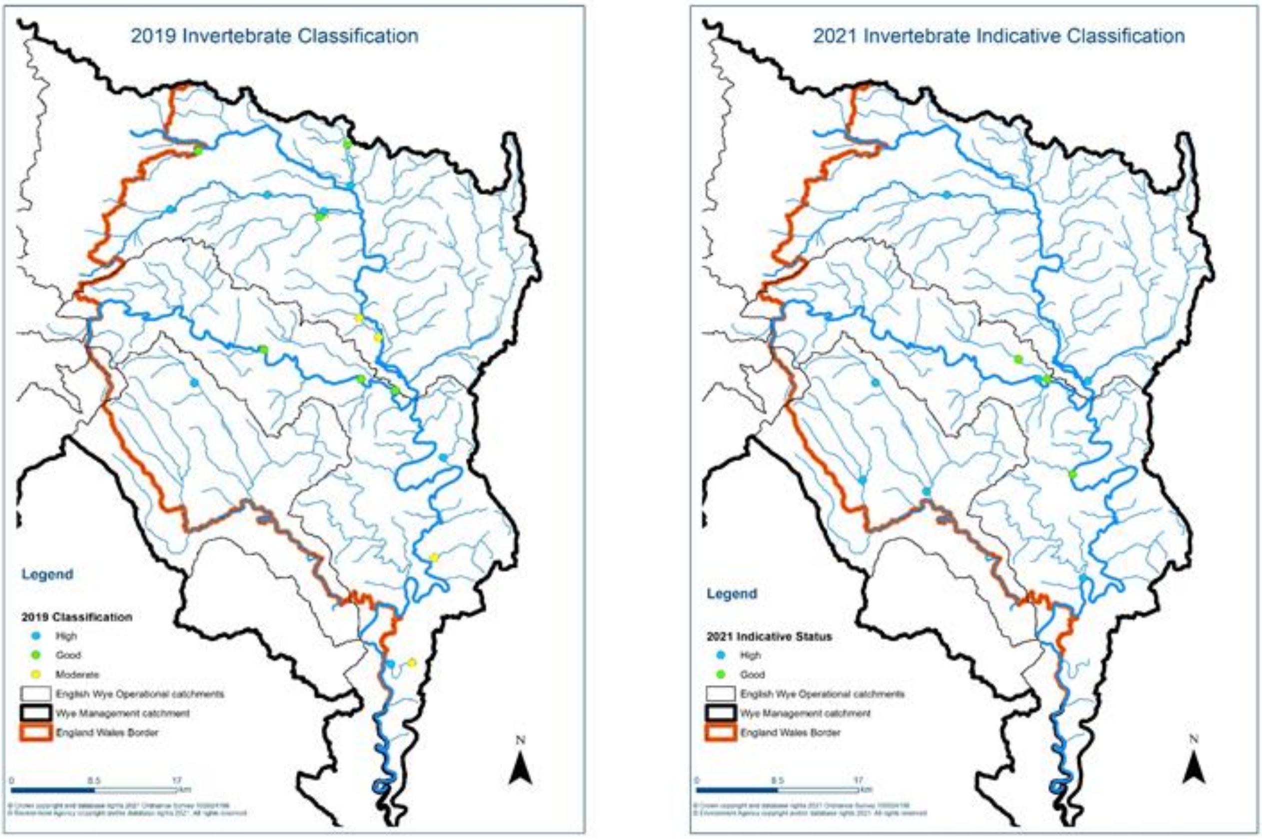


Figure 30: 2021 macroinvertebrate indicative status compared to 2019 WFD classification

All but one site within the Wye catchment complied with the relevant targets for the indicative invertebrate status. The analysis of data shows that site the River Wye at Hoarwithy Bridge has an indicative status of Good and therefore would not comply with the SAC target of High status. The samples taken in 2021 were consistent with the historic data but it is a difficult site to survey and take a representative sample due to numerous large boulders, the substrate being embedded and the very fast flowing nature of the site.

There are several sites within the Wye catchment which have had invertebrate samples taken in 2021 which are awaiting analysis in the laboratory. Once these samples have been analysed further information and data will be available to give a broader picture across the catchment.

Future analysis of the invertebrate data will involve Hydroecological validation (HEV). This uses ecological and hydrological data to help us assess the ecological response of a site to river flow. It compares the ecological community we would expect to find at a site with particular physical and chemical characteristics under un-impacted conditions with the ecological community we observe in our collected sample data. By incorporating hydrological data, we can then look at whether there any observable patterns in measured flow and the condition of the ecological community. HEV will also be used to infer the effect of other pressures, such sediment and morphology on the invertebrate population.

3. Which locations, sectors and activities were responsible for the ecological and water quality issues identified in the data?

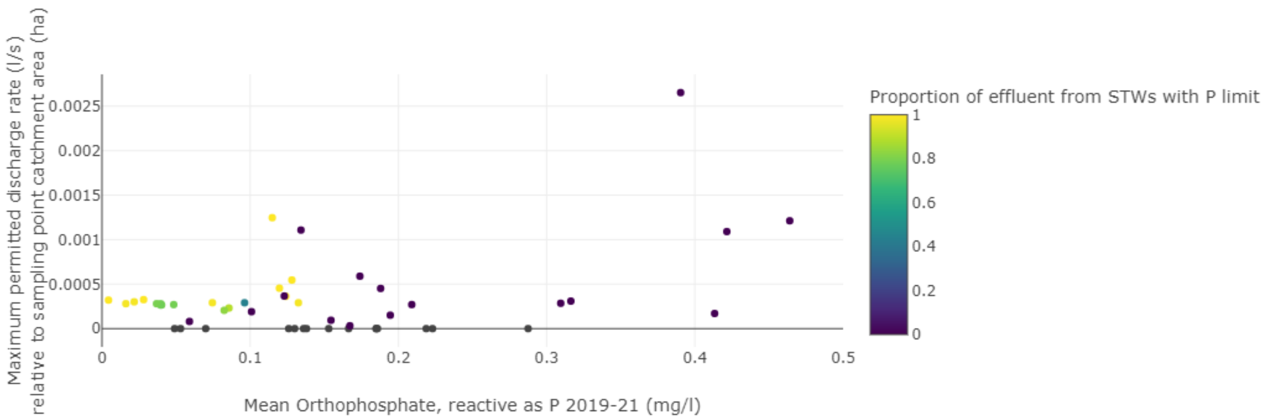
Temperature

Data collected by the sondes suggests that elevated temperature is a key factor triggering algal blooms in the River Wye. Climate change, lower flows and lack of shade are likely to contribute to increased temperatures.

Nutrients

Watershed analysis of sampling points supports the results of previous modelling work, suggesting that arable agriculture and sewage treatment works without phosphorus limits are both major contributors to the nutrient loading of the wider catchment.

There is, as expected, a positive correlation between the total maximum permitted discharge rate of sewage treatment works (STWs) discharging to the catchment upstream of a sampling point and the mean orthophosphate at that sampling point. Catchments where most effluent is discharged from STWs with phosphorus limits show lower orthophosphate measurements than catchments without these limits.



There appears to be a positive correlation between the volumes that combined sewer overflows have spilled within a catchment and the mean orthophosphate concentrations in that catchment when the volume is estimated based on the maximum permitted rate and the reported hours spilled, however very few CSOs could be linked to instantaneous maximum discharge rate conditions so the data are few and this is an estimate of volume only.

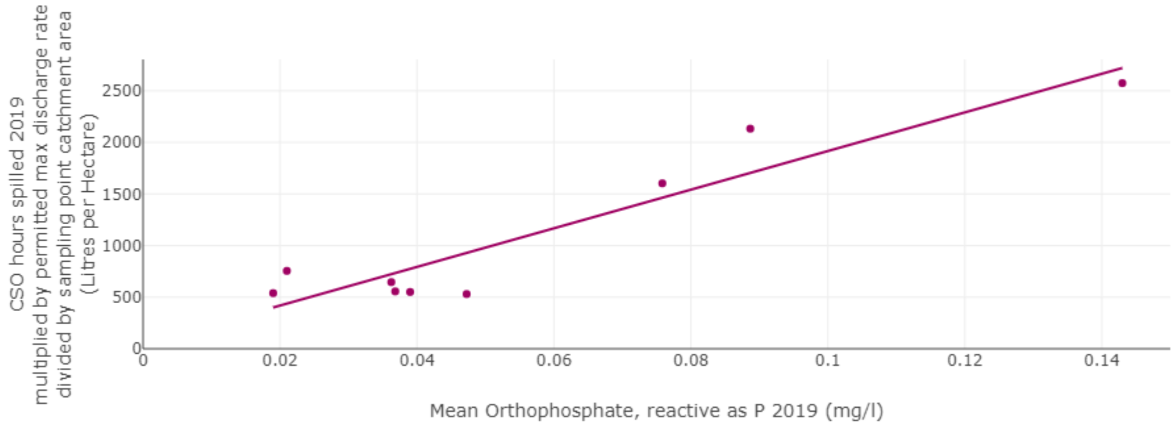


Figure 31: Combined sewer overflow estimated spill volumes in 2019 relative to the catchment area draining to each sampling point, where data was available against orthophosphate measurements.

There has been a decline in coverage of pasture and hedgerows in the Wye Management Catchment in England, with permanent grassland being replaced by arable crops.

The CROME data for the English Wye shows considerable change in rural land use between 2016 and 2020 (Figure 32), with the agricultural land use shifting from over 50% permanent grassland in 2016 to 70% arable in 2020. There have also been large increases in the amount of land used for maize and potato production, with maize increasing by 289%. The increases in maize and potato cover will in part be due to crop rotation. However, the reduction in permanent grassland to accommodate increased production of arable crops is likely to affect sediment loading into the Wye catchment, and potentially increase runoff of fertilisers and other agrochemicals.

The growth of maize and, to a lesser extent, potato can increase sediment runoff due to the late harvest times (mid-late autumn), which can coincide with wet weather. This can increase the risk of runoff of exposed soil and compaction by machinery reducing the soil's ability to absorb water compared to non-arable land or overwintering crops.

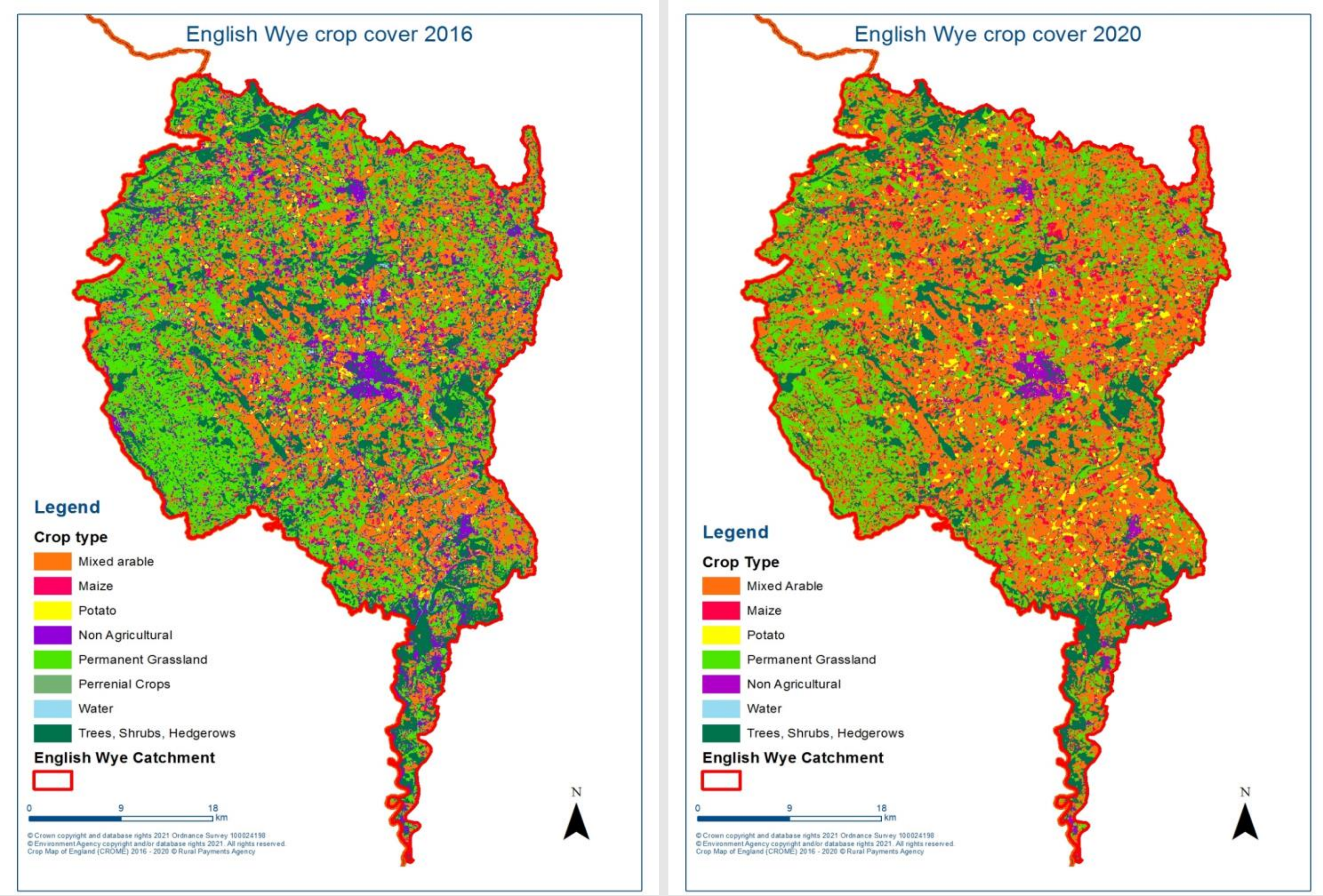


Figure 32: 2016 and 2020 CROME derived land cover maps for the English Wye catchment.

Table 1:Comparison of selected rural land use between 2016 and 2020 and % change in cover using CROME land cover assignment.

Year	Mixed Arable (Hectares)	Maize (Hectares)	Potato (Hectares)	Total Arable (Hectares)	Permanent Grassland (Hectares)	Trees, Shrubs, Hedgerows (Hectares)
2016	53251	3224	2735	59210	66784	35236
2020	87737	12540	6556	106833	45507	31808
% Change	**⇧65**	**⇧289**	**⇧140**	**⇧80**	**⇩32**	**⇩10**

Table 2:Comparison of the percentage covers of total land arable and permanent grassland and the percentage cover of farmland (arable + permanent grassland) arable and permanent grassland between 2016 and 2020 using CROME land cover assignment.

Year	Percentage of total land arable	Percentage of farmland arable	Percentage of total land permanent grassland	Percentage of farmland permanent grassland
2016	28	47	35	53
2020	⇧46	⇧70	⇩24	⇩30

There is a positive correlation between the proportion of land draining to a sampling point that is managed as arable and the mean orthophosphate at that sampling point. The crop types with the strongest correlation with orthophosphate are maize, winter wheat, winter field beans and spring field beans. This analysis averaged crop cover over 3 years to account for crop rotation but rotation influences this correlation so caution must be exercised interpreting crop type correlations. The soil baseflow index as a measure of the permeability of the soil combines to make a catchment more susceptible to loss of phosphate.

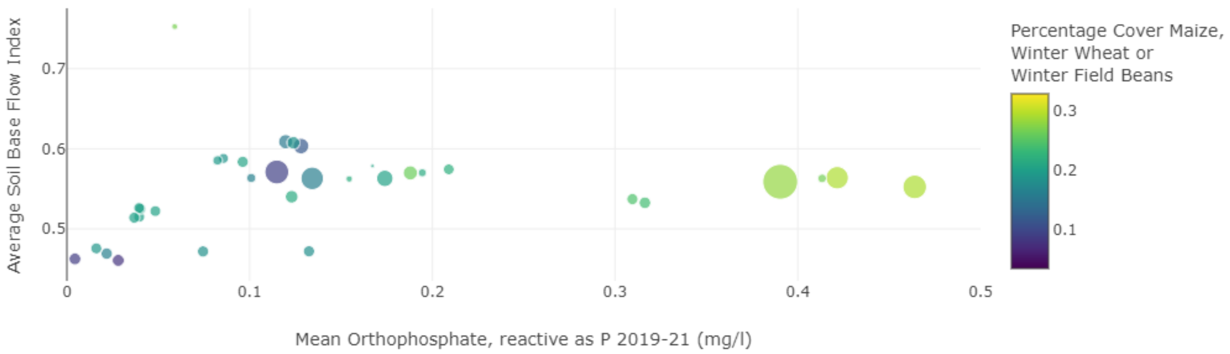


Figure 33: Mean percentage cover of Maize, Winter Wheat and Winter Field Beans between 2018-2020 and average soil base flow index in the catchment draining to each sampling point plotted against mean orthophosphate as P between 2019-2021. Marker size denotes STW discharge rate and accounts for additional variation.

Whilst these correlations suggest the likely dominant sources of orthophosphate in the catchment and corroborate previous modelling outputs, definitive sources for high measurements cannot be inferred from this analysis. To do so requires a higher temporal resolution of data, both for orthophosphate and catchment activities.

There are similar correlations for total oxidised nitrogen.

The proportion of arable land upstream of each sampling point showed a strong correlation with total oxidised nitrogen. This was complemented by a strong negative correlation between the area of grassland, particularly acid grassland, and total oxidised nitrogen.

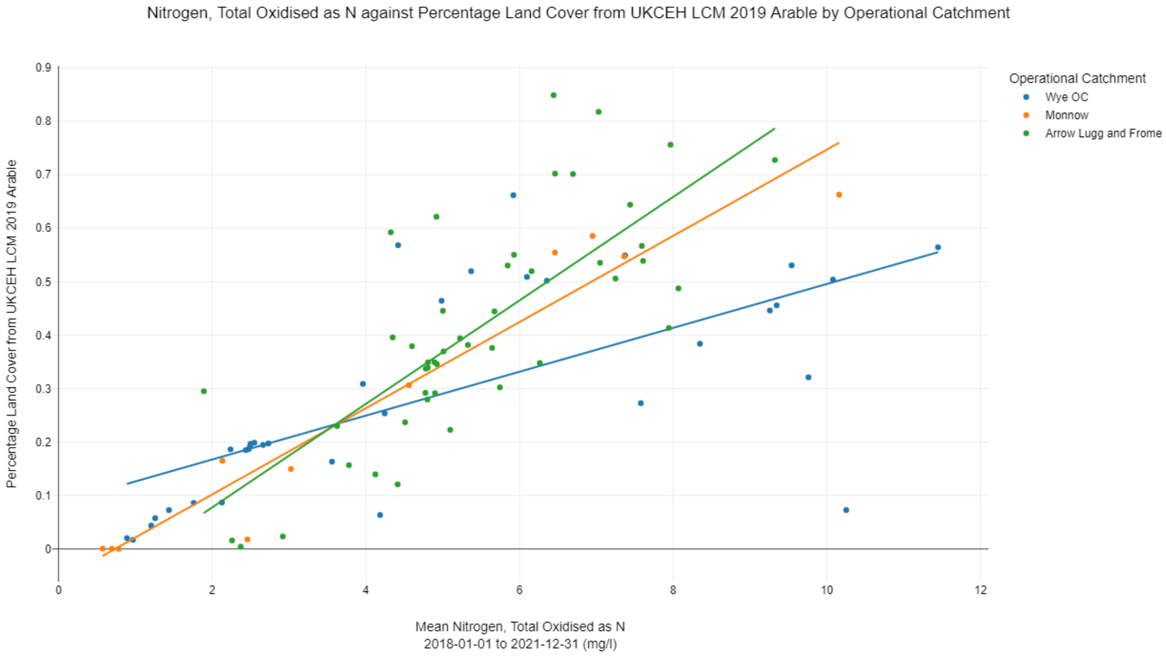


Figure 34: Correlation between percentage land cover arable in 2019 and mean total oxidised nitrogen between 2018-2021.

The crop types that showed the strongest correlations with total oxidised nitrogen were winter wheat, maize, potato, winter oilseed, winter field beans and spring field beans.

There were no strong correlations between sewage treatment works discharge outlets or combined sewer overflow spills and total oxidised nitrogen. However there appears to be a positive correlation between permitted agricultural discharges and total oxidised nitrogen. The data is sparse given there are relatively few such permitted discharges, so caution is required interpreting this data.

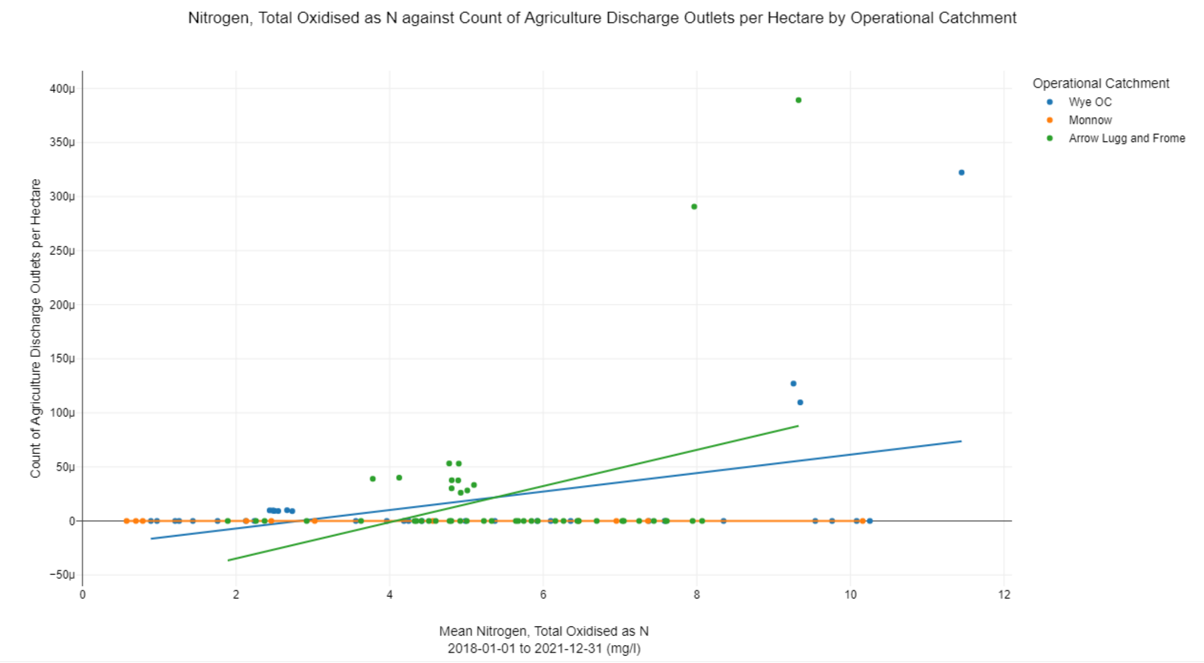


Figure 35: Correlation between count of agriculture discharge outlets and total oxidised nitrogen.

There also appears to be a positive correlation between the number of chicken sheds in a catchment and total oxidised nitrogen. There is no similar correlation for phosphate and greater understanding of where manure from these sites is spread is required.

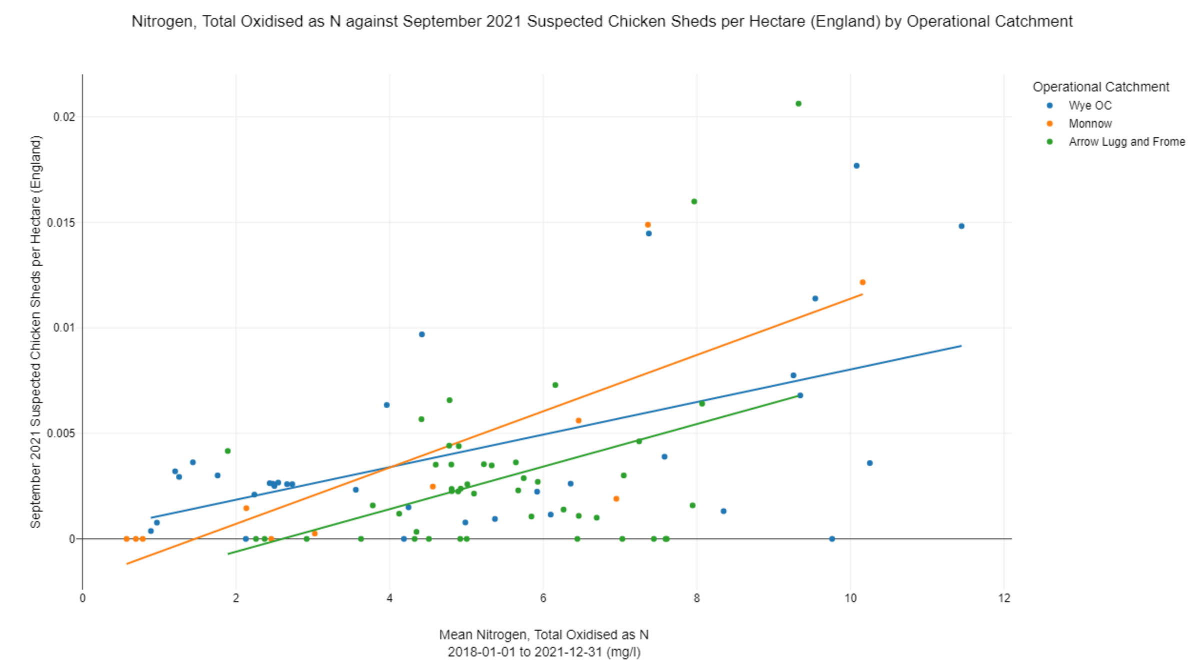


Figure 36: Correlation between number of chicken sheds in a catchment and total oxidised nitrogen, estimated using analysis of satellite imagery.

Total Phosphorus

To date, Phosphorus, Total as P (total phosphorus) has been analysed at relatively few sites across the catchment and more widespread data is required for more robust analysis of correlations between land use, total phosphorus, and ecological impacts as we have done for orthophosphate and nitrogen.

Total phosphorus appears to correlate more strongly than orthophosphate with poultry units, arable and improved grassland. However, there are not enough sampling points to understand the statistical significance of these correlations. Further investigation is required to demonstrate that these are causes and confirm the pathways.

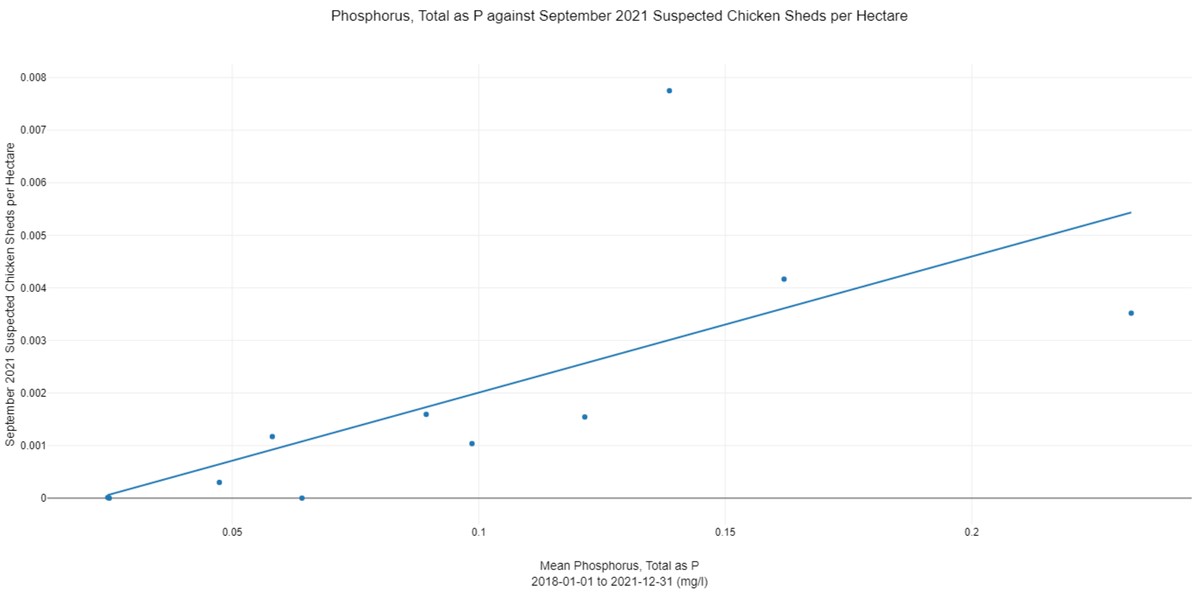


Figure 37: Total-P plotted against the suspected count of intensive poultry units per hectare in the catchment upstream of each sampling point.

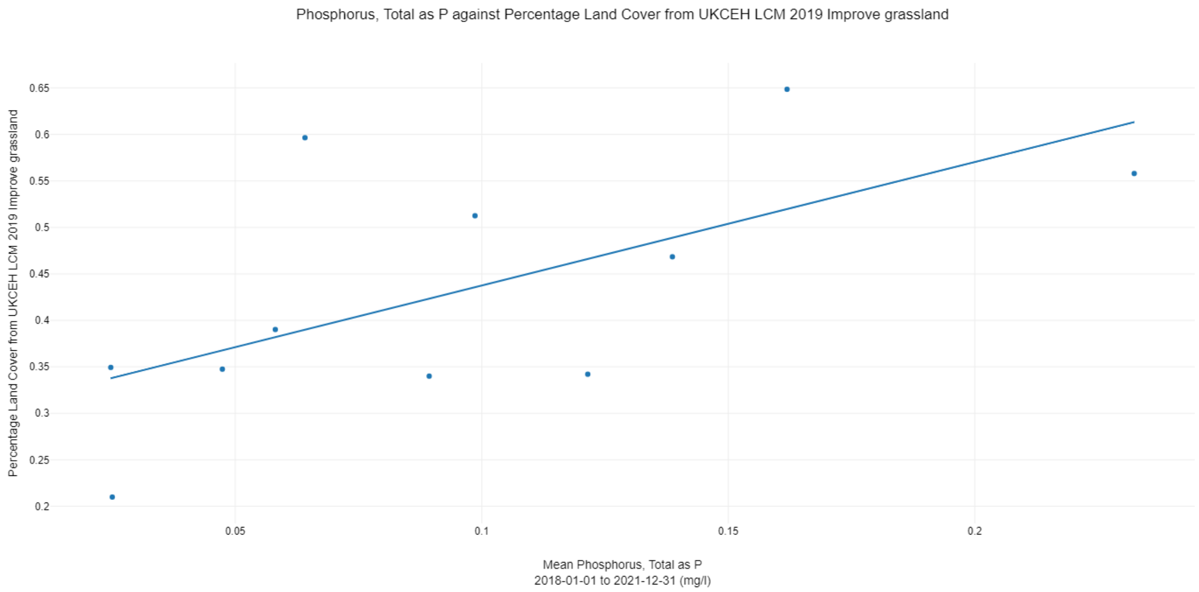


Figure 38: Total-P plotted against the proportion of improved grassland in the catchment upstream of each sampling point.

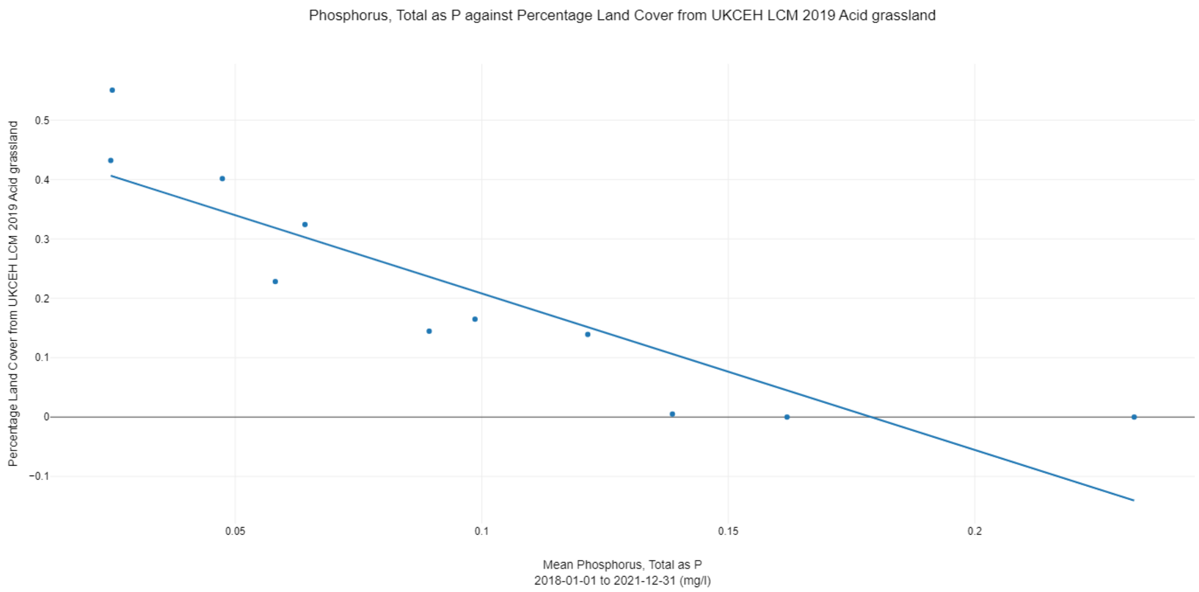


Figure 39: Total-P plotted against the proportion of semi-natural acid grassland in the catchment upstream of each sampling point.

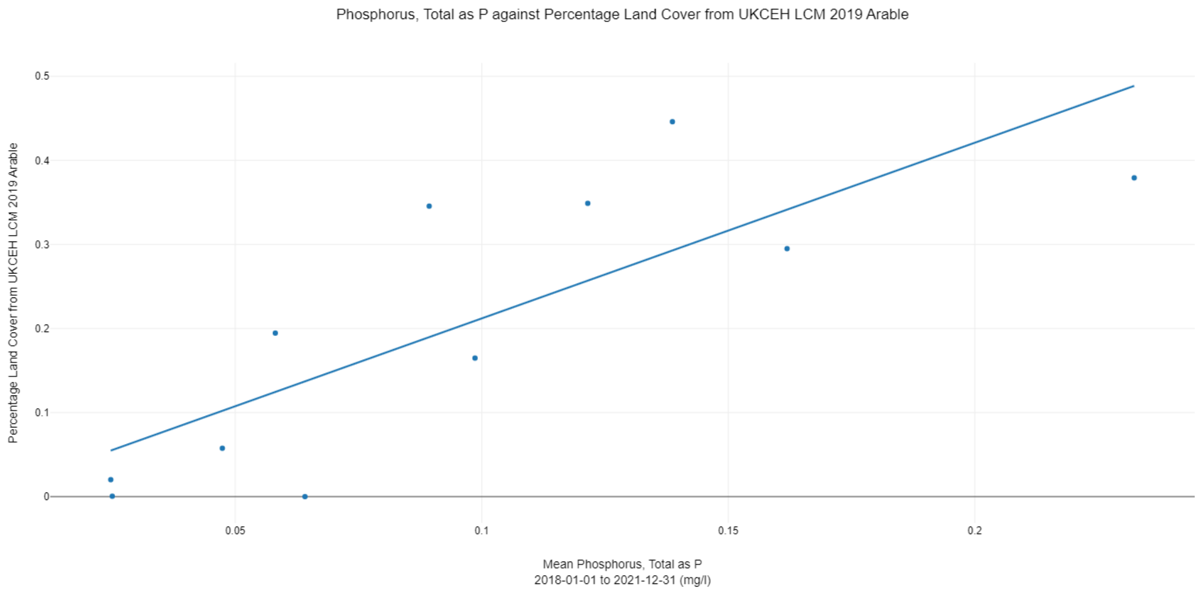


Figure 40: Total-P plotted against the proportion of arable land use in the catchment upstream of each sampling point.

Ratio of Orthophosphate to Total Phosphorus

We measure Orthophosphate, reactive as P and Phosphorus, total as P at several sites within the Wye Catchment, this enables us to analyse variation in the ratio of Ortho-P to Total-P and investigate possible causal factors.

The mean ratios of Ortho-P to Total-P vary between waterbodies and Operational Catchments (Figure 41).

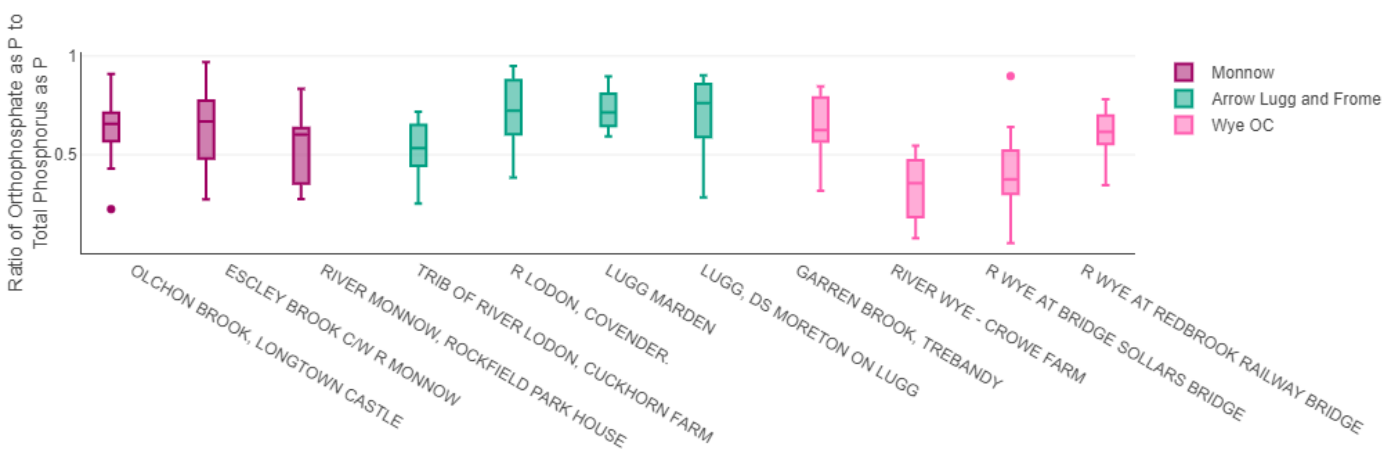


Figure 41: Distribution of the calculated ratio of orthophosphate as P to total phosphorus as P for each sampling point in the Wye Management Catchment where both determinands were sampled.

There is also seasonal variation within measurements at each sampling point, the ratio of Ortho-P to Total-P is generally lowest in May and highest over the late summer months (Figure 42).

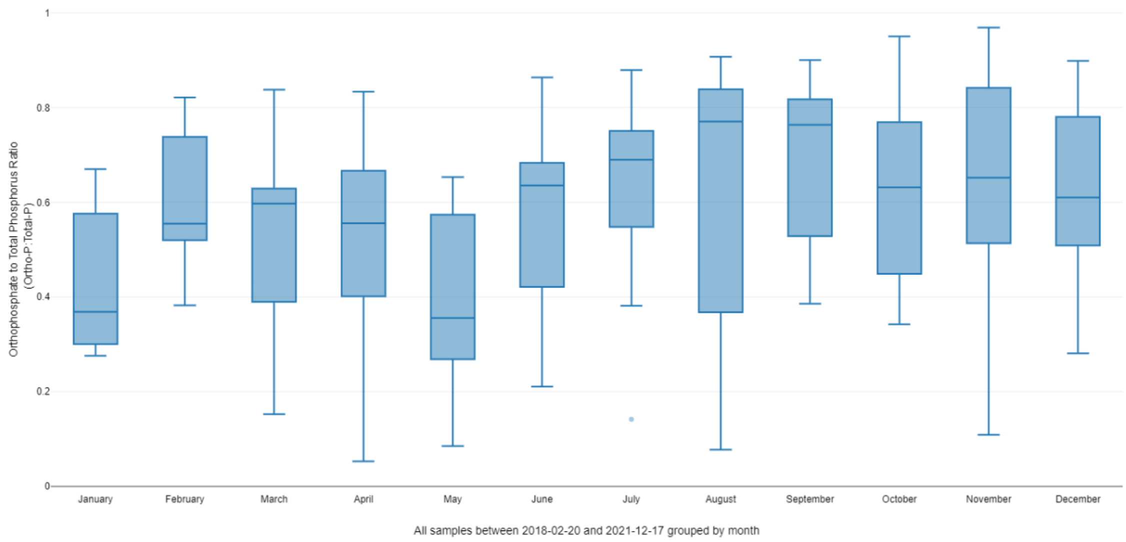


Figure 42: Distribution of the calculated ratio of orthophosphate as P to total phosphorus as P by month in the Wye Management Catchment in England.

While the data is sparse due to the small number of sites where both determinands are currently measured, initial trends suggest that Water Company Sewage Treatment works with Phosphorus limits (Figure 43), non-Water Company Sewage Treatment Works (Figure 44), and the proportion of arable land in the catchment (Figure 45) contribute to a higher ratio of Ortho-P to Total-P.

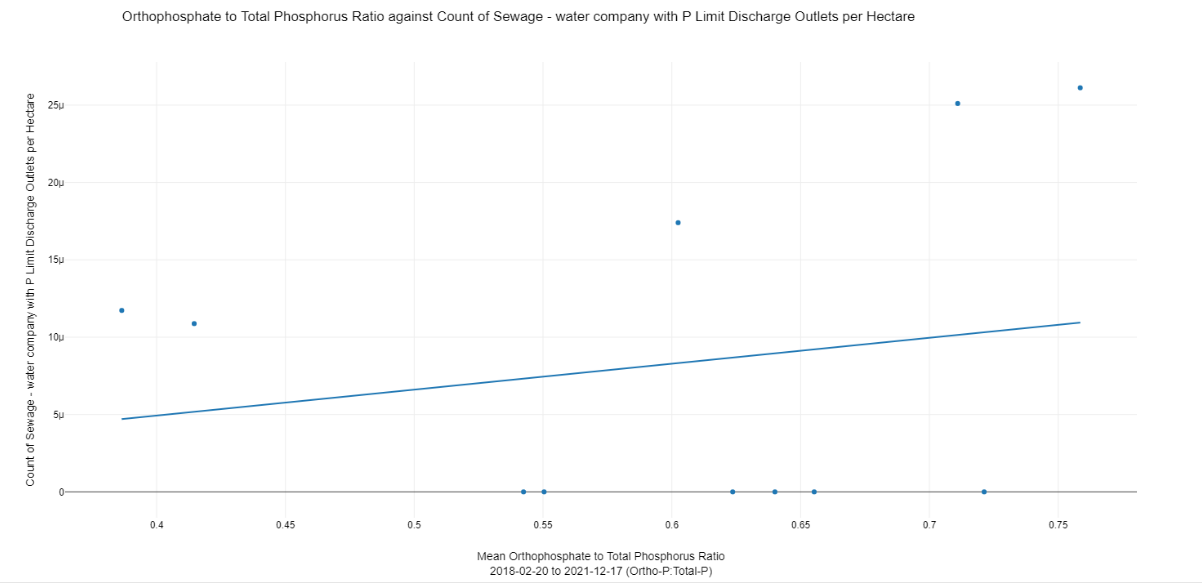


Figure 43: Ratio of Ortho-P to Total-P plotted against the count of water company sewage treatment works discharges with phosphorus limits per hectare in the catchment upstream of each sampling point.

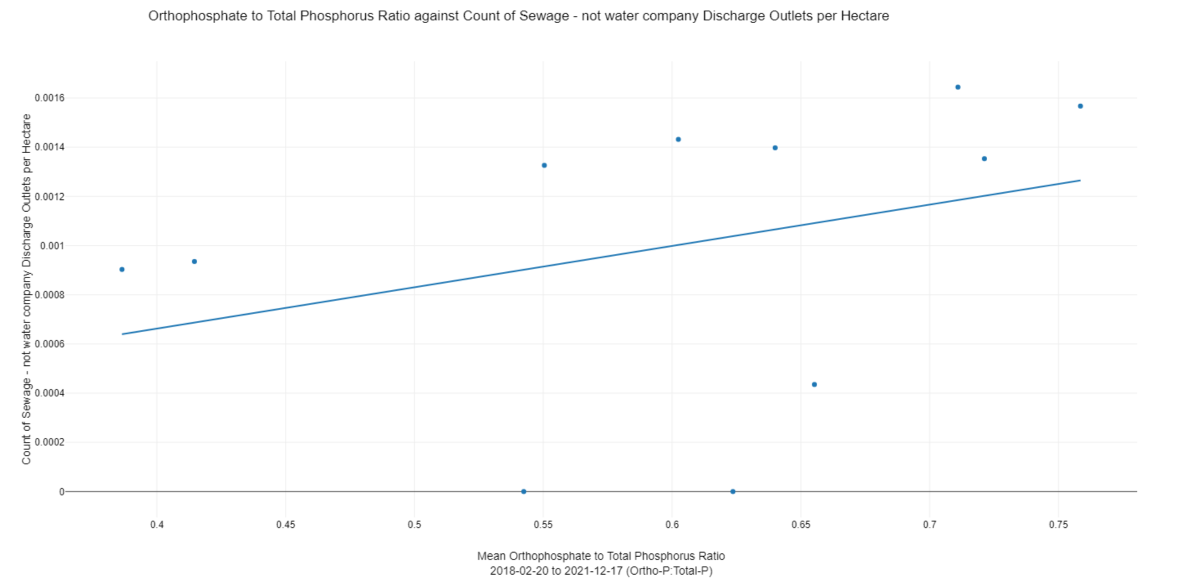


Figure 44: Ratio of Ortho-P to Total-P plotted against the count of non-water company sewage treatment works discharges per hectare in the catchment upstream of each sampling point.

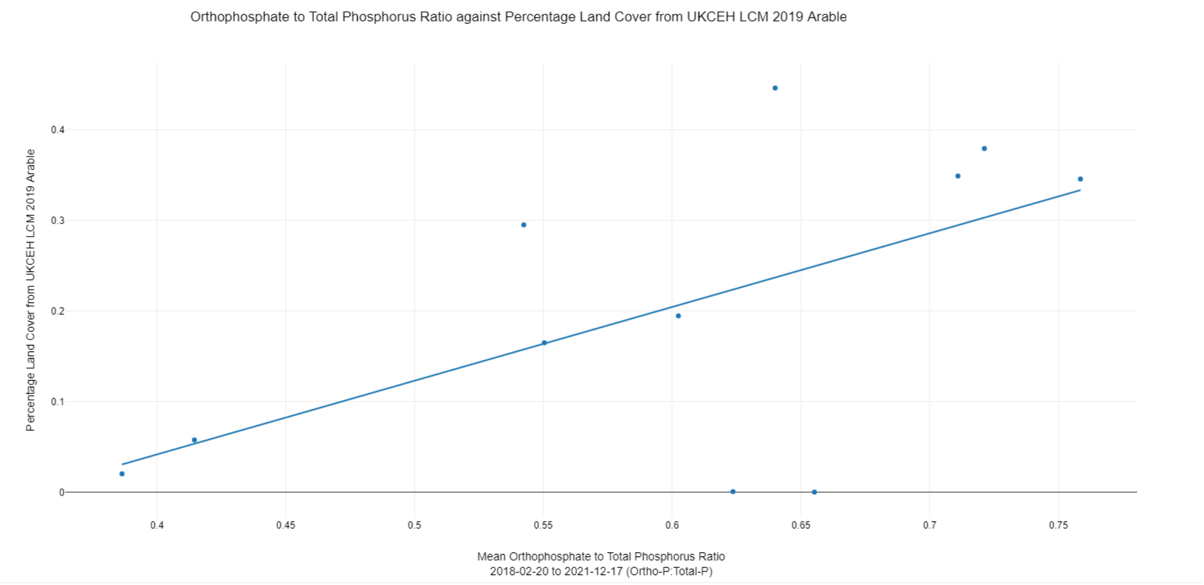


Figure 45: Ratio of Ortho-P to Total-P plotted against the proportion of land in the catchment upstream of each sampling point that was identified as Arable in the UKCEH Land Cover Map 2019.

Incident Reports

Reports of environmental incidents from members of the public to the Environment Agency give an indication of the sectors and activities that are contributing to ecological and water quality problems in the English parts of the Wye Catchment (Figure 46). The location and number of incident reports is heavily biased towards areas of higher population or recreational activity, where there are greater numbers of observers, however this data does generally support the findings from spatial, water quality and ecological monitoring, that both agricultural land management and sewage discharges are major contributing factors.

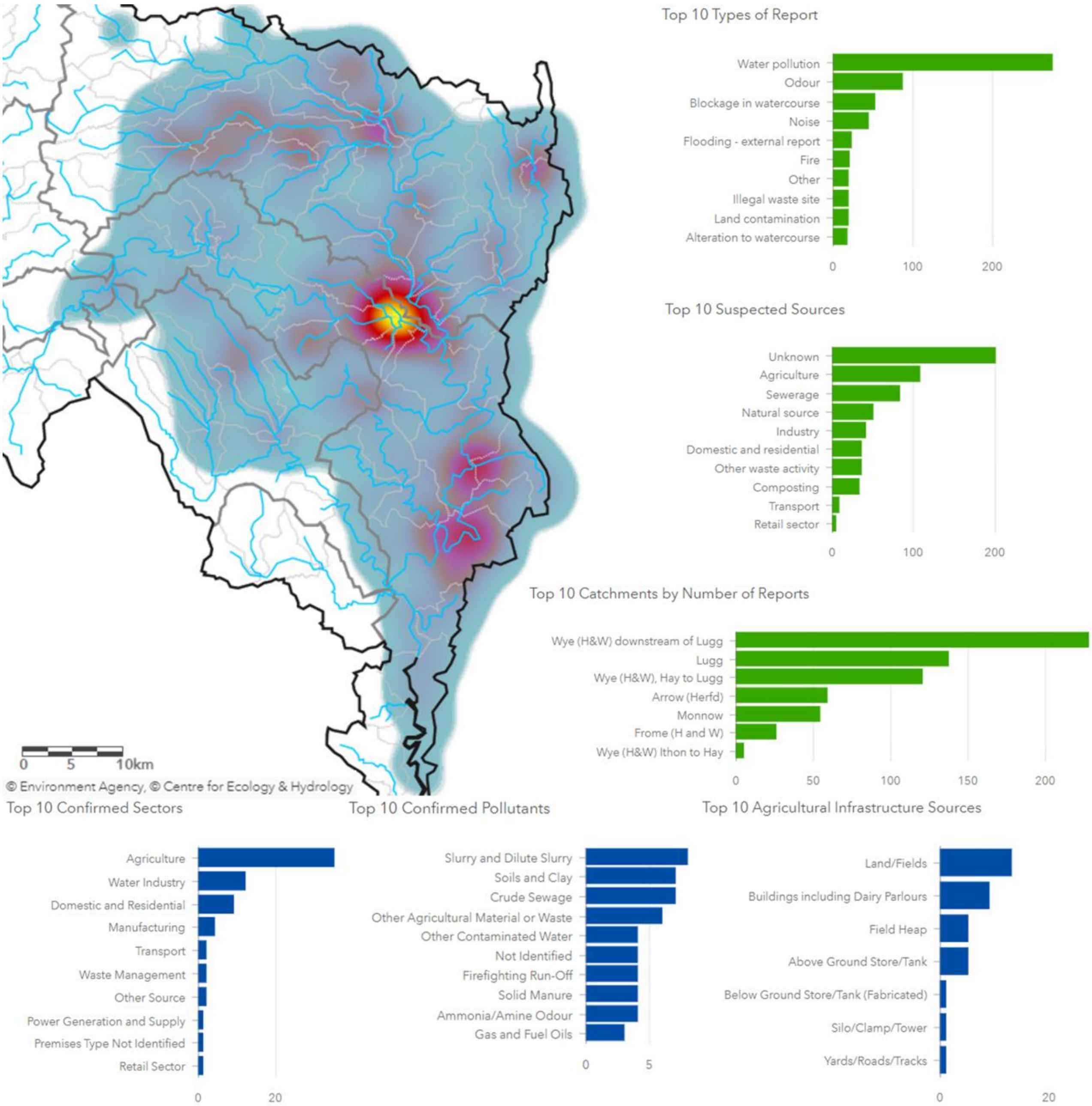


Figure 46: Heatmap of number of incident reports by location. Multiple reports can be received for the same incident. Green bar charts show the breakdown of types of report, sources suspected by the reporter and locations. Blue bar charts show confirmed incident details where the Environment Agency attended and/or investigated the incident (source sector, pollutant and source agricultural infrastructure where applicable).

Recommendations

Additional data and analysis required

There is a large amount of citizen science monitoring that has taken place within the Wye catchment by third parties in the past year. This data was not made available to the Environment Agency in time for this report. In the future, citizen science data needs to be analysed to increase the temporal and spatial resolution of orthophosphate data in the catchment. We will include as much citizen science data as possible in future reports.

Further investigations into the species of algae involved in blooms on the Wye are required to determine more conclusively whether free floating or benthic algae is more of a problem and whether this interaction changes over the course of a bloom event. We are developing an algal monitoring programme to do this during 2022.

Further work is also required to assess the sources of nutrient uptake to macrophytes and algae which are not detectable by water column monitoring. Sediment sampling especially, should be explored to fill this gap in understanding. We will pursue all available funding and delivery routes for this, including asking for support from partners where our resources do not allow us to undertake the desired sampling.

Describing the habitat through Habscore and River Habitat Surveys would help in understanding the interplay between the physical conditions and biological communities and contribute to understanding the impacts of climate change on habitat availability. We will pursue all available funding and delivery routes for this, including asking for support from partners where our resources do not allow us to undertake the desired sampling.

Our future analysis of invertebrate data will involve Hydroecological validation (HEV). By incorporating hydrological data, we can analyse patterns in measured flow and the condition of the ecological community. We can also use HEV to infer the effect of other pressures, such as sediment and morphology on the invertebrate population.

More detailed time series data on volumes spilled by CSOs is required to rigorously assess the relative contribution that such sources play. We will ask for support from partners, particularly Dwr Cymru Welsh Water to contribute this information to the shared understanding in the catchment.

Targeting Regulatory and Partnership Action

While more information is still required to provide more detailed recommendations to support targeted action, we can recommend the following:

Efforts to increase shade by tree planting and better management of riparian trees could help mitigate high temperatures.

Extreme reduction in nutrient input from all sources is required across the whole catchment to contribute to the recovery of river macrophytes.

Taking a catchment-based approach, all contributing partners in the Wye Management Catchment could target investigations, analysis and remedial actions in key focus catchments that meet the following criteria:

- As far upstream as possible
- High phosphate concentrations relative to the wider catchment
- A high proportion of the following factors and drivers are present:
    - Arable land use
    - Maize
    - Poultry sheds
    - Anaerobic digesters
    - Sewage treatment works
    - Combined sewer overflows
    - Macrophytes status less than good and indicative of eutrophication
    - Declining Atlantic salmon populations
    - Land allocated for development to which Nutrient Neutrality guidance applies
    - Active citizen science groups
    - Active partnership projects

Based on these criteria the following functional groups of waterbodies seem most suitable initially:

1. River Arrow near Kington
2. River Arrow near Pembridge and Curl Brook
3. River Lugg and tributaries near Presteigne
4. Little Lugg and Withington Marsh Brook
5. River Frome

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