A Scottish Registered Charity
No. SC 020751

Galloway Fisheries Trust / Peatland Action annual water quality monitoring report 2022/2023

For further information on this report please contact:

Name of GFT Project Manager – K Galt
Galloway Fisheries Trust
Fisheries House
Station Industrial Estate
Newton Stewart
DG8 6ND
Telephone: 01671 403011
E-mail: kenny@gallowayfisheriestrust.org

This report should be quoted as:

Galloway Fisheries Trust. June 2023. Annual water quality monitoring report on behalf of Peatland Action.
Galloway Fisheries Trust Report No. – 2023_AWQM-KG

Summary

Annual water quality monitoring report on behalf of Peatland Action – Water of Luce catchment

Year of publication: June 2023

Keywords

Peat; Peatland Restoration; EXO1 Sonde; Brown trout; Atlantic salmon; Water of Luce; Main Water of Luce; Cross Water of Luce; Water Quality, pH; acidification

Galloway Fisheries Trust (GFT) have been actively involved with encouraging and supporting peatland restoration in South West Scotland. GFT's main interest in this work is associated with the potential water quality benefits from peatland restoration, particularly to help address acidification problems and restore impacted fish populations. In November 2019, Peatland Action (PA) agreed to fund an annual Water Quality Monitoring program monitoring peatland restoration sites within the Galloway region under the guidance of Emily Taylor, Galloways' local Peatland Officer.

Water Quality Monitoring carried out during winter 2022/2023 centred on the Water of Luce because of an opportunity becoming available for Crichton Carbon Centre (CCC) to carry out peatland restoration around Lagafater Lodge in the upper Main Water of Luce catchment. The headwaters of the Water of Luce (Main Water of Luce and Cross Water of Luce) are dominated by blanket peat which has been heavily drained/dried out to turn the peatland into land dominated by grass that can be used for sheep grazing. Since the late 70's/early 80's the area has also been impacted by acidification, which has impacted fish populations in the area, as shown by historic GFT fish survey data. As such, the Water of Luce water quality monitoring during winter 2022/2023 was essentially split into three interconnected projects. The first was a review of the electrofishing data held by GFT. Given the sensitivity of salmon and trout to low pH during sensitive periods of development the aim of the review was to look at the current distribution and density of trout and salmon, to see if there were any areas where fish numbers showed signs of being impacted by poor water quality and to see if there were any changes in fish numbers over time that would indicate improving or declining conditions. The second was to record pre-restoration water quality data for the aforementioned peatland restoration project, with post restoration data planned to be collected after completion of the works. Water quality parameters were recorded at 15 m intervals using EX01 Sondes from three sites in the upper Main Water of Luce. Parameters recorded include pH, Dissolved Oxygen (DO), depth, conductivity and Fluorescent Dissolved Organic Matter (fDOM), the latter two being a representative measure of peatland erosion. The third was to collect a general record of catchment wide water quality across the upper Luce catchment. The aim was to look at variation in water quality (primarily pH) across upper catchments to highlight areas of poorer water quality for further gathering of information. It is hoped that once the areas with the poorest water quality have been identified water quality can eventually be linked to land use and/or the current state of the peat. Water quality monitoring was again with EX01 Sondes which recorded the same water quality parameters, at the same intervals, as used during the

pre-restoration monitoring. Spot water samples were also taken from selected sites throughout the Water of Luce catchment to show spatial variation in pH levels across the catchment after periods of high flows.

The GFT fish data review showed that there has been some recovery in fish numbers and distribution in the Water of Luce since first recording in the late 90's when salmonid populations were clearly depleted in some upland watercourses as a result of low pH levels. The improvements most likely relate to improvements in air quality and associated reductions in atmospheric acidic pollutants. However, fish populations remain impacted in some areas and acidification persists. The uppermost tributaries of the Main Water of Luce have only recently shown improvements in salmonid numbers with acidification most likely still impacting fish survival during some years.

As well as providing important pre-restoration data for the Lagafater peatland restoration the pre-restoration monitoring from the headwaters of the Main Water of Luce provide detailed water quality data which backs up the conclusions made from the GFT electrofishing data review. Some of the pH levels recorded after high flows are potentially damaging to salmonid populations and it is advised that monitoring continues during and post restoration to allow accurate recording and to highlight any benefits that results from the restoration.

The general water quality monitoring for the Water of Luce catchment allowed spatial variations in water quality to be mapped and provided detailed water quality data from central points in both of the upper catchments (Main Water of Luce and Cross Water of Luce) and from targeted monitoring sites within some of the most acidified watercourses in the upper Main Water of Luce catchment. The results again show that acidification persists within the upper reaches of the Water of Luce catchment with low pH levels most likely being as a result of damaged blanket peat, which appears to be amplifying the impacts of acidification and potentially slowing recovery. This is possibly highlighted by what appears to be a difference in water quality/acidification based on peat type, with watercourses within areas on semi-confined peat showing much higher (less acidic) pH readings. This relationship requires further research to explore the differences in water quality based on peat type. The report has highlighted the watercourses within the upper Main Water of Luce catchment as being amongst, if not the, most acidified within the Water of Luce catchment. As the peatland restoration being undertaken by CCC lies within this area, and given the potential benefits to water quality and aquatic ecosystems as a whole, this report fully supports the restoration and encourages any additional restoration within this area. This report supports full peatland restoration where possible/practical as full restoration will see the most benefit to water quality.

Main findings/recommendations

- GFT to regularly repeat at least one electrofishing site on the Laganabeastie Burn to monitor trout responses to water quality in general and to any water quality changes associated with the CCC led peatland restoration project, which covers a large percentage of the Laganabeastie Burn catchment.

- Lagafater water quality monitoring to be continued during and prior to any peatland restoration work taking place to allow changes in water quality to be recorded.

- Temperature loggers to be deployed at Lagafater monitoring sites on the Main Water of Luce, Laggie Burn and Laganabeastie Burn (note: completed Spring 2023).

- The gap in data from the upper Cross Water of Luce is to be filled during any future sampling.

- Of the sites sampled the upper sites on the Main Water of Luce consistently show the lowest pH levels and are therefore the most acidified. Burns such as the Laggie, Pilhatchie and Laganabeastie Burns and the very top of the Main Water of Luce (Black Glen Burn) are the main watercourses impacted and are most likely to have impacted fish populations and freshwater ecology in general. As a result this report supports and encourages any peatland restoration that can be carried out within these areas and fully supports the peatland restoration currently being planned by CCC. This report supports full peatland restoration where possible/practical as full restoration will see the most benefit to water quality and aquatic ecosystems.

- The spot sampling results from the Luce have indicated that there is probably a relationship between water quality (particularly pH) and peat type. This should be explored further in future work and any joint projects that bring additional expertise into future studies should be encouraged.

- Work should be undertaken to better understand the relationship between fDOM and peat erosion.

- More work should be carried out in summer to assess the impact of degraded peatland on Dissolved Oxygen levels within watercourses that drain through damaged peatlands.

- The data and conclusions from this report should be used within any future management planning within the Water of Luce catchment and should act as a reference point for managing peatland and/or water quality within other areas where applicable.

For further information on this project contact:
Name of Project Manager – K Galt
Telephone No. of Project Manager – 01671 403011

Table of Contents **Page**

1 INTRODUCTION

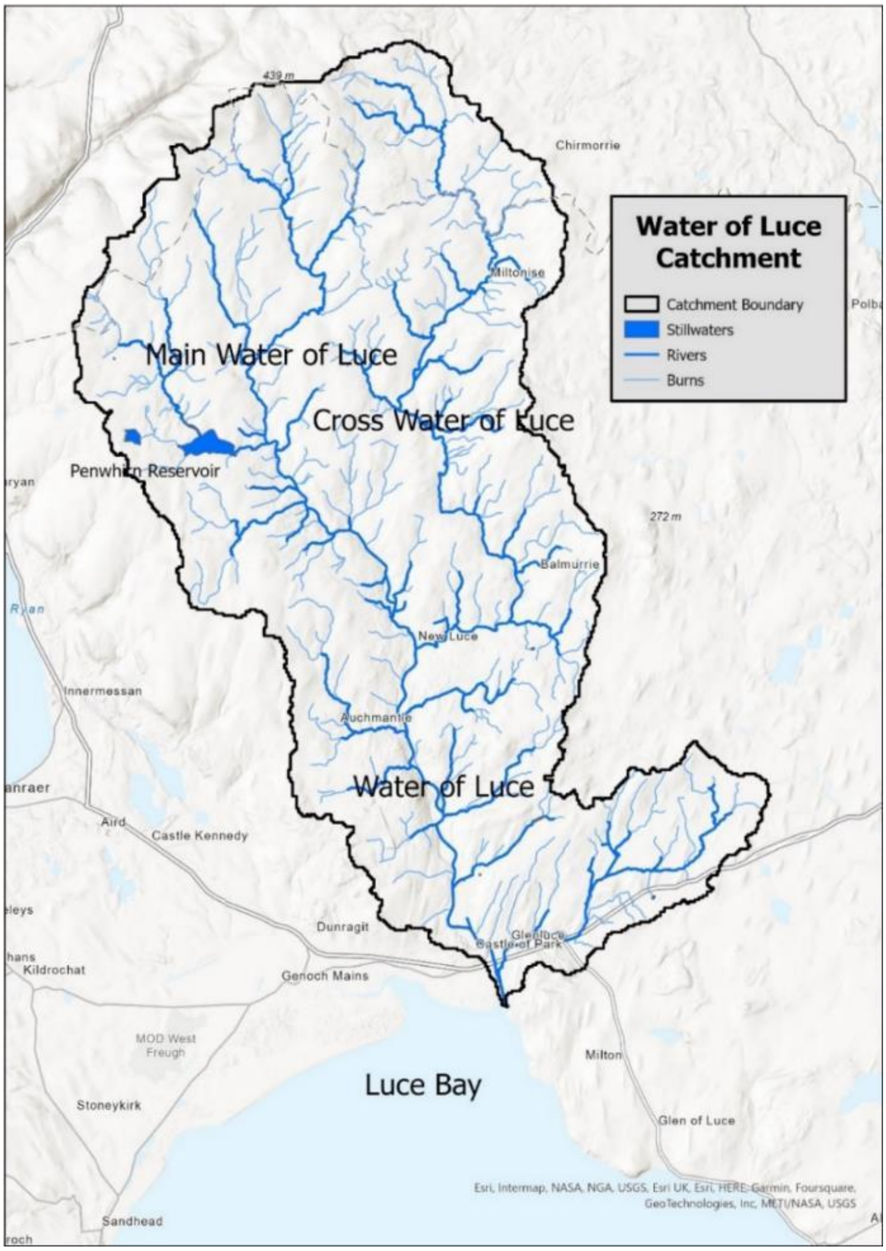
The Galloway region of South West Scotland has been well documented in being subject to the effects of acidification. Atmospheric acid deposition largely from the burning of fossil fuels in areas of base-poor geology has resulted in soils exceeding their capacity to buffer against acid inputs, leading to artificially lowered pH within soils and waterbodies in these areas. Where large scale conifer plantations are present (in particular Sitka spruce) the impacts of acidification are often greater, with a number of authors finding a direct link between plantations and lowered pH (e.g. Harriman & Morrison, 1982) resulting from increased rates of wet and dry deposition of acidic pollutants. The Galloway region is one of the most afforested areas in the UK with most plantations typically consisting of Sitka spruce (*Picea sitkensis*). Much of the planting was historically carried out in the "lower-value", base-poor upland areas that are more susceptible to acidification. This has resulted in widespread artificially lowered pH levels in many upland areas within the Galloway region, with many upland lochs being reported as fishless in the late 1980's (Maitland et al., 1987).

The two main native fish species within these areas are typically Brown trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*). Low pH can have significant impacts to both trout and salmon at critical stages within their lifecycle. At the time of hatching pH below 4.5 can block the action of the hatching enzyme chorionase leading to mortalities in Atlantic salmon (Waiwood & Haya, 1983). One of the main impacts of lowered pH is the association with increased levels of labile Aluminium (Driscoll, 1985), which can be toxic to trout and salmon. Mobilised Aluminium in soils can form complexes with water molecules, enabling them to bind to fish gills at low pH levels resulting in both ionoregulatory and respiratory impacts (Gensemer & Playle, 1999), whilst the physiological transformations that Atlantic salmon smolts undergo to cope with changes in salinity levels makes them particularly sensitive to Aluminium levels and has been associated with mortalities (Kroglund et al., 2008). Due to the complex interactions between pH and the environment and the subsequent impacts on fish Crisp (2000) summarises the general levels of concern of low pH for trout and salmon as being harmful at values below five and lethal at values below four. As a result of reduced pH levels within watercourses one of the major impacts within the Galloway region was the reduction, and in many cases complete loss, of Brown trout and Atlantic salmon populations. Maitland et al in their 1987 publication *Acidification and Fish in Scottish Lochs* reported that in eleven lochs studied in the Galloway region that were known to once hold fish, six were now fishless whilst others showed impacts consistent with increased acidity. Since the late 1980's improvements in air quality, liming and changes in land use have resulted in some improvements to fish populations with recovery of trout populations in some areas. However, recovery appears slow in some areas where improvements have been made, whilst other areas still remain at pH levels that severely impact fish populations (Ferrier et al., 2001, Battarbee et al., 2011, Brown et al., 1998, Shilland et al., 2009). Electrofishing surveys carried out by Galloway Fisheries trust (GFT) still routinely record low or absent trout and salmon numbers from some upland areas that once held either or both.

Peatlands are common within many of the acidified areas within the Galloway region, with Dumfries and Galloway holding some of the largest areas of peat within Scotland (Chapman et al., 2009). The importance of Peatlands cannot be understated. Their role as a carbon store is gaining increasing exposure in the public eye given the importance being placed upon acting on climate change. However, they also carry out a number of other ecological services including water purification, improving climate resilience, flood control and act as unique habitats for flora and fauna (Harenda et al., 2018). Their occurrence on waterlogged, often nutrient poor "low-value" uplands has resulted in the degradation of many peat bogs within Dumfries and Galloway, primarily from draining for agriculture and forestry (Peacock et al., 2018). Draining peatlands lowers the water table and exposes the peat to aerobic decomposition, resulting in the stored carbon being released into the atmosphere (Martin-Ortega et al., 2014). In addition to the release of carbon, drained peatlands can have impacts on waterbodies with increases in the quantity of Fine Particulate Organic Matter, metal concentrations, dissolved organic carbon (DOC), water turbidity and lowered pH (Martin-Ortega et al., 2014). In areas where conifer plantations have been planted on peat the resulting changes (in particular the extensive draining) can be very damaging. Drainage and loss of vegetation, combined with the increased scavenging of atmospheric acidic pollutants associated with conifers, can result in conifers planted upon peat amplifying acidification issues within watercourses beyond that experienced within degraded peatlands or conifer plantations alone. Conifer plantations planted on peat can result in an additional lowering of pH, a further increase in toxic metals, a further increase in ammonia, a further increase in DOC and a further increase in turbidity (Harrison et al., 2014; Puhr et al., 2000).

The identification of areas where acidification impacts fish populations and working to address, mitigate or inform land management practice, forms a large part of the work carried out by GFT. Within this the identification of areas of degraded peatlands (and in particular areas where conifers are planted on deep peat) that are causing significant water quality issues forms a key component of this work. Where land use results in degraded peatlands that are impacting fish populations there may be the opportunity for multiparty work towards peatland restoration that fulfils a number of environmental and climatic goals such as carbon storage, repopulating unique peatland flora and fauna and improved water quality with resulting benefits for fish populations. For that purpose, GFT has been working in partnership with Peatland Action (PA) and the Crichton Carbon Centre (CCC) since 2019 to monitor water quality in sections of Galloway rivers that are impacted by acidification as a result of damaged/degraded peatlands. The project aims to monitor the impacts of peatland restoration on water quality (particularly in relation to salmonids), assess water quality across upland sections of rivers where degraded peat is present and to use the information gathered to raise awareness, prioritise areas where peatland restoration will result in the biggest improvements to water quality and to provide data to feed into land management plans. The collaboration between GFT, CCC and PA is funded by NatureScot (NS) with funding being secured in Autumn in 2022 to monitor water quality over the winter 2022/23 (winter is the period when rainfall is typically highest resulting in more frequent acid flushes into watercourses).

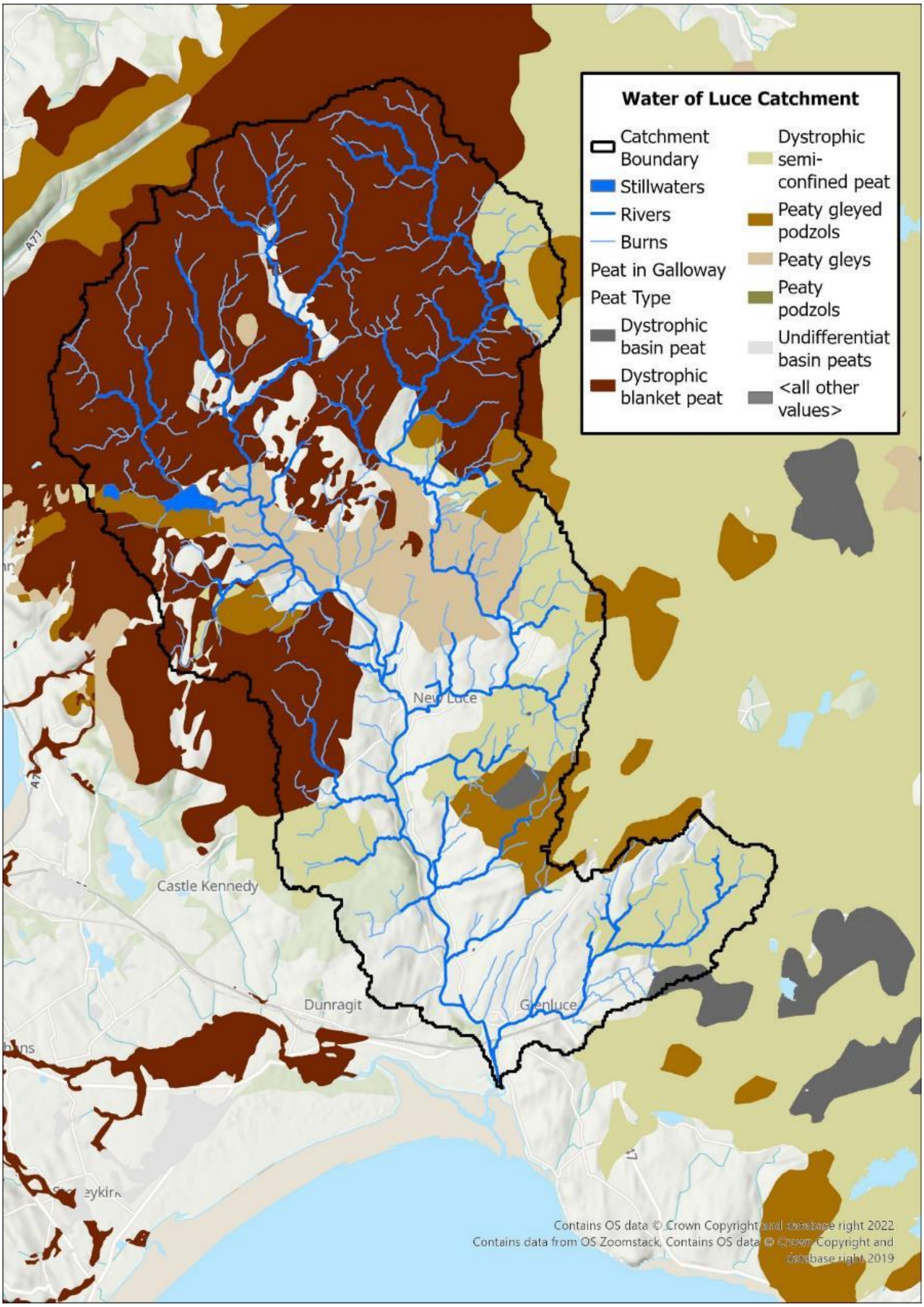
Water Quality Monitoring carried out during winter 2022/2023 centred on the headwaters of the Water of Luce as a result of an opportunity becoming available for CCC to carry out peatland restoration. The Water of Luce is a small to medium sized river which is approximately 40 km long and has a catchment of roughly 200 km^2. The river originates in the South Ayrshire hills at an altitude of approximately 400 m and flows into the Solway Firth at Luce Bay. The river runs North to South and is roughly “Y” shaped with two major headwater tributaries, the Main Water of Luce and Cross Water of Luce joining together at New Luce to form the Water of Luce.



Map 1: Catchment map of the Water of Luce showing the two major headwater tributaries

One major tributary of the Main Water of Luce, the Penwhirn Burn, was dammed in the 1950's to provide a drinking water reservoir. The construction of the reservoir has resulted in the isolation of the Brown trout population above the dam, the exclusion of Atlantic salmon from the area above the dam wall, altered flows and interrupted the natural movement of gravel down the burn. As a result the burn downstream of the dam is largely depleted of cobbles, pebbles and gravel which form vital spawning habitat for fish and habitat for invertebrates.

The upper Luce catchment has extensive deposits of blanket peat as shown in Map 2, covering much of the upland headwaters of the river system.



Map 2: Catchment map of the Water of Luce showing peat distribution and type

The vast majority of the peat is damaged, primarily as a result of historic drainage used to convert the peatland vegetation into grassland for sheep grazing. The extent of the drainage can be clearly seen from satellite aerial photography as shown in Picture 1. A small percentage of the peatland land area has been converted to conifer plantations, the largest of which is Arecleoch Forest which now also incorporates a windfarm. The primary land use in the lower reaches of the Water of Luce catchment (from the confluence of the Main Water and Cross Water) is improved grassland which is concentrated around the catchment valley floor, with a variety of land use at higher altitude on the valley sides. These include commercial forestry, mixed woodlands and rough grassland.

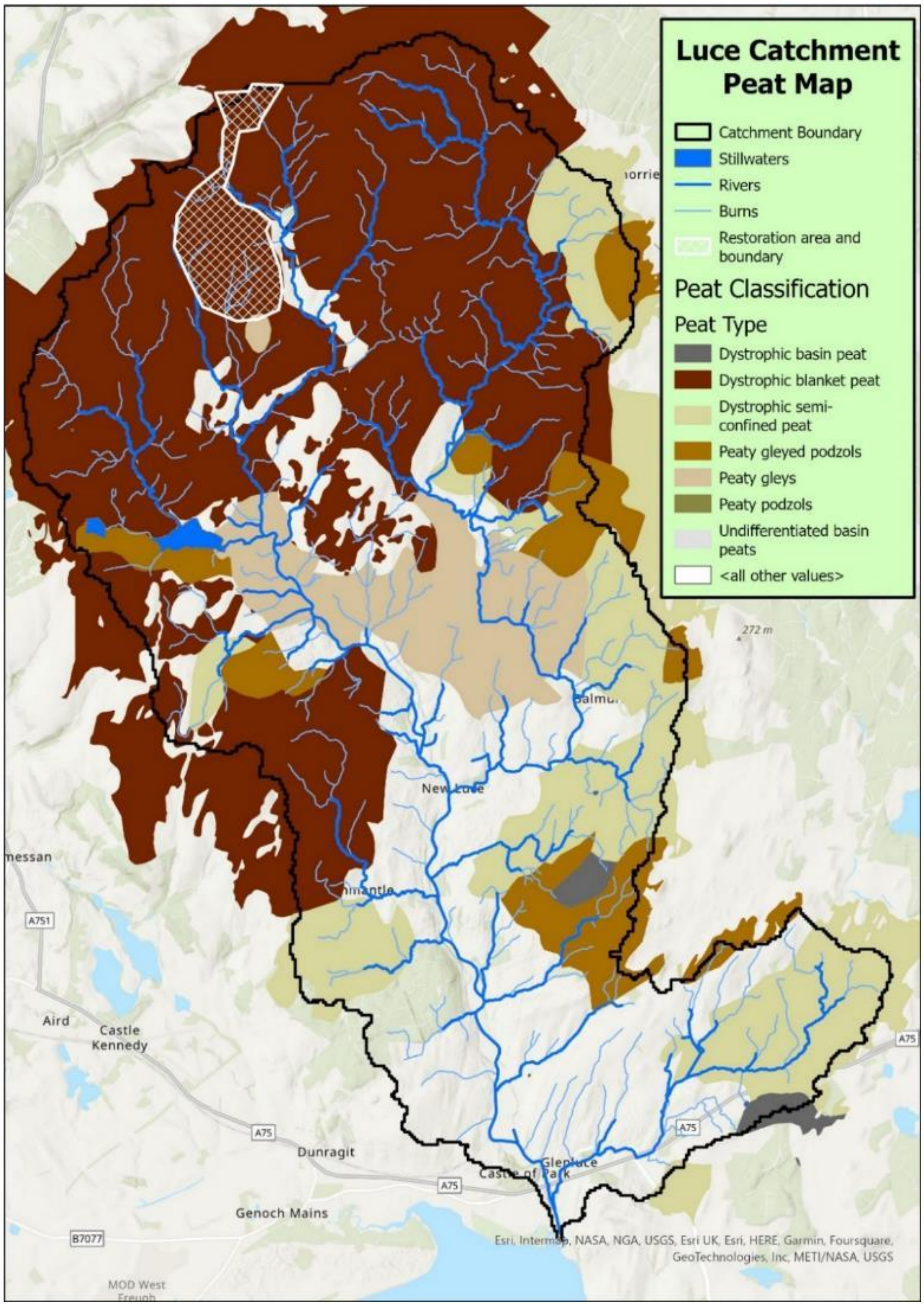
Picture 1: Aerial image of the Upper Main Water of Luce near Lagafater with the extensive hillside drainage clearly visible

Acidification and its impacts on fish populations have been well documented in the Galloway region. However, there appears to be limited information for the Water of Luce catchment. This may be as a result of the Luce catchment having a lower percentage of conifer plantations than neighbouring rivers, and as such being less impacted. If neighbouring Galloway rivers such as the Bladnoch, Cree and Fleet are anything to go by then it is likely that the Luce has suffered from the impacts of acidification (albeit to a lesser extent) but, as a result of improvements in air quality and changes in land use, is in the process of recovery. Some evidence on the current and historic levels of acidification is available through GFT fish surveys. This will be discussed later in this report in the review of GFT electrofishing (fish survey) data.

Some information on current water quality status is available through the Scottish Environment Protection Agency (SEPA) water hub which summarises their water quality monitoring data. The hub splits the Water of Luce catchment into the Water of Luce (below New Luce), the Main Water of Luce, the Cross Water of Luce and the Penwhirn Burn. The most recent SEPA water classification scores the Water of Luce as having “Good” overall status based on a scoring system of “High”, “Good”, “Moderate”, “Poor” and “Bad”. The Main Water and Cross Water of Luce both rate as “Moderate” whilst the Penwhirn Burn above the reservoir rates as “Poor”. For Ecology the Water of Luce scores as having “Good” overall status based on the same scoring system. The Main Water of Luce rates as “Moderate”, the Cross Water of Luce as “Moderate” and the Penwhirn Burn above the reservoir scores as “Poor”. For overall hydrology the Water of Luce scores as having “Good” overall status. The Main Water of Luce scores as “Moderate”, the Cross Water of Luce as “High” and the Penwhirn Burn above the reservoir scores as “High”. It is not clear from the data how many monitoring sites are used to establish classifications so localised variations across each section is likely.

The Water of Luce water quality monitoring during winter 2022/2023 was essentially split into three interconnected projects. The first was a review of the electrofishing data held by GFT. Given the sensitivity of salmon and trout to low pH during sensitive periods of development the aim of the review was to look at the current distribution and density of trout and salmon, to see if there were any areas where fish numbers showed signs of being impacted by poor water quality and to see if there were any changes in fish numbers over time that would indicate improving or declining conditions.

The second was to record pre-restoration water quality data for a proposed peatland restoration project potentially being undertaken by CCC, with post restoration data planned to be collected after completion of the works. The area where peatland restoration is planned is in the upper reaches of the Main Water of Luce around Lagafater Lodge, as shown in Map 3.



Map 3: Water of Luce catchment peat map showing the area where peatland restoration is planned

Like much of the upper Luce catchment the moorland around Lagafater Lodge in the Luce headwaters is dystrophic blanket peat. Over the years the peat has been drained to allow grasses to grow for sheep grazing, which remains the current land use. CCC is currently in discussions with the land owner/tenant farmer regarding potential works. Whilst the long-term plan for the restoration work is still in discussion, the first stage of the works have been agreed in principle in the form of hagg reprofiling to repair areas of active peat erosion. It was hoped that the work would commence in during early 2023, however the work has been delayed and it looks likely that it will now commence during winter 2023/2024.

Picture 2: Clearly visible peatland drainage within the area around Lagafater Lodge where peatland restoration is to take place

Two main watercourses flow from the area where restoration is to take place, the Laggie Burn and the Laganabeastie Burn. GFT has fish data for both burns. However, as a result of an impassable waterfall restricting fish access and limiting numbers fish data from the Laggie Burn has limited use in regards to assessing impacts of water quality on fish populations. However, the Laganabeastie Burn is accessible to migratory fish. As will be seen from the electrofishing review later, fish numbers in the Laganabeastie Burn have generally been poor during the time that GFT has been collecting fish data, with numbers only recently improving to near the levels that would be expected. This historic suppression in fish numbers being a result of acidification/low pH.

The third section of the winter 2022/2023 monitoring was to collect a general record of catchment wide water quality across the upper Luce catchments. The aim was to look at variation in water quality (primarily pH) across both upper catchments to highlight areas of poorer water quality for further gathering of information. It is hoped that once the areas with the poorest water quality has been identified more data can be collected and that this can eventually be linked to land use and/or the current state of the peat.

2 METHOD

2.1 Water of Luce electrofishing data review

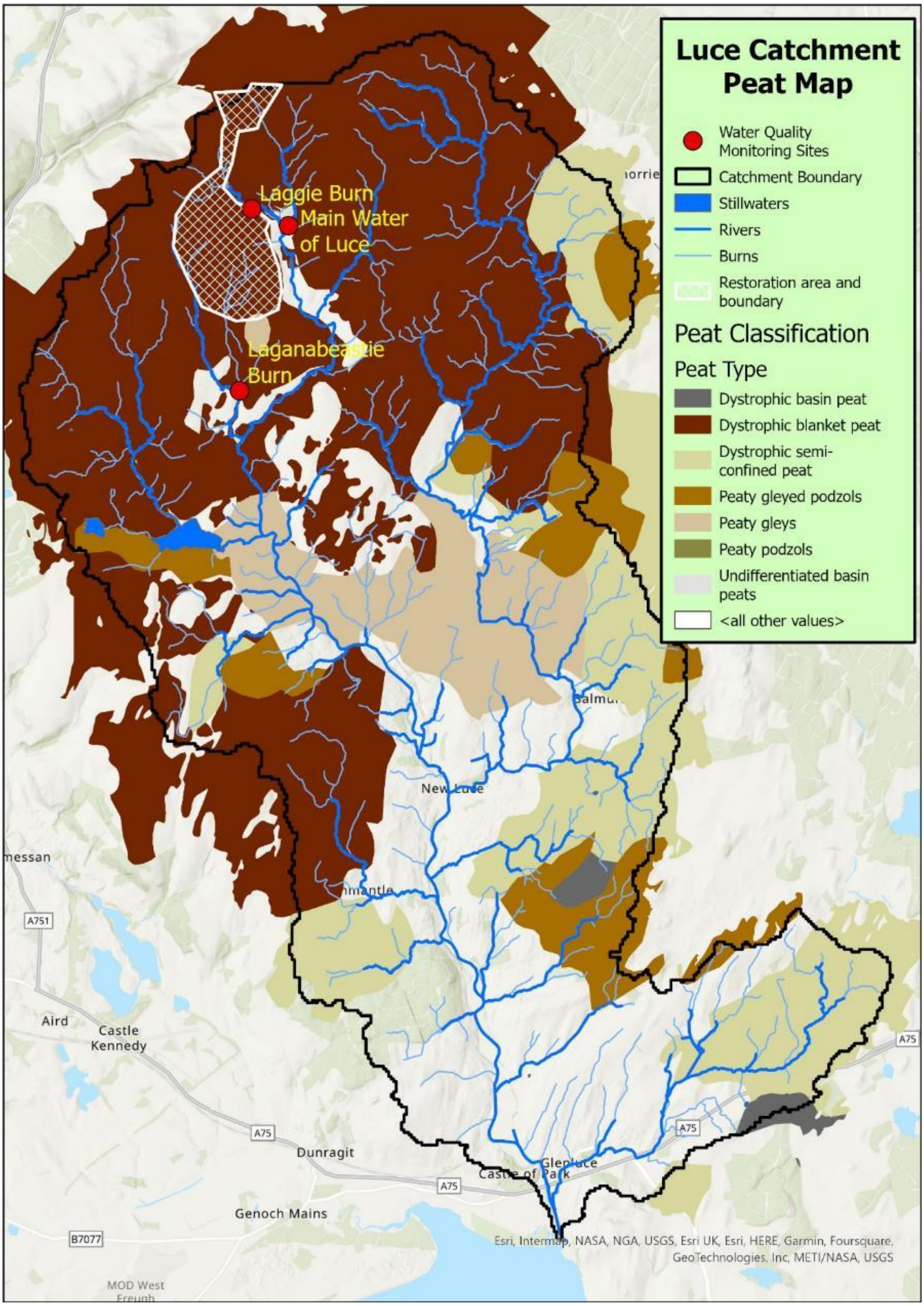
GFT has been carrying out electrofishing surveys on the Water of Luce since the late 1990's, with sites having been visited on and off between 1997 and 2022. Luce electrofishing sites have been chosen and/or visited for a number of purposes. These include general monitoring of fish populations, assessing spatial distribution, monitoring habitat works, contract work and investigative work (e.g. investigating the impacts of acidification on fish populations). As a result the time period within which each site was visited, and the number of times each site has been repeated, varies greatly between electrofishing sites. As the purpose of this electrofishing review is to look at the areas impacted, or potentially impacted, by acidification, only sites within the base-poor geology headwaters and on the main stem of the Main Water of Luce, Cross Water of Luce and lower river have been included (in the case of the latter to see how far the impacts of the acidified headwaters extend downstream).

The electrofishing sampling methodology adopted for most of the electrofishing is one to three run area delineated sampling following the Scottish Fisheries Co-ordination Centre (SFCC) methodology (Scottish Fisheries Co-ordination Centre, 2021). This gives quantitative or semi-quantitative results based on the number of runs completed and gives, at the very least, a minimum estimate of fish density per 100 m^2 for each site. This allows, at the very least, for the first run fish density to be compared between sites. Due to the practical limitations of electrofishing the fish habitat sampled is typically shallow riffle and run habitat which is normally dominated by juvenile salmon and trout, with salmon and trout being both the target species and typically the main native fish species present within watercourses. Sites are normally visited during July, August or September (when fry have grown big enough to be influenced by the electrofishing process). A recent development in electrofishing is the National Electrofishing Programme for Scotland (NEPS) which has been developed by the government funded Marine Directorate to assess juvenile salmon numbers on a national level. As part of the programme the Marine Directorate have used electrofishing data from across Scotland to develop a model which can predict juvenile salmon densities across any stream order 2 - 5 watercourse (Malcolm et al., 2019). This allows electrofishing results from area delineated electrofishing at any site or time period to be compared against the NEPS prediction/benchmark, and whilst the model's predictions are still being developed and refined the predictions provide a point for comparisons between sites and over time. Yet the model cannot predict juvenile trout densities and does not take instream habitat into account. Where possible area delineated salmon electrofishing results have been compared to the NEPS predictions. In all other cases the results are given as a minimum density per 100 m^2 (single run). The results given in this report are for the fry (0 year old "young-of-the-year") stage of salmon and trout. Fry are chosen as their movements from the areas in which they were spawned are more limited than older life stages (Hesthagen, 1988) and therefore give the most accurate indication of whether the eggs of salmon and trout are able to develop and hatch (the stage most susceptible to the impacts of acidification) and, as such, give the best indication of any potential impacts on fish populations caused by acidification. Parr (one year old and over juveniles) move around much more within watercourses meaning they can often be present in areas where water quality may be impacting egg survival. While parr results are shown in some cases they are less reliable in regards to assessing spawning success. Where area delineated electrofishing sites have been visited on five or more occasions the individual results for these sites are shown. However, to allow some sort of comparison that can be used to assess whether there have been changes in trout and salmon numbers over time the results have been assigned into three roughly equal time periods – 1997 to 2005; 2006 to 2014 and 2015 to 2022. Where a site has had more than one visit during a given time period the results have been averaged. It should also be noted that salmon and trout tend to segregate at spawning time with salmon spawning in larger, wider channels (rivers) and trout in smaller, narrower channels (burns). The exact channel width at which salmon spawning changes to trout spawning varies from location to location (and can overlap) but generally speaking shallow riffles and runs within burns under 2 - 3 m average width should be dominated by trout fry (with salmon fry often absent), with larger channels dominated by salmon fry. This has been taken into account within the data analysis with salmon fry results shown for larger channels, trout fry results shown for burns and both shown where salmon and trout fry overlap in significant numbers.

In addition to the area delineated electrofishing GFT has been carrying out a timed salmon fry electrofishing survey of the Luce catchment since 2017. Unlike quantitative/semi-quantitative electrofishing, timed electrofishing uses time instead of area as an indication of capture effort, with the numbers of fish captured giving an imprecise, but comparable, indication of fish density. GFT samples for five minutes during timed electrofishing. Whilst timed electrofishing gives less accurate data on fish numbers it does allow comparisons between sites with similar characteristics. In addition, timed electrofishing is quicker and allows greater coverage within a catchment in a much shorter period of time. As such the timed electrofishing on the Luce is generally used to show spatial variation in salmon fry density across the whole catchment. The variation in fish numbers captured between sites, and over time, from the Luce have been used to assess what the timed electrofishing results represent in regards to relative fish densities, and a rough scoring system has been devised that allows results to be assessed based on a "traffic light" system. More detailed information on the Luce timed electrofishing methodology and scoring can be found at: https://www.gallowayfisheriestrust.org/timed-electrofishing-surveys-luce-urr.php

2.2 Lagafater pre-peatland restoration water quality data collection

The pre-restoration monitoring for the potential Lagafater peatland restoration centred on two burns which drain the restoration area (the Laggie Burn and the Laganabeastie Burn) and one control site at the top of the Main Water of Luce (sometimes known as the Black Glen Burn). The sites are shown on Map 4.



Map 4: Pre-peatland restoration water quality monitoring sites at Lagafater

Water quality was recorded using EXO1 Sondes. The Sondes record water quality parameters at 15 minute intervals after deployment. Sondes were trialled in previous years of the project to assess their accuracy/suitability to monitor water quality. During that period, of the Sonde sensors that are currently available, the decision was made to record pH, Dissolved Organic Matter (DOM), Dissolved Oxygen (DO) and conductivity at monitoring sites.

Each parameter was chosen for the following reason:

- pH – acidification of upland waterbodies on base-poor geology is a significant problem within the Galloway region. A number of scientific papers have linked degraded peat with increased acidification in watercourses.
- Dissolved Organic Matter – as extensive drainage is often the primary cause of damage to Peatlands and as the drainage results in the peat eroding around the drains and entering watercourses DOM represents a direct measure of the levels of suspended solids within watercourses.
- Dissolved Oxygen – as peat is partly decomposed organic matter decomposition is likely to continue (but at a faster oxydised rate) when it enters rivers/burns through bacterial action. The increase in bacteria associated with increased volumes of organic matter increases Biological Oxygen Demand and can lead to reduced oxygen levels within watercourses.
- Conductivity – the ease at which an electric current can pass through water is directly related to the level of particulate matter in the watercourse. As such conductivity represents another method of recording the amount of suspended solids resulting from Peatland erosion.

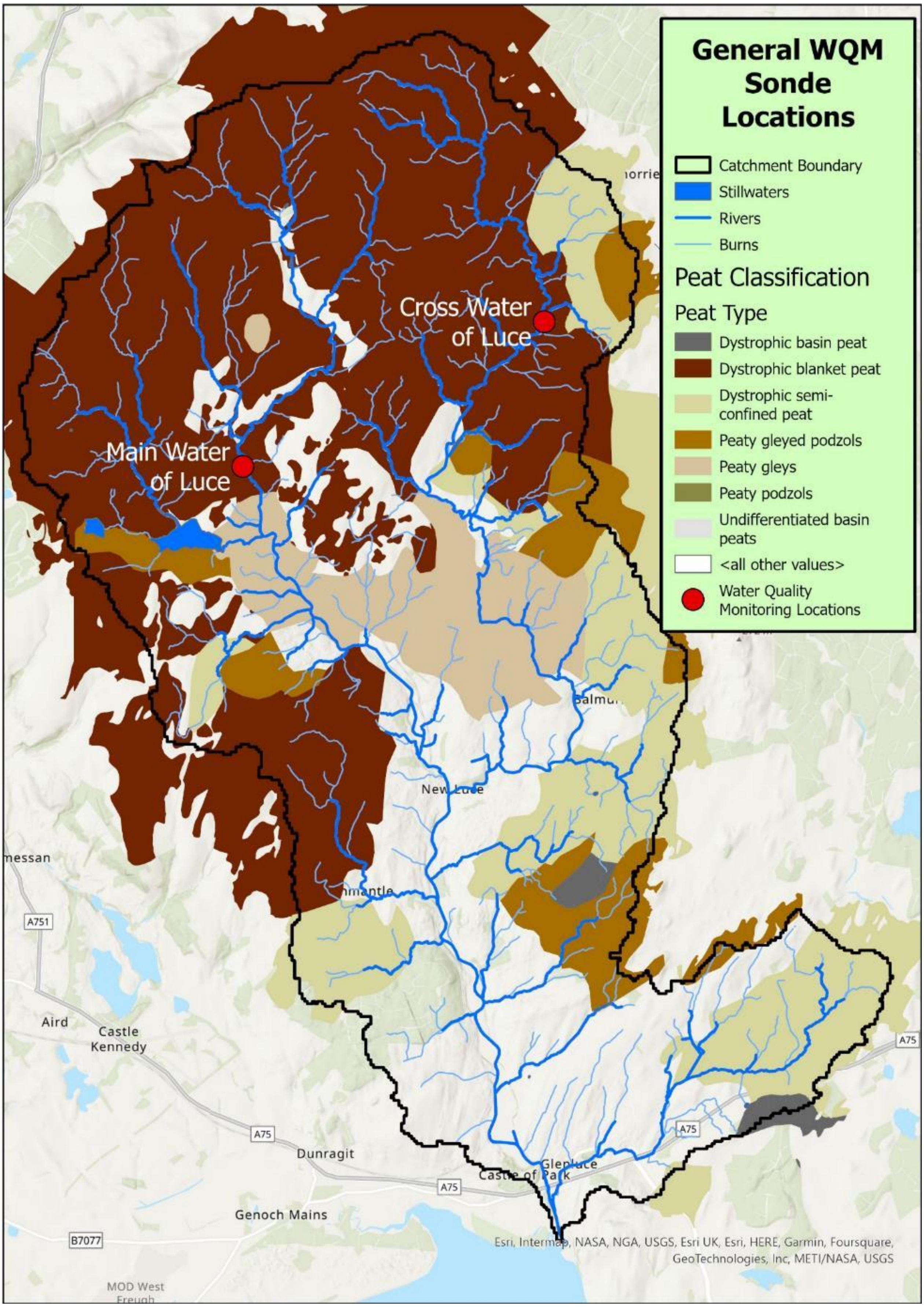
Sondes were calibrated before each deployment and after every month of continual use. The Sondes were held in place submerged within monitoring sites using frames constructed out of drainpipe and supported by wooden stobs as shown in Picture 3.

Picture 3: Frame designed to support the EXO1 Sonde at the Laggie Burn water quality monitoring site

The Sondes are located within the lower, submerged sections of pipe, which are perforated to allow water to pass through. During winter 2022/2023 Sondes were deployed at the three sites from 23/12/2022 to 25/01/2023.

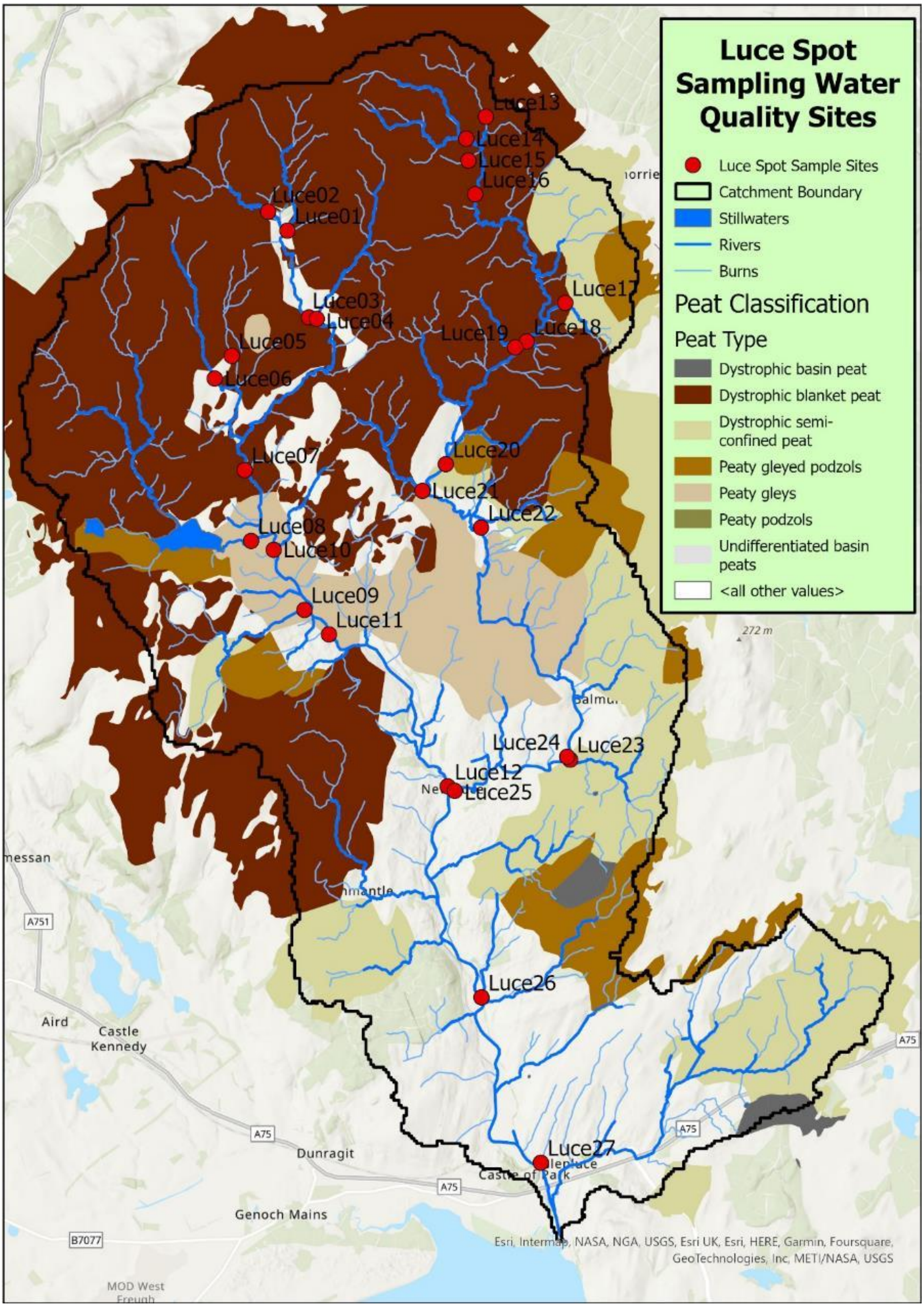
2.3 Water of Luce water quality overview

To gain an overview of water quality for the Water of Luce Sondes were initially deployed at central locations on the Main Water of Luce and Cross Water of Luce between 03/02/2023 and 08/03/2023. The locations chosen were at Dalnigap (MWoL) and Miltonise (CWoL) and are shown in Map 5. The water quality parameters recorded are the same as those for the Lagafater pre-restoration monitoring, for the same reasons.



Map 5: Water quality monitoring locations on the Main Water of Luce at Dalnigap and Cross Water of Luce at Miltonse

In addition to the deployment of the EXO1 Sondes a number of spot water samples were taken from sites spread around the Luce catchment. This involves collecting water samples from chosen locations within watercourses after periods of high flows to catch pH at, or near, its lowest levels. Once collected water samples are taken back to the GFT office and water quality parameters are recorded using an EXO1 Sonde retained within the office. Whilst Sondes deployed in the field provide detailed information on trends in water quality their cost limits the number of locations from which data can be collected at any one time. Although only one reading is collected from a single point in time, spot sampling allows data to be collected from a large number of sites in a relatively short period of time allowing any spatial relationships to be investigated and allowing areas to be highlighted for further, more detailed investigation.

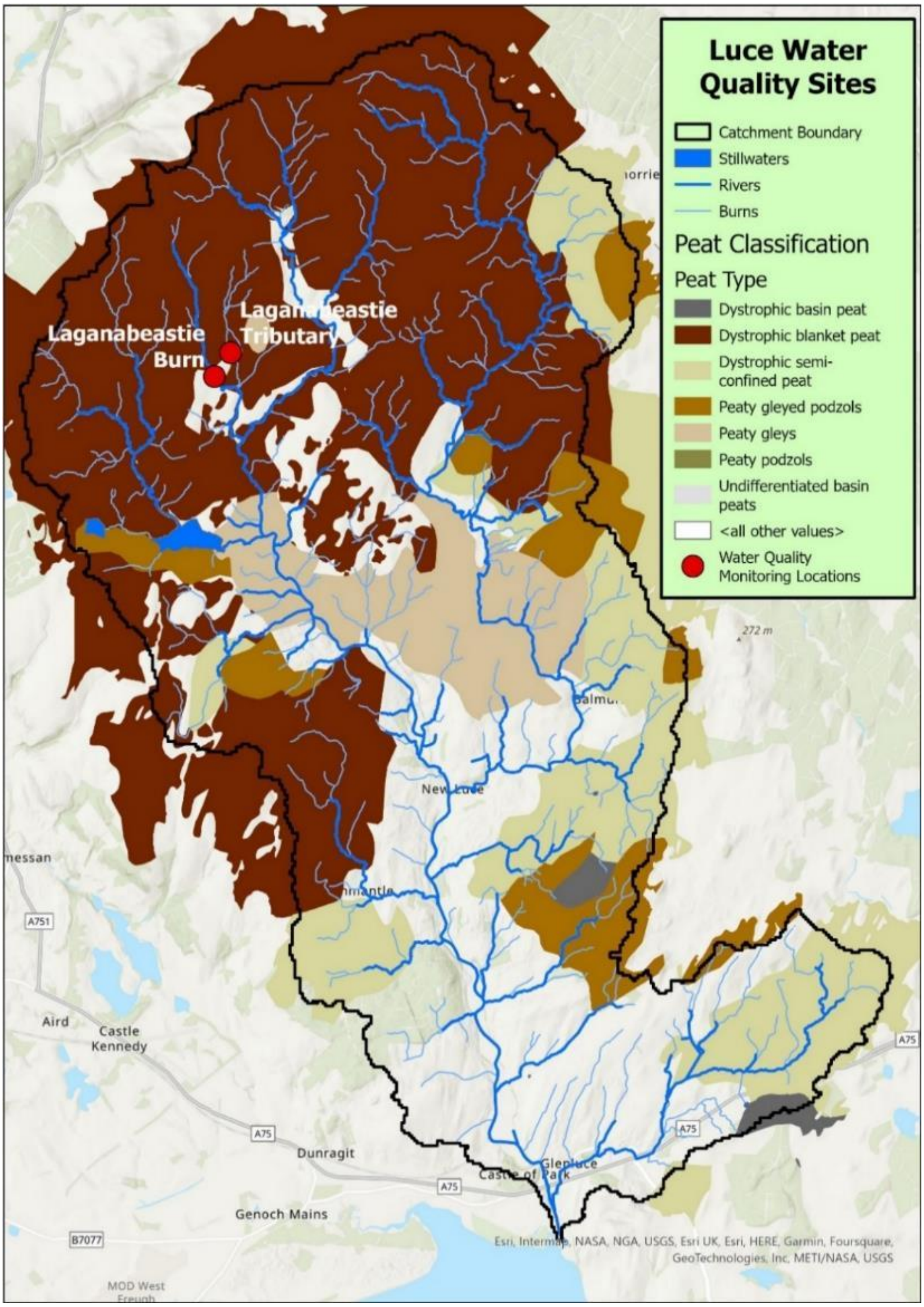


Map 6: Proposed spot sampling sites within the Water of Luce catchment

Map 6 shows the chosen spot sampling sites for the Water of Luce catchment. Sites were chosen to give the maximum coverage possible within the time available. Spot sampling was carried out after periods of rainfall on 17/02/2023, 13/03/2023 and 16/03/2023. Unfortunately due to issues securing access sites Luce13, Luce14, Luce15, and Luce16 could not be sampled during each sampling event. It is hoped access issues can be sorted out and one more spot sampling event can be carried out in winter 2023/2024 and added to the results at a later date. The number of times spot sampling events could take place was also restricted to three as a result of a period of unseasonably dry weather during February and early March.

2.4 Additional targeted data collection

After analysis of the results from the general water quality monitoring sites on the Main and Cross Waters of Luce and from the spot sample sites the decision was taken to redeploy two Sondes for the final period of the project to allow for more targeted data collection. This was to give detailed water quality data for watercourses that recorded some of the lowest pH values. The upper Main Water of Luce was identified as the area in which pH readings were generally lowest. The decision was taken to re-deploy one of the Sondes in the Laganabeastie Burn, although the monitoring site was moved further upstream from the previous (planned) peatland restoration monitoring site to be above where a small un-named tributary burn flows in. The second Sonde was deployed within the small un-named tributary burn. Map 7 shows the sites. Water quality data was collected between 17/03/2023 and 26/04/2023.

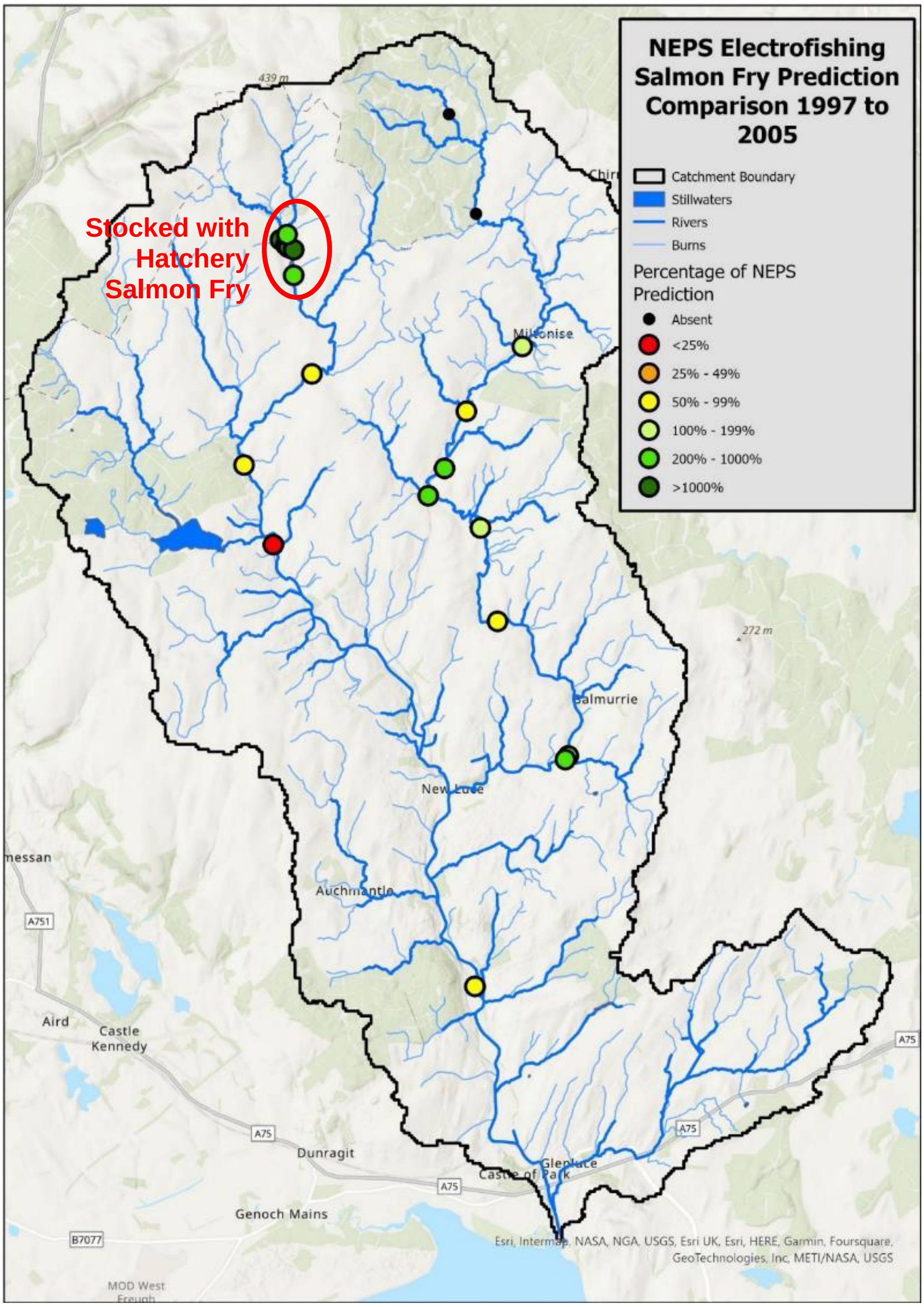


Map 7: Water quality monitoring locations on the Laganabeastie Burn and Laganabeastie tributary

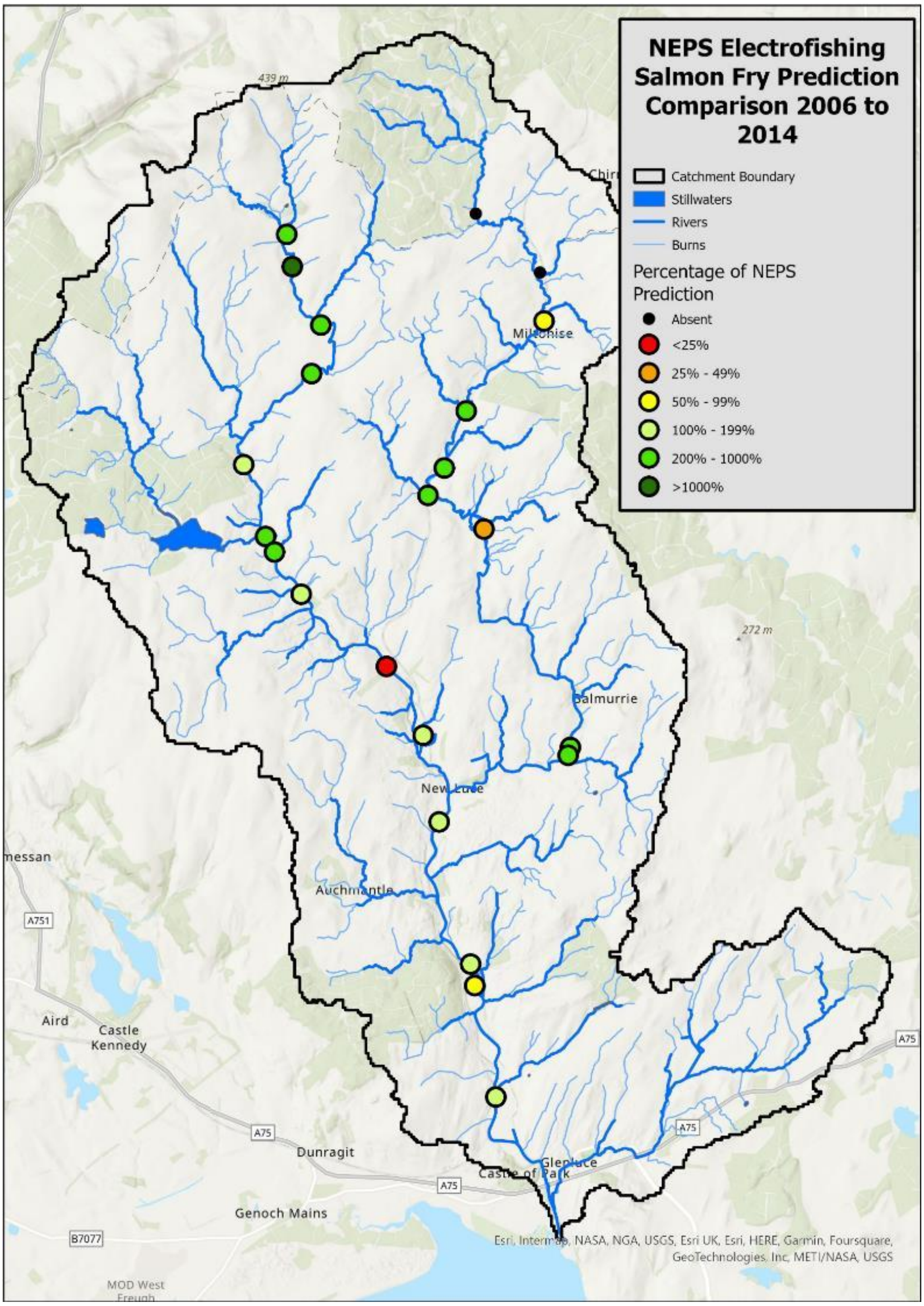
3 RESULTS

3.1 Water of Luce electrofishing data review

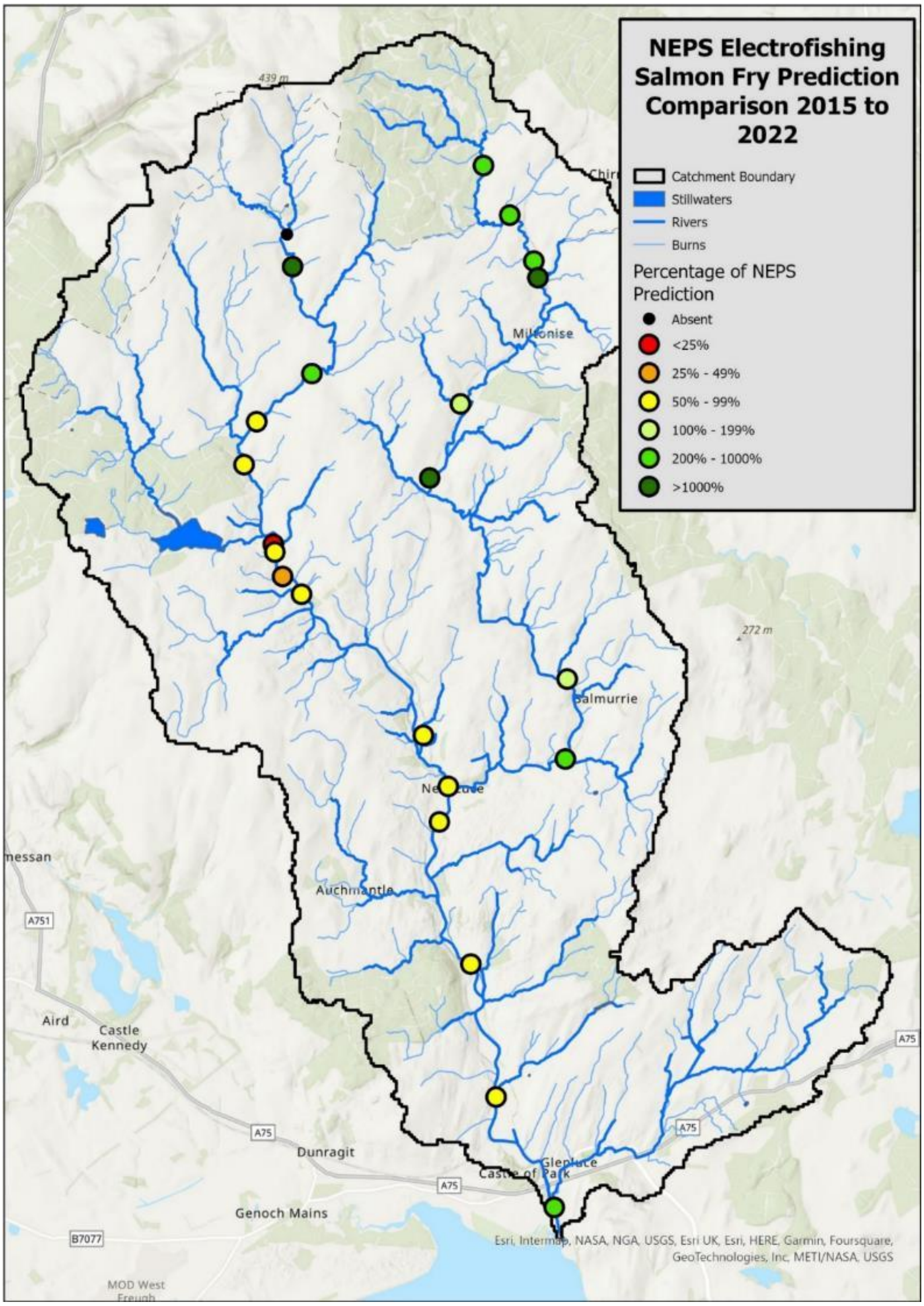
The salmon fry electrofishing results for the Water of Luce from the 1997 – 2005, 2006 – 2015 and 2015 - 2022 time periods have been compared to the NEPS predictions and are shown on Maps 8 to 10. Within the maps the GFT electrofishing results have been displayed as a percentage of the NEPS prediction and converted into a rough scoring system as shown on the map legends.



Map 8: Luce salmon fry electrofishing results from 1997 – 2005 compared to NEPS predictions



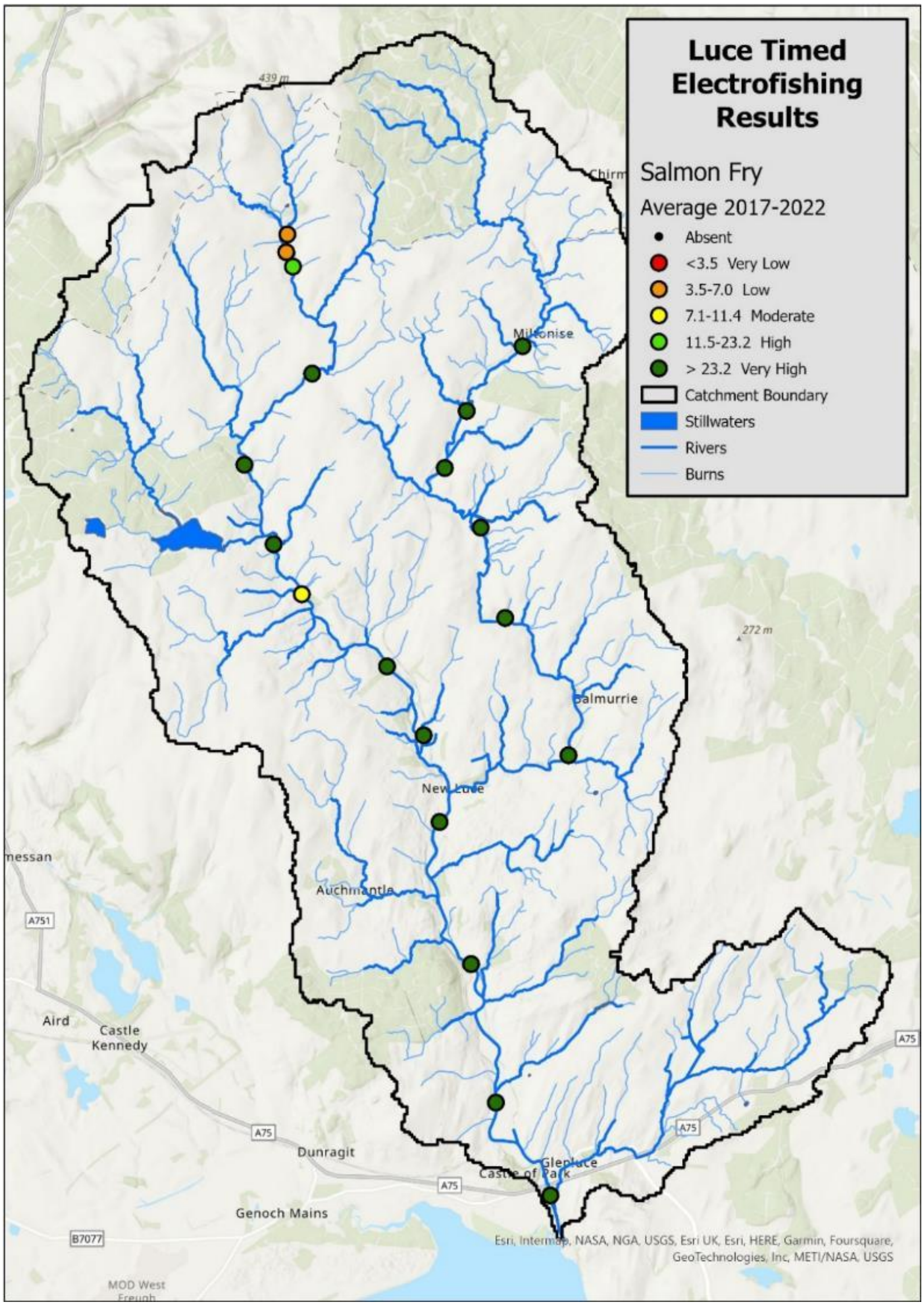
Map 9: Luce salmon fry electrofishing results from 2006 – 2014 compared to NEPS predictions



Map 10: Luce salmon fry electrofishing results from 2015 – 2022 compared to NEPS predictions

Due to the difference in the location and number of sites between each period it is difficult to draw anything conclusive from the salmon fry results. There does, however, seem to be some improvement in salmon fry numbers. There appears to be some improvement on the Main Water of Luce between the 1997-2005 and the 2006-2015 time periods. However, the most noticeable improvement is seen on the Cross Water of Luce above Miltonise. Salmon fry were mostly absent from this section of river between 1997 and 2014 but were found at densities well above the NEPS predictions after 2014, likely indicating a recovery in water quality from a more acidified state. One other point of note is the fall in salmon fry densities between 2006-2014 and 2015-2022 on the main stem of the Water of Luce and lower Main Water of Luce.

This is likely unrelated to water quality and more likely a consequence of a fall in numbers of adult salmon returning from the sea as has been recorded in salmon rod catches across Scotland. Whilst the results show a drop in numbers the densities recorded still represent numbers close to the NEPS benchmark. This is supported by the timed electrofishing map (Map 11) were average captured salmon numbers in the last five years still mostly score within the higher ranges of the scoring system.



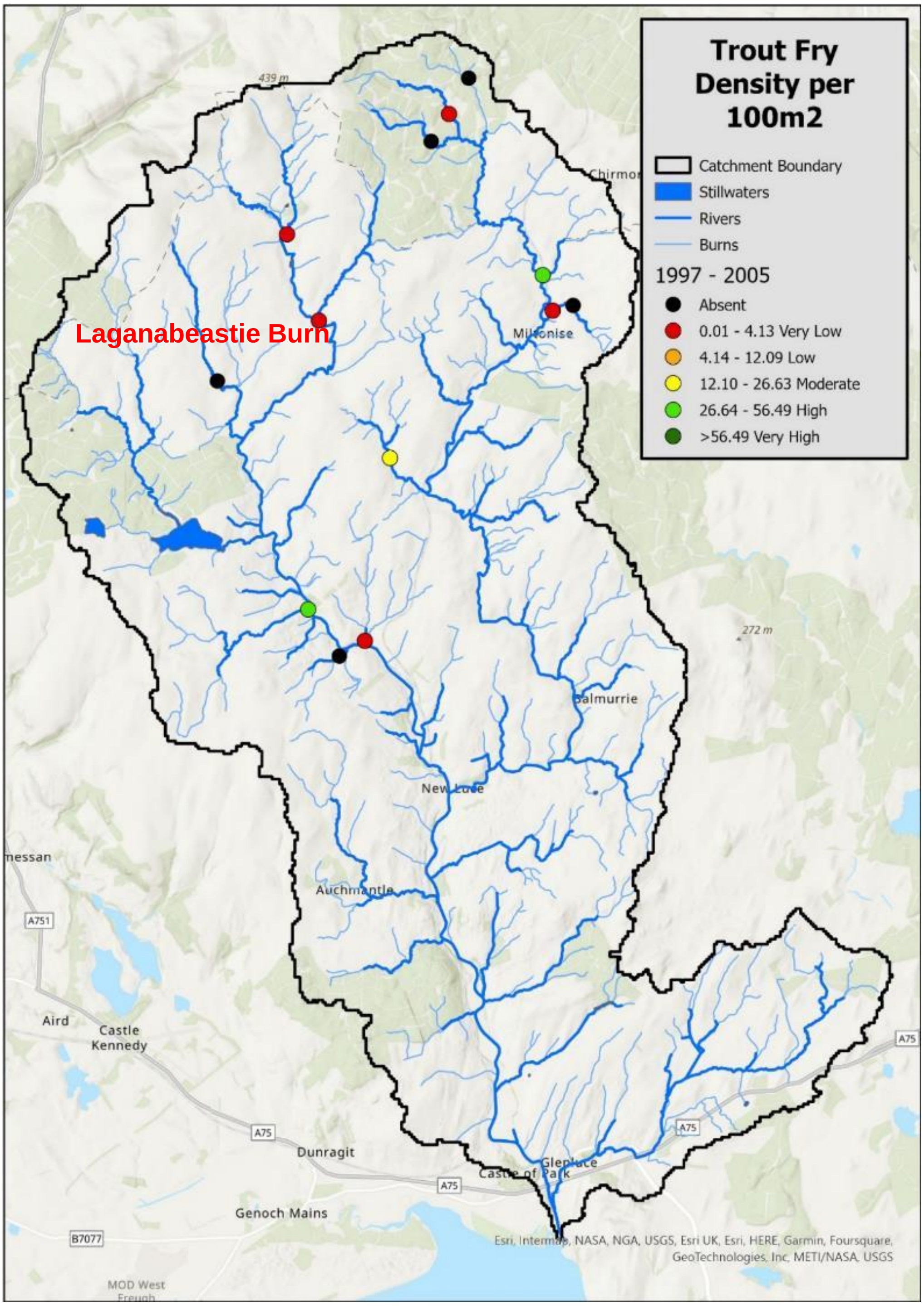
Map 11: Average timed electrofishing results per five minutes sampling from the Luce 2017 to 2022

Whilst there are no NEPS predictions for trout fry a scoring system for one run area delineated electrofishing has been created for the Solway rivers (Godfrey, 2006) as shown in Table 1, allowing analysis of Luce trout fry results.

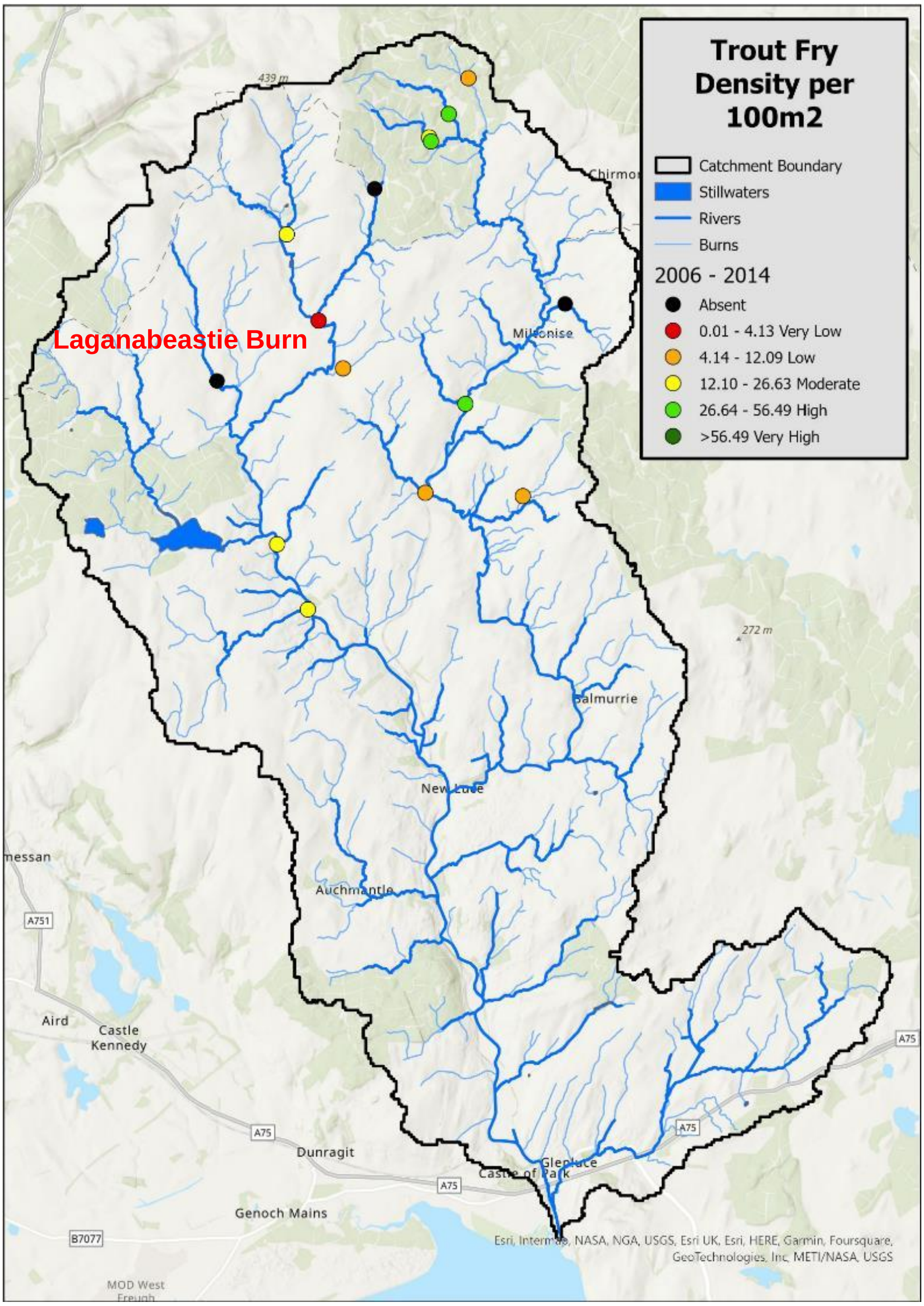
Table 1: Quintile ranges for trout fry per 100 m^2 based on one run electrofishing events, calculated on densities >0 from 291 sites in the Solway statistical region

Percentile	One Run Trout Fry Density/100 m^2
Minimum (Very Low)	0.38
20th Percentile (Low)	4.14
40th Percentile (Moderate)	12.09
60th Percentile (High)	26.63
80th Percentile (Very High)	56.49

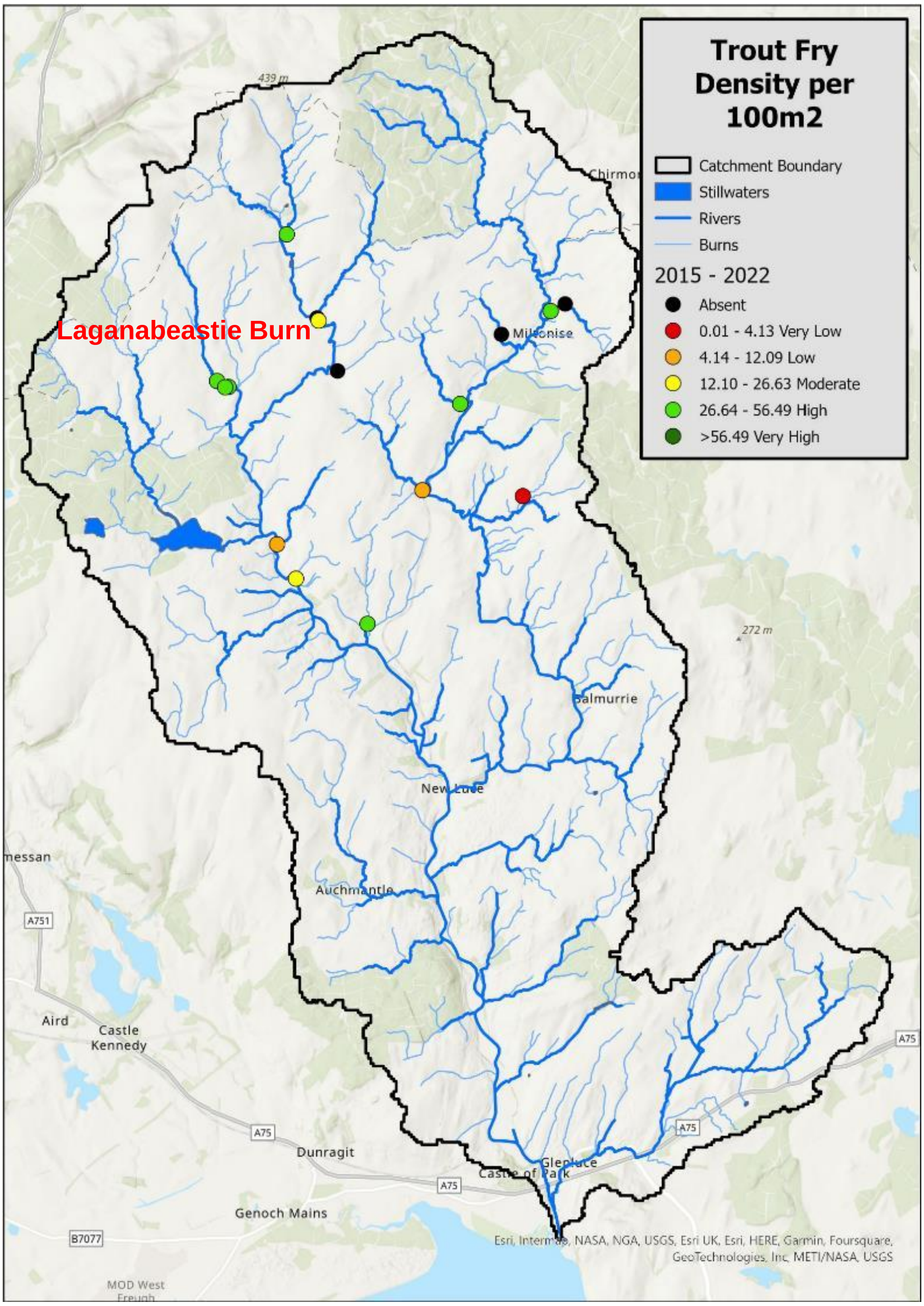
The trout fry results from the Main Water of Luce and Cross Water of Luce trout spawning burns for the 1997 - 2005, 2006 - 2015 and 2015 - 2022 time periods are shown in Maps 12, 13, and 14.



Map 12: Trout fry electrofishing results from 1997 – 2005



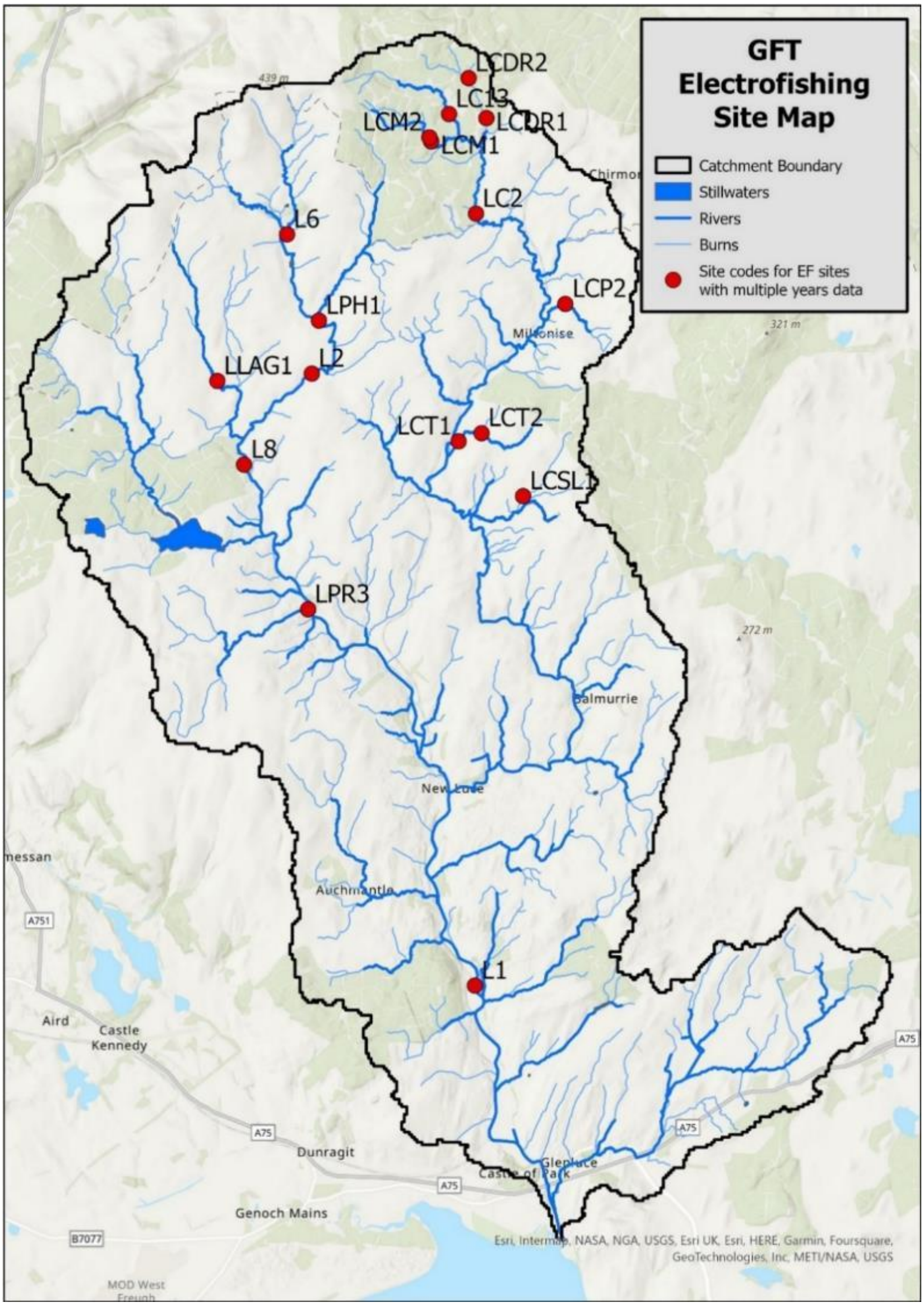
Map 13: Trout fry electrofishing results from 2006 – 2014



Map 14: Trout fry electrofishing results from 2015 – 2022

As with the salmon fry electrofishing results the variation in the number of sites, and locations of sites, between the different time periods make it difficult to judge the results with high confidence. However, the results again appear to show an improving picture with a reduction in the percentage of sites scoring in the “Absent” or “Very Low” categories when compared to the earliest data. Two trends appear of note. First is the change in results in the uppermost sites on the Cross Water of Luce above Miltonise between the 1997-2005 and 2006-2014 time periods. Second is the 2015-2022 results from the Laganabeastie Burn (marked on the 2015-2022 map). Both showed significant increases in trout fry numbers from mostly “Absent” results during earlier surveys and most likely show the results of improving water quality and a reduction in acidity.

Within the electrofishing results there are a number of sites that have been visited repeatedly since GFT electrofishing began. Sites with five or more years of data are shown, juvenile trout or salmon results (or both) are shown depending on which should be/is the dominant spawning species within the areas surveyed. Map 15 shows the location of the sample sites, Table 2 gives the site information and the results are displayed on Graphs 1 to 17.

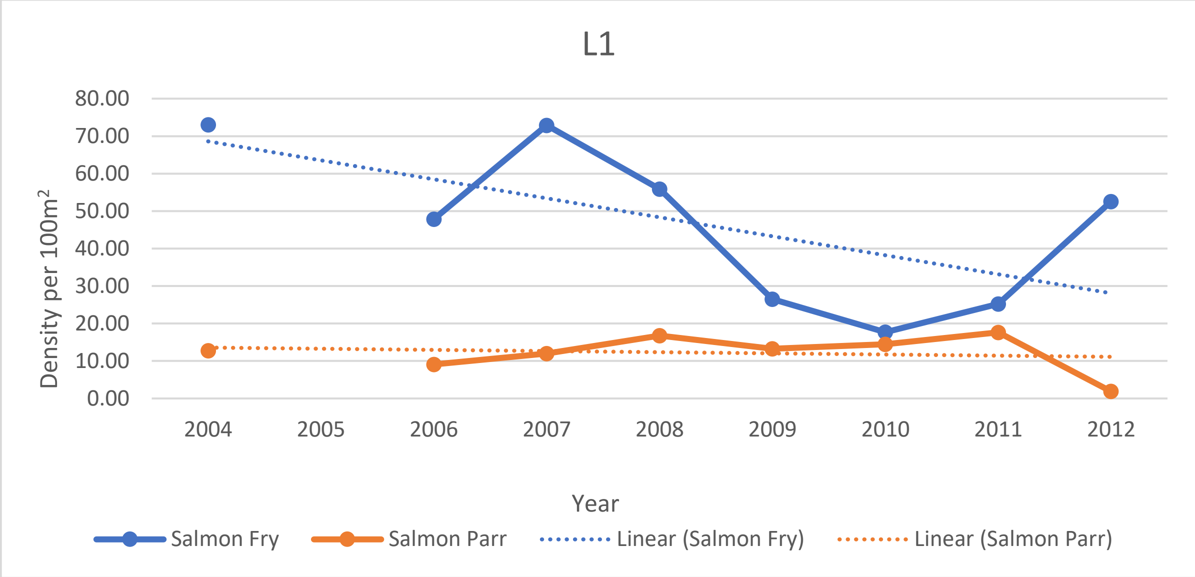


Map 15: Locations of electrofishing sites with five or more years of electrofishing data

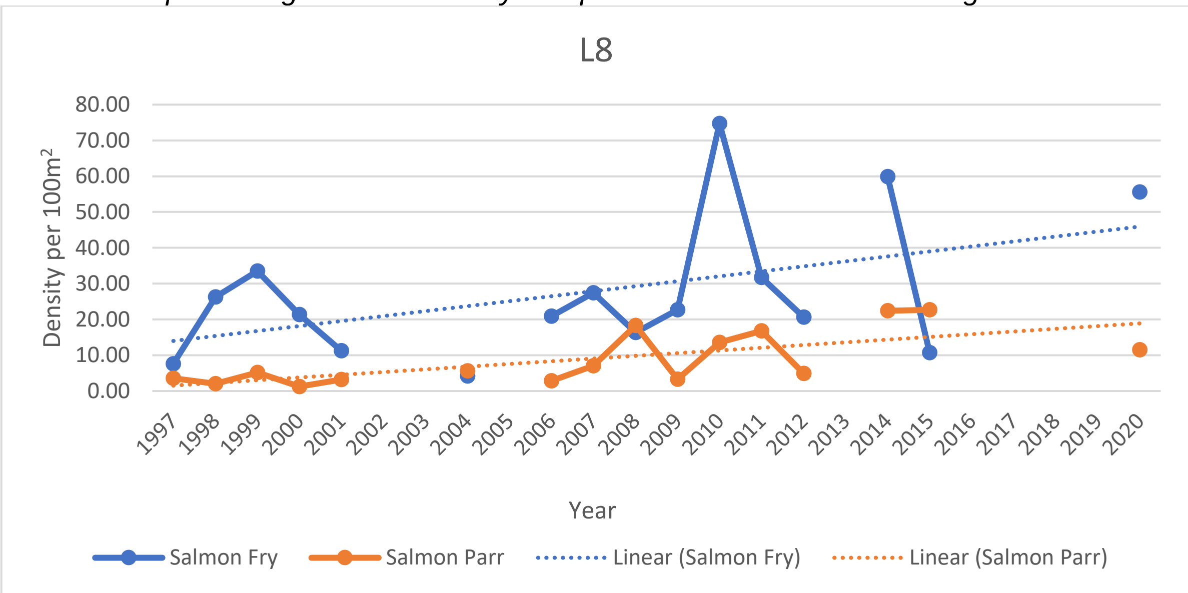
Table 2: Location details for electrofishing sites with five or more years of electrofishing data

Site Code	Easting	Northing	Channel Order 1	Channel Order 2	Channel Order 3
L1	217868	560807	Water of Luce		
L8	213328	571064	Water of Luce	Main Water of Luce	
L2	214658	572860	Water of Luce	Main Water of Luce	
L6	214168	575600	Water of Luce	Main Water of Luce	
LPR3	214585	568215	Water of Luce	Cross Water of Luce	Pulryan Burn
LLAG1	212799	572714	Water of Luce	Main Water of Luce	Laganabeastie Burn
LPH1	214800	573900	Water of Luce	Main Water of Luce	Pilhatchie Burn
LC2	217886	576007	Water of Luce	Cross Water of Luce	
LCSL1	218814	570446	Water of Luce	Cross Water of Luce	Shiels Lane
LCT1	217548	571527	Water of Luce	Cross Water of Luce	Tryock Burn
LCT2	218000	571690	Water of Luce	Cross Water of Luce	Tryock Burn
LCP2	219648	574234	Water of Luce	Cross Water of Luce	Pilwhirn Burn
LCM1	217007	577432	Water of Luce	Cross Water of Luce	Mull Burn
LCM2	216966	577509	Water of Luce	Cross Water of Luce	Mull Burn
LC13	217353	577974	Water of Luce	Cross Water of Luce	Un-named burn
LCDR1	218091	577889	Water of Luce	Cross Water of Luce	Drummacorra Burn
LCDR2	217739	578677	Water of Luce	Cross Water of Luce	Drummacorra Burn

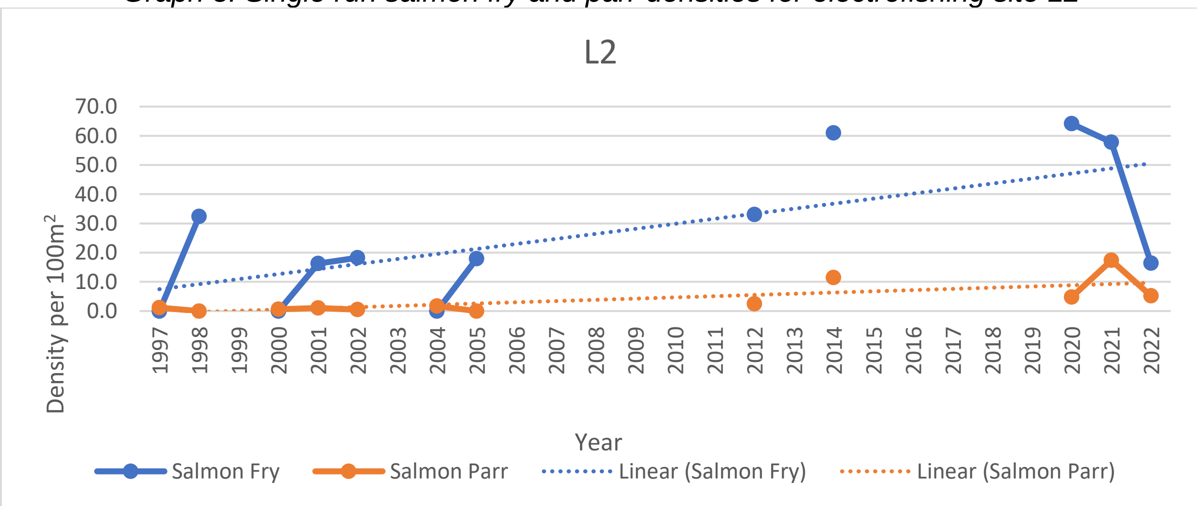
Graph 1: Single run salmon fry and parr densities for electrofishing site L1



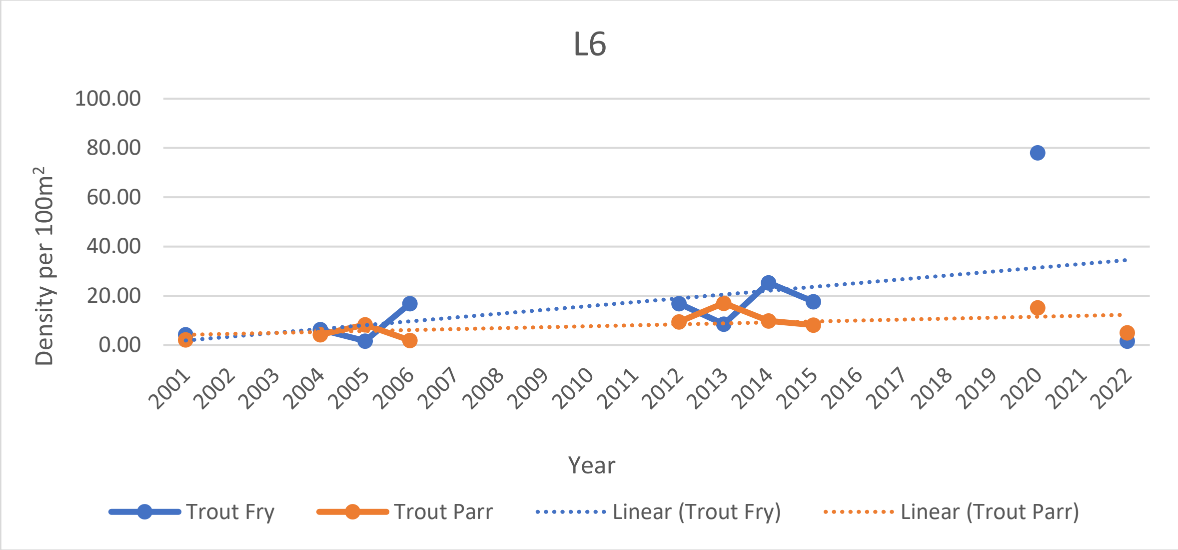
Graph 2: Single run salmon fry and parr densities for electrofishing site L8



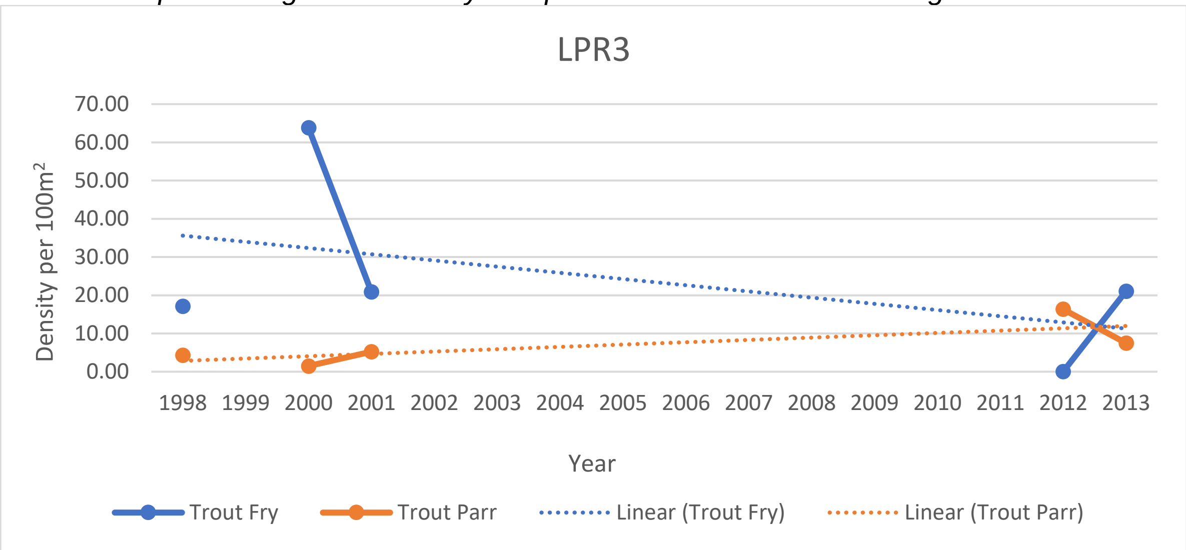
Graph 3: Single run salmon fry and parr densities for electrofishing site L2



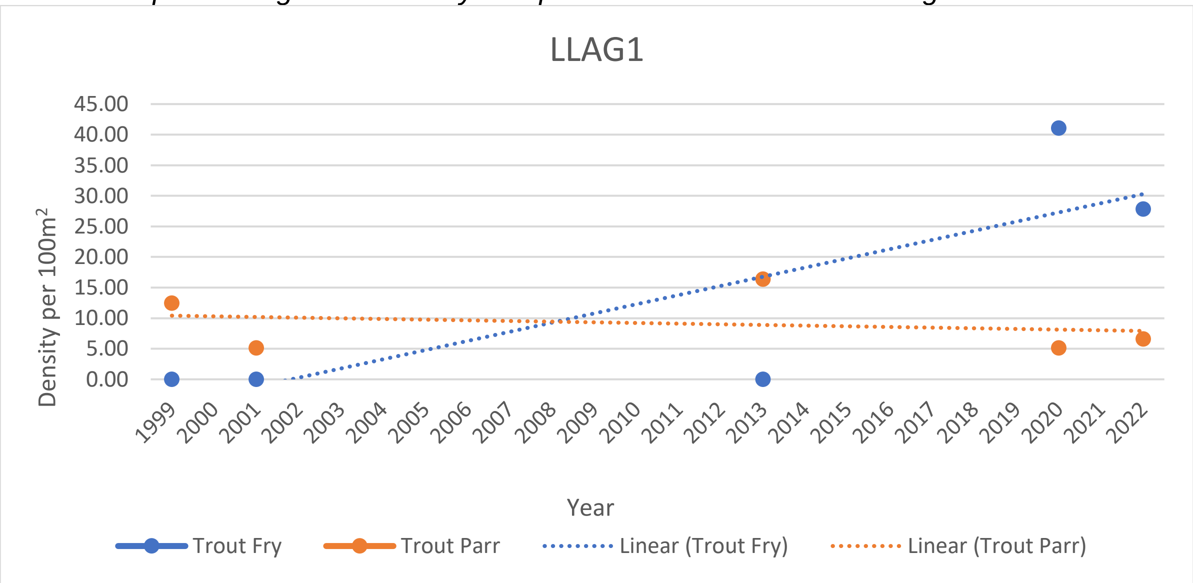
Graph 4: Single run trout fry and parr densities for electrofishing site L6



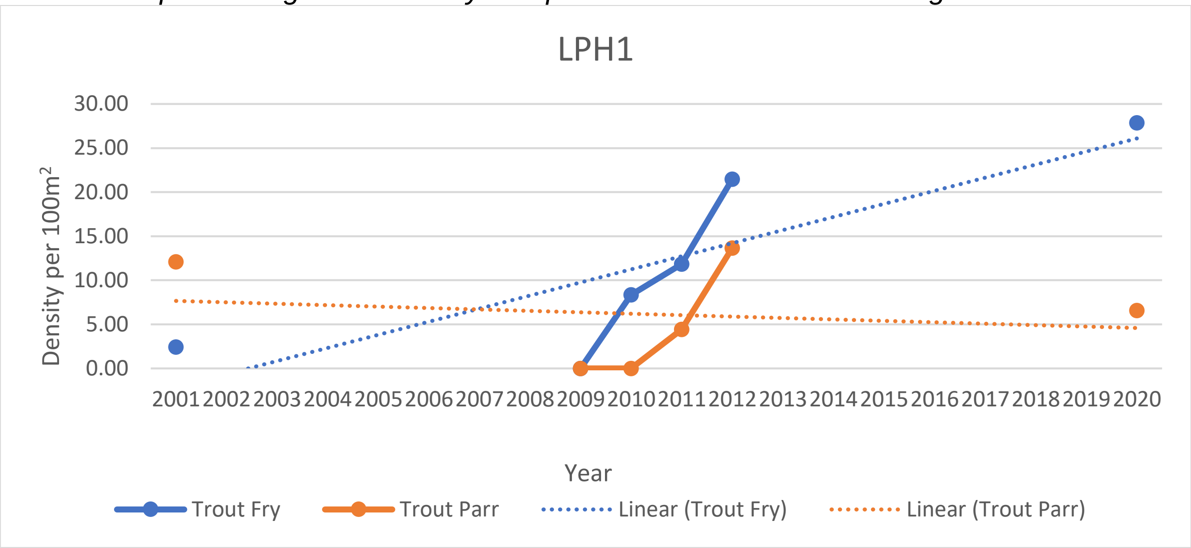
Graph 5: Single run trout fry and parr densities for electrofishing site LPR3



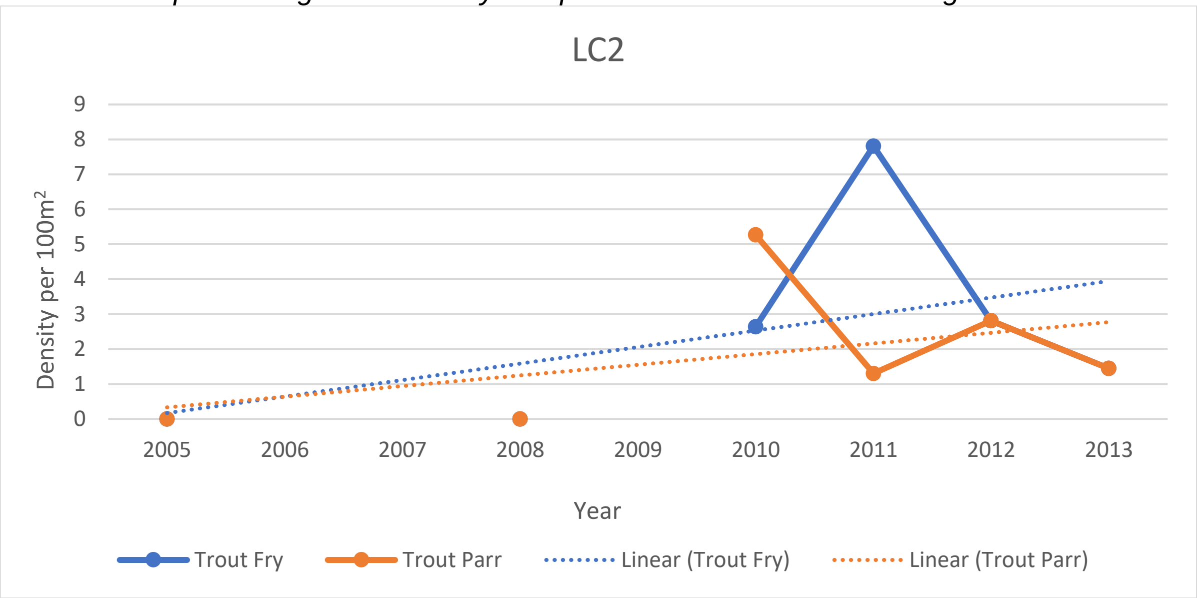
Graph 6: Single run trout fry and parr densities for electrofishing site LLAG1



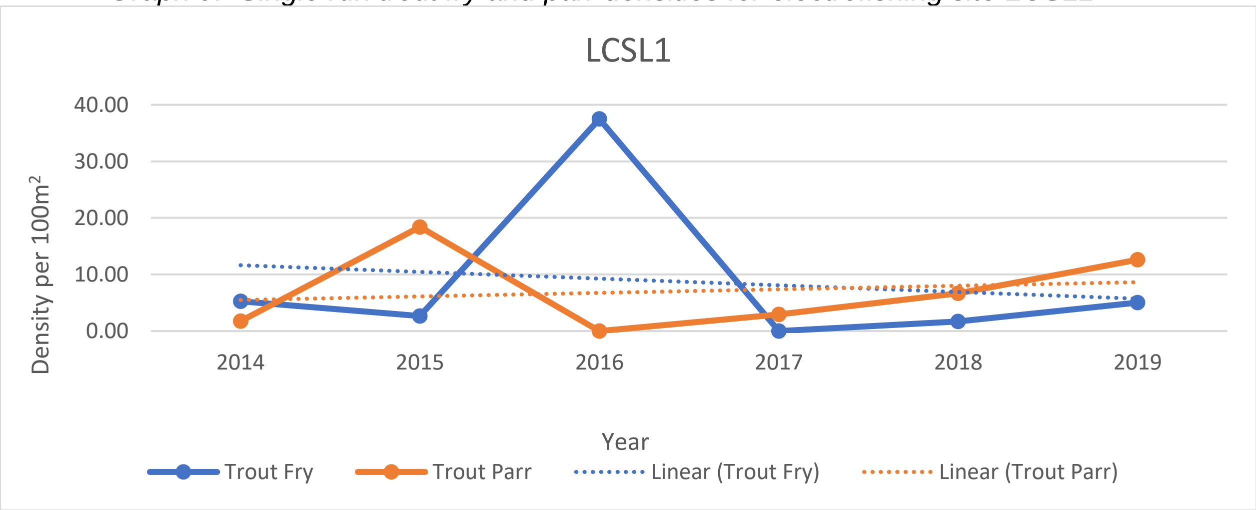
Graph 7: Single run trout fry and parr densities for electrofishing site LPH1



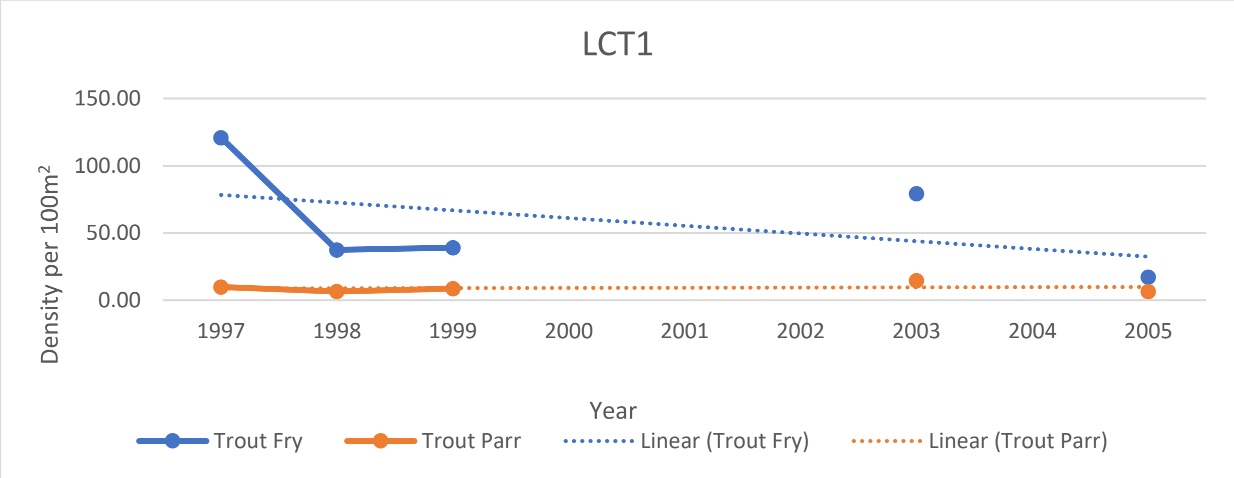
Graph 8: Single run trout fry and parr densities for electrofishing site LC2



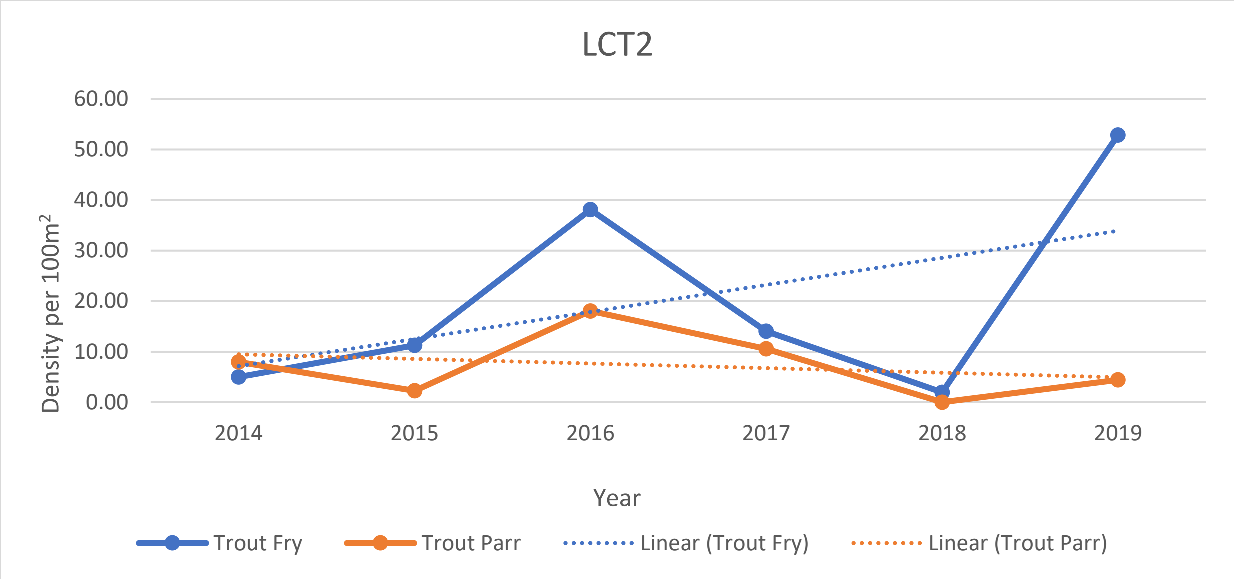
Graph 9: Single run trout fry and parr densities for electrofishing site LCSL1



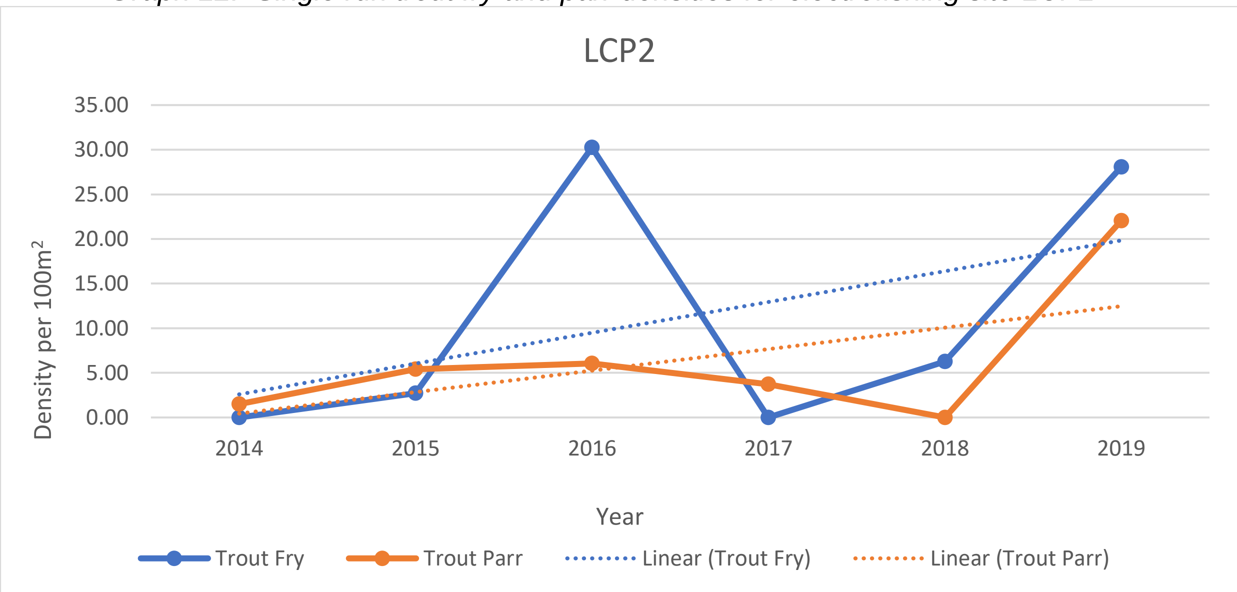
Graph 10: Single run trout fry and parr densities for electrofishing site LCT1



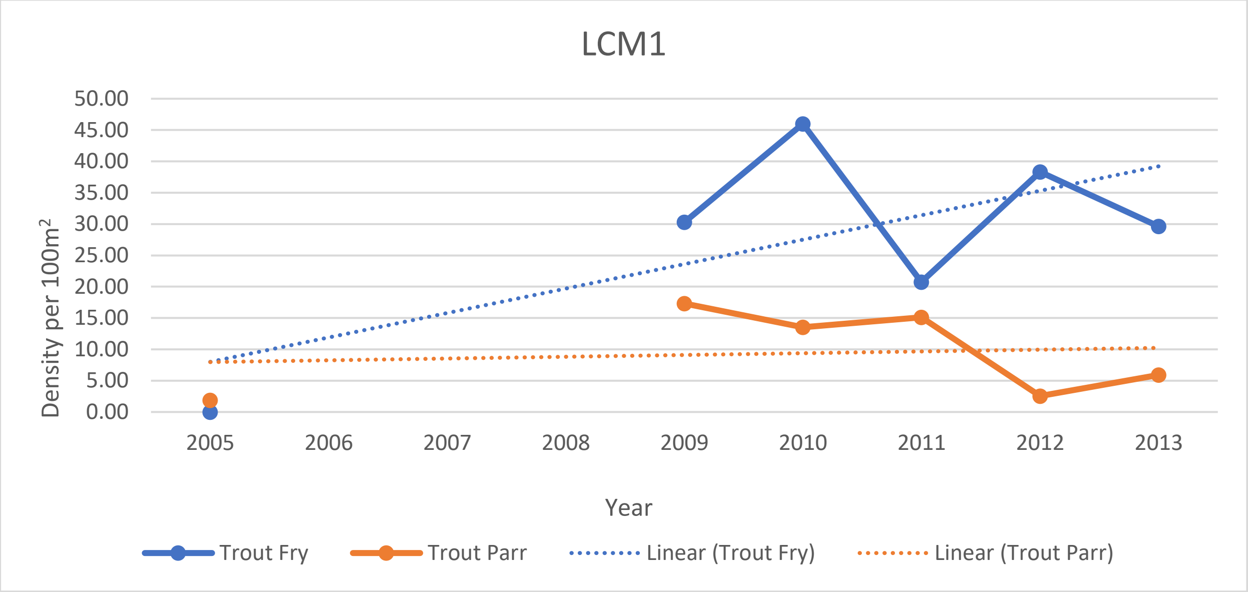
Graph 11: Single run trout fry and parr densities for electrofishing site LCT2



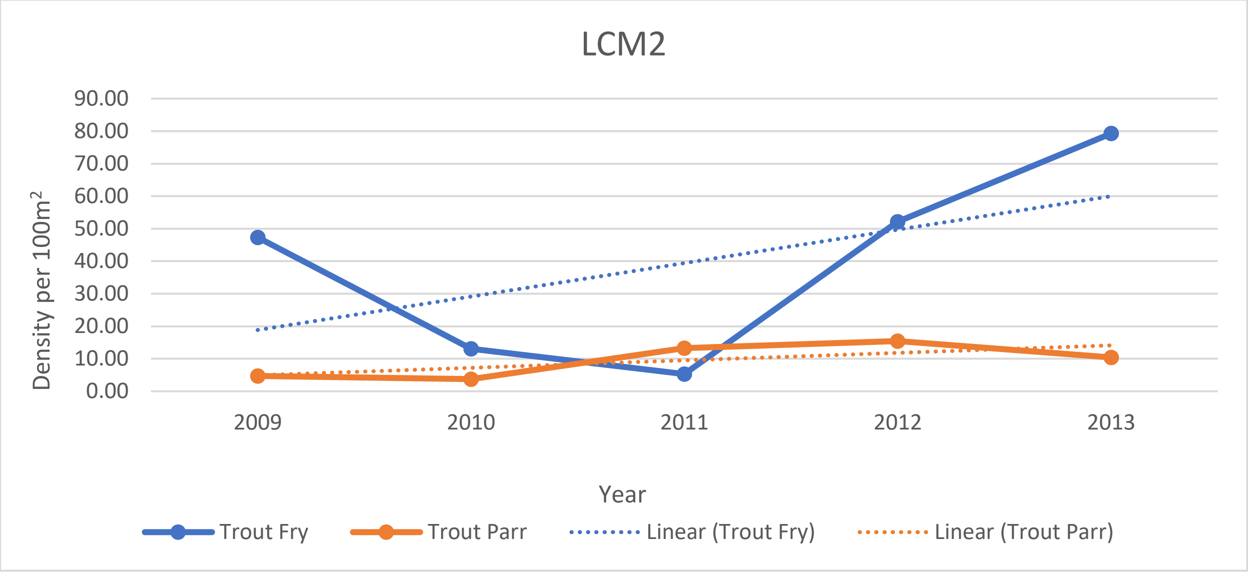
Graph 12: Single run trout fry and parr densities for electrofishing site LCP2



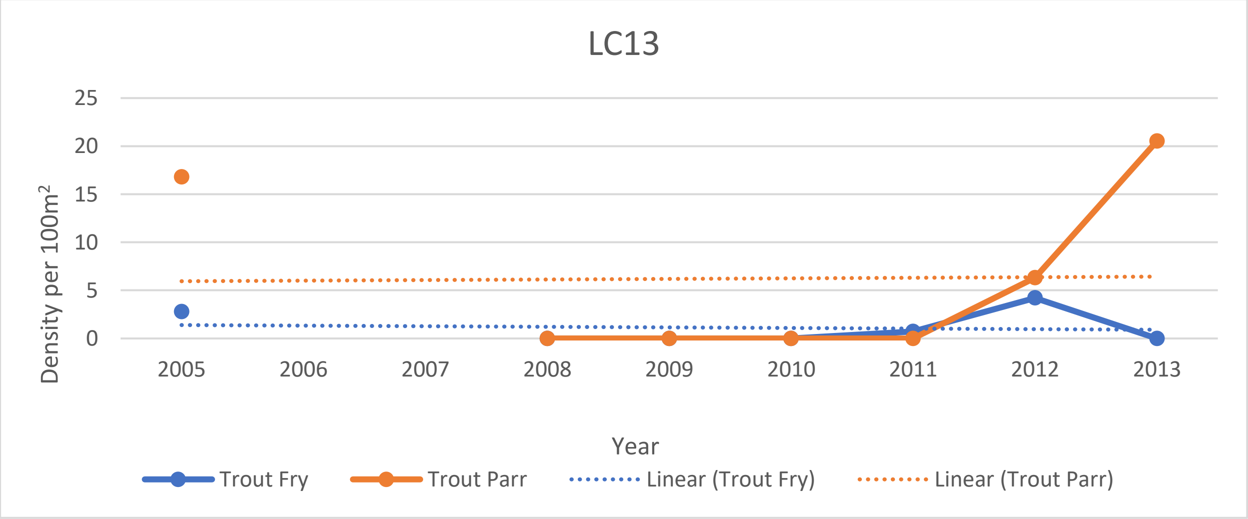
Graph 13: Single run trout fry and parr densities for electrofishing site LCM1



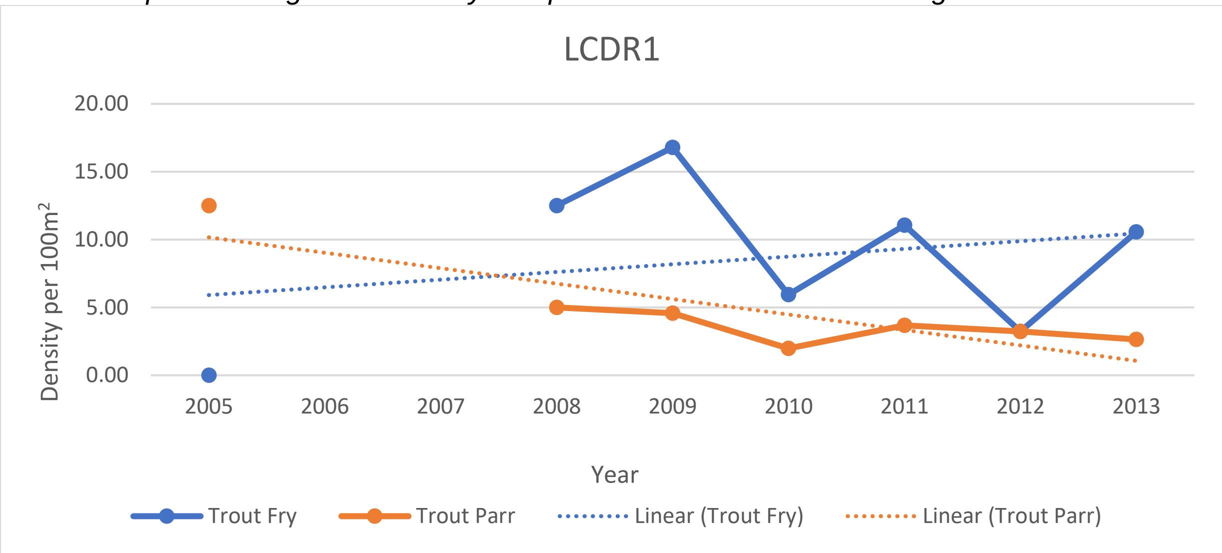
Graph 14: Single run trout fry and parr densities for electrofishing site LCM2



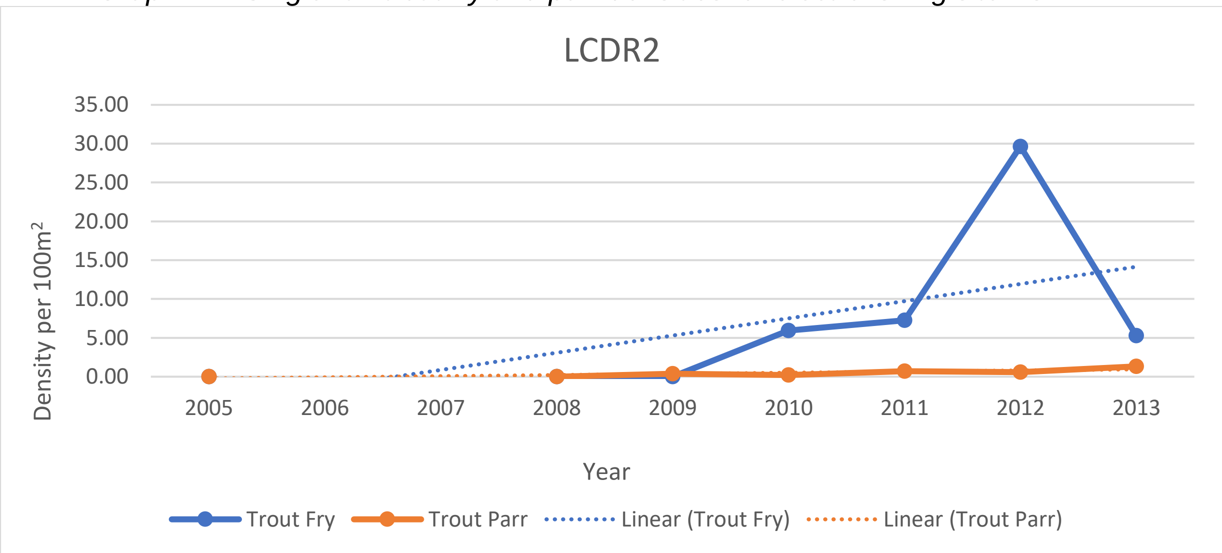
Graph 15: Single run trout fry and parr densities for electrofishing site LC13



Graph 16: Single run trout fry and parr densities for electrofishing site LCDR1



Graph 17: Single run trout fry and parr densities for electrofishing site LCDR2

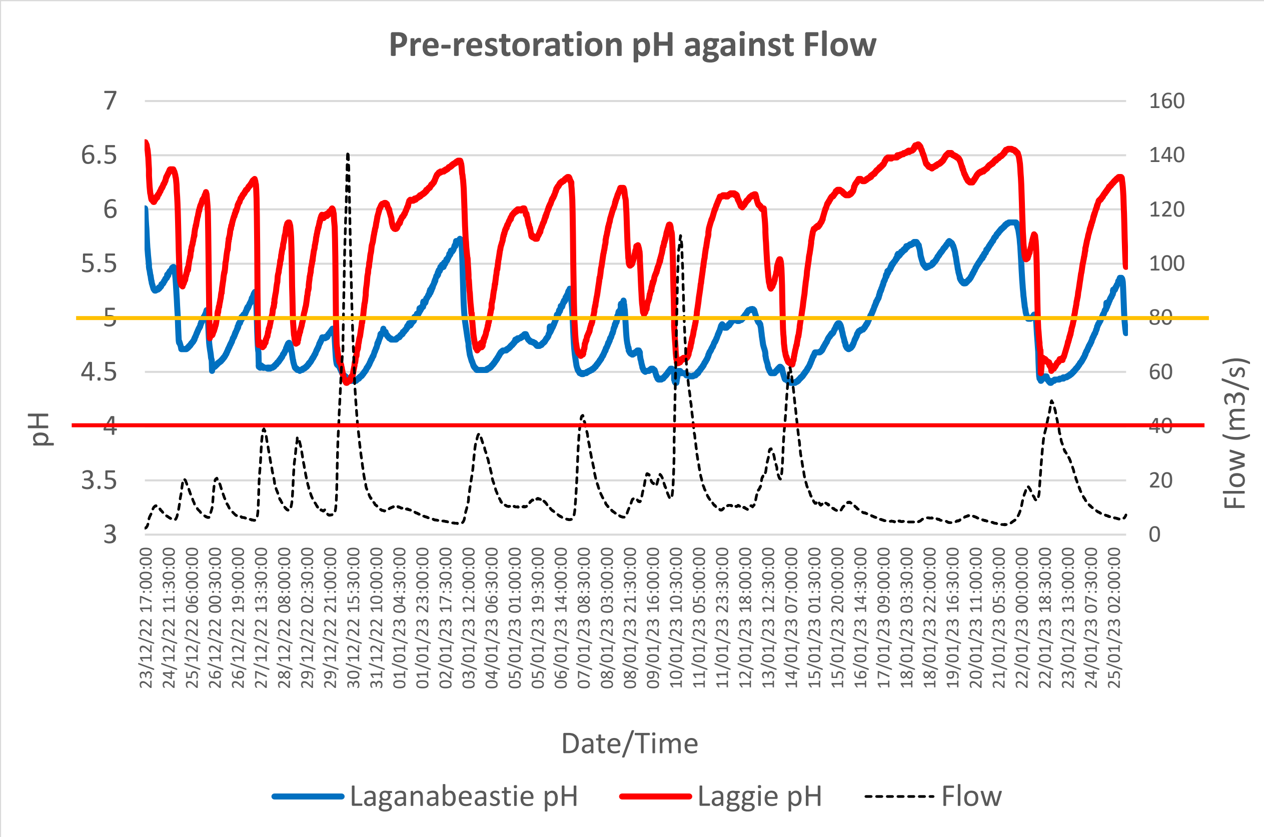


It should be noted that the period over which each individual site was sampled varies. The trends over time for each site also vary. There are only three sites that are located in wider channel widths that are dominated by salmon fry (L1, L8 and L2). The rest of the sites are located on burns and are dominated by trout fry. The three salmon sites follow the same trend as was seen in the NEPS benchmark comparisons, with site L1 in the lower catchment showing an overall decline and sites L8 and L2 in the Main Water of Luce showing overall increases in salmon fry and parr densities. The trout fry results are more varied but generally show the same trends as was seen previously. Sites LLAG1, LPH1, L6, LCT2, LCP2, LCM1, LCM2, LCDR1 and LCDR2 all showed an overall increases in trout fry densities. Sites LPR3, LCSL1, LCT1 and LC13 showed a declining trend. However, of the sites showing a decline all but LC13 are burns lower down the system where acidification is likely to have had less of an impact, with two of the sites only being surveyed during the earliest recording period (1997 – 2005) before improvements in fish numbers generally started to pick up speed within the upper catchments.

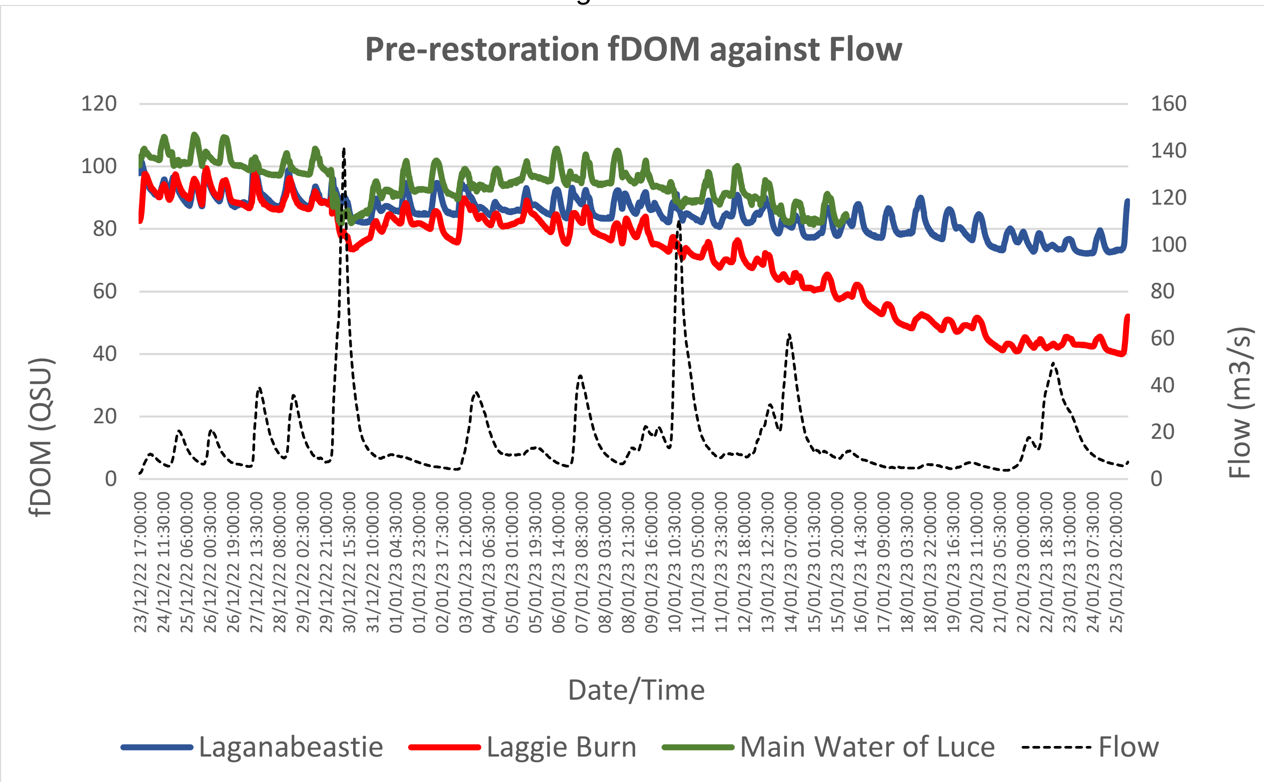
3.2 Lagafater pre-peatland restoration water quality data collection

The pre-restoration water quality data for the Laggie Burn, Laganabeastie Burn and Main Water of Luce (control) was downloaded on the 21st January 2023, giving just over one month of water quality readings at 15 minute intervals (over 6,000 records). On viewing the data it was realised that the Sonde deployed in the Main Water of Luce sampling control site developed a fault in the pH sensor after only two readings, essentially resulting in no useable pH data being collected. Whilst the other sensors from this Sonde recorded data initially, additional issues with the batteries resulted in no data being collected beyond 16th February. There were no issues with the Sondes in the Laggie and Laganabeastie Burns with the results for pH, fDOM, conductivity and DO shown on Graphs 18 to 21. The pH levels of concern to trout and salmon (as discussed earlier in the report) are highlighted on the pH map. This is standard on all pH maps within this report.

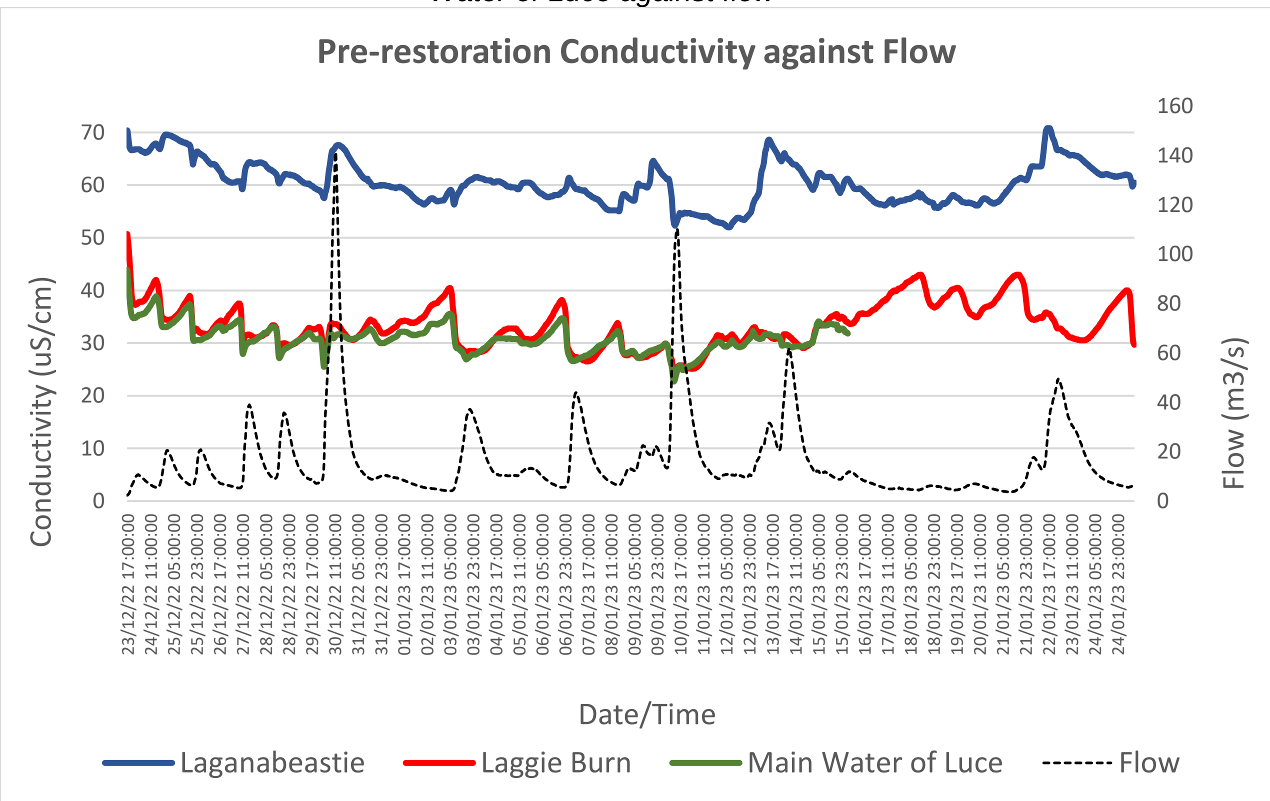
Graph 18: pH comparison for the Laggie and Laganabeastie Burns against flow with ph4 and ph5 highlighted on the graph



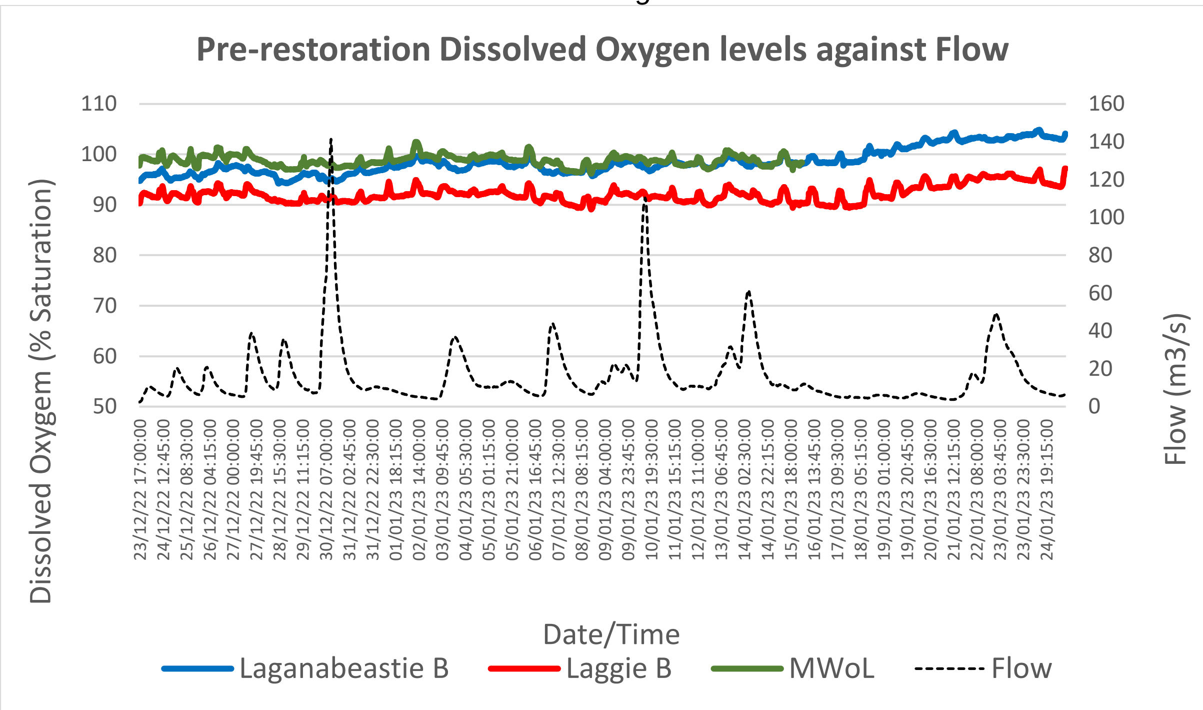
Graph 19: fDOM comparison for the Laggie and Laganabeastie Burns and Main Water of Luce against flow



Graph 20: Conductivity comparison for the Laggie and Laganabeastie Burns and Main Water of Luce against flow



Graph 21: Dissolved Oxygen comparison for the Laggie and Laganabeastie Burns and Main Water of Luce against flow



Relative depth readings are recorded by pressure sensors on the Sondes. Unfortunately, they cannot give accurate flow reading. To provide more accurate data flow readings (in m^3/s) the SEPA gauging station on the main stem of the Water of Luce at Airyhemming has been used. The station is just over 20 km downstream from most recording sites. As such there will be a time delay between water levels rising at the monitoring sites and at the gauging station, and the flows will not show localised variations between sites. However, even when taking this into account it was decided that the SEPA data was the most accurate data available in regards to assessing the impact of flow on the recorded water quality parameter's. As a result the SEPA flow data is used to represent flows in all graphs within this report where flow levels are shown.

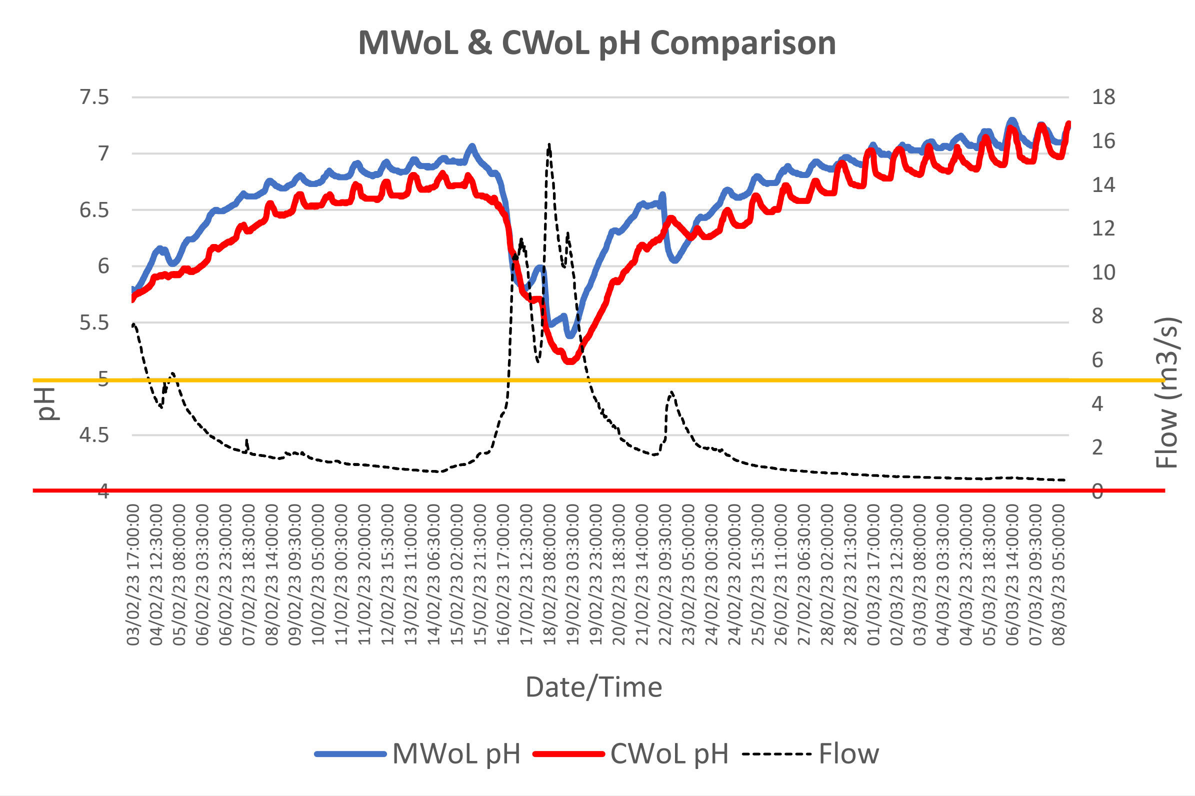
The data collected within this section of the report provides detailed pre-restoration data for comparison with data collected during and after restoration works have been completed.

Of note is the pH levels recorded from the Laggie and Laganabeastie Burns which show that whilst pH does not drop below 4 (the levels considered fatal to trout and salmon) they do frequently fall below 5 after rainfall. pH levels between 4 and 5 can still cause problems during sensitive stages of egg development and whilst fish numbers have improved in the upper Main Water of Luce the levels recorded in both burns indicate that a level of acidification persists. The variation in pH from both sites and speed of recovery in the pH levels indicates that neither watercourse is grossly acidified and that the Laganabeastie Burn was the more acidified of the two watercourses during the time of recording. The DO levels from the Laggie Burn appear to be notably lower than in the other two monitored watercourses. Whilst the level is still reasonably high it may be a cause for concern during summer low flows.

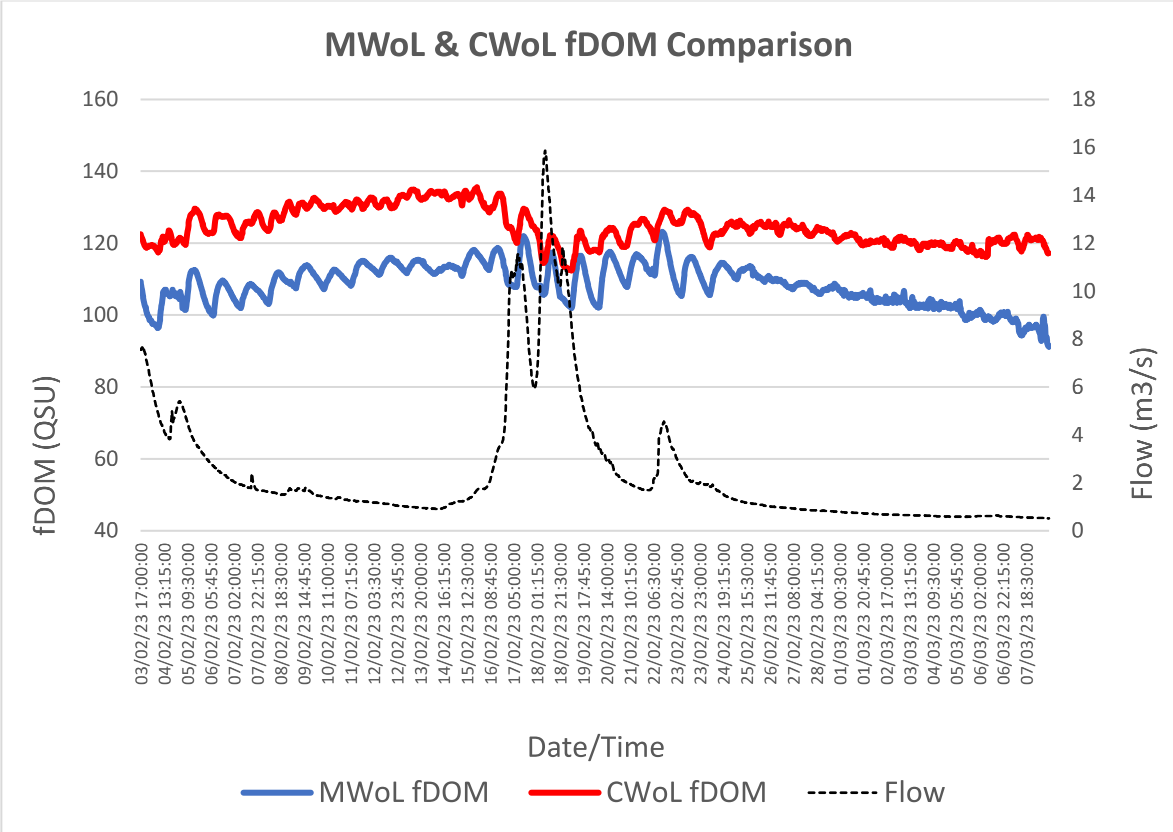
3.3 Water of Luce water quality overview

The EXO1 Sondes in the Main and Cross Waters of Luce started recording at 17.00 hours on 03/02/2023 and finished recording at 14.30 hours on 08/03/2023. During recording rainfall was well below average for the time of year with only one significant wet spell occurring during the middle of recording period. The water quality monitoring data can be seen in Graphs 22 to 25.

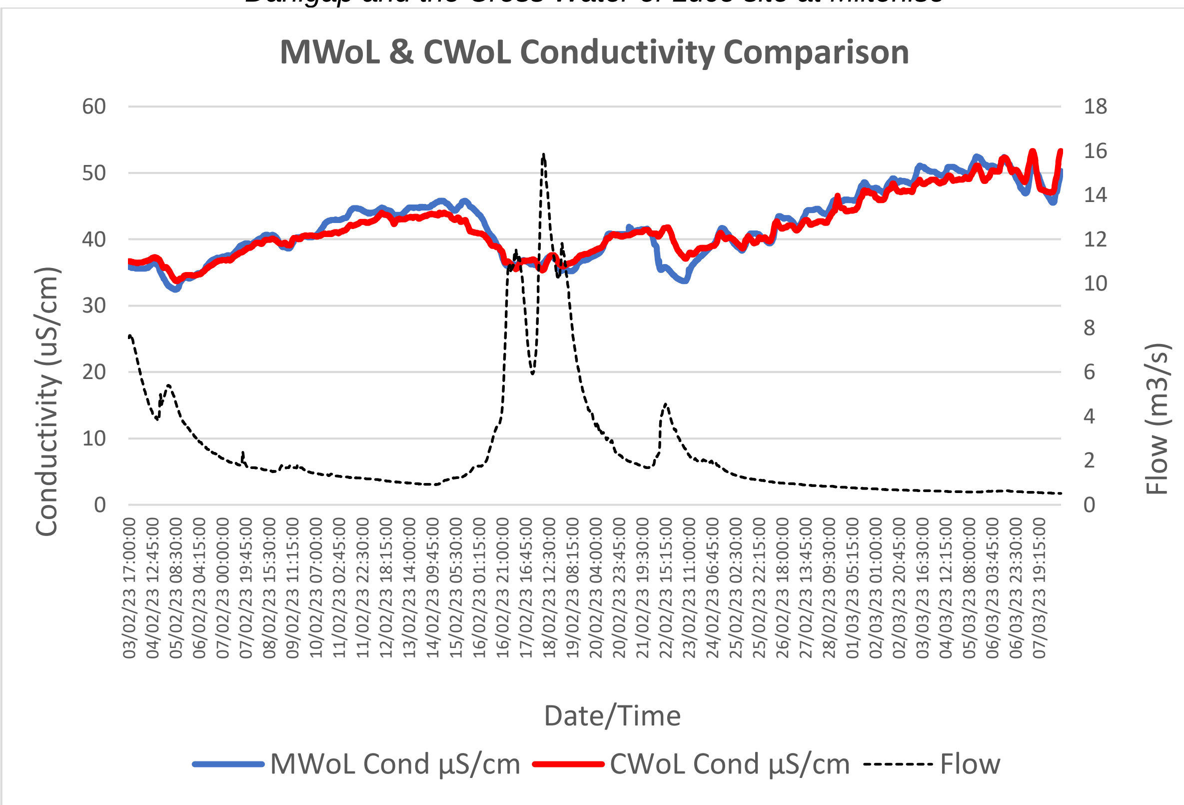
Graph 22: pH comparison between the Main Water of Luce monitoring site at Danigap and the Cross Water of Luce site at Miltonise



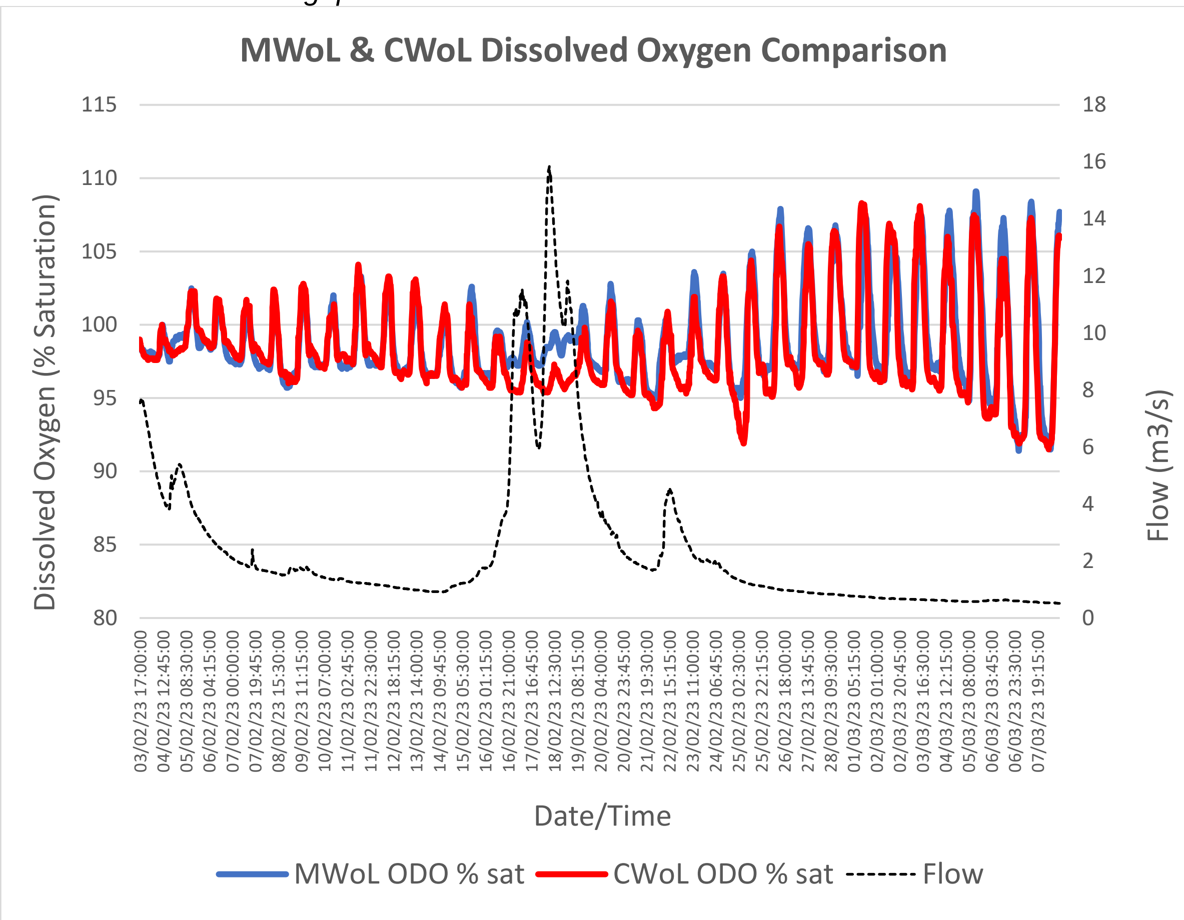
Graph 23: fDOM comparison between the Main Water of Luce monitoring site at Danigap and the Cross Water of Luce site at Miltonise



Graph 24: Conductivity comparison between the Main Water of Luce monitoring site at Danigap and the Cross Water of Luce site at Miltonise



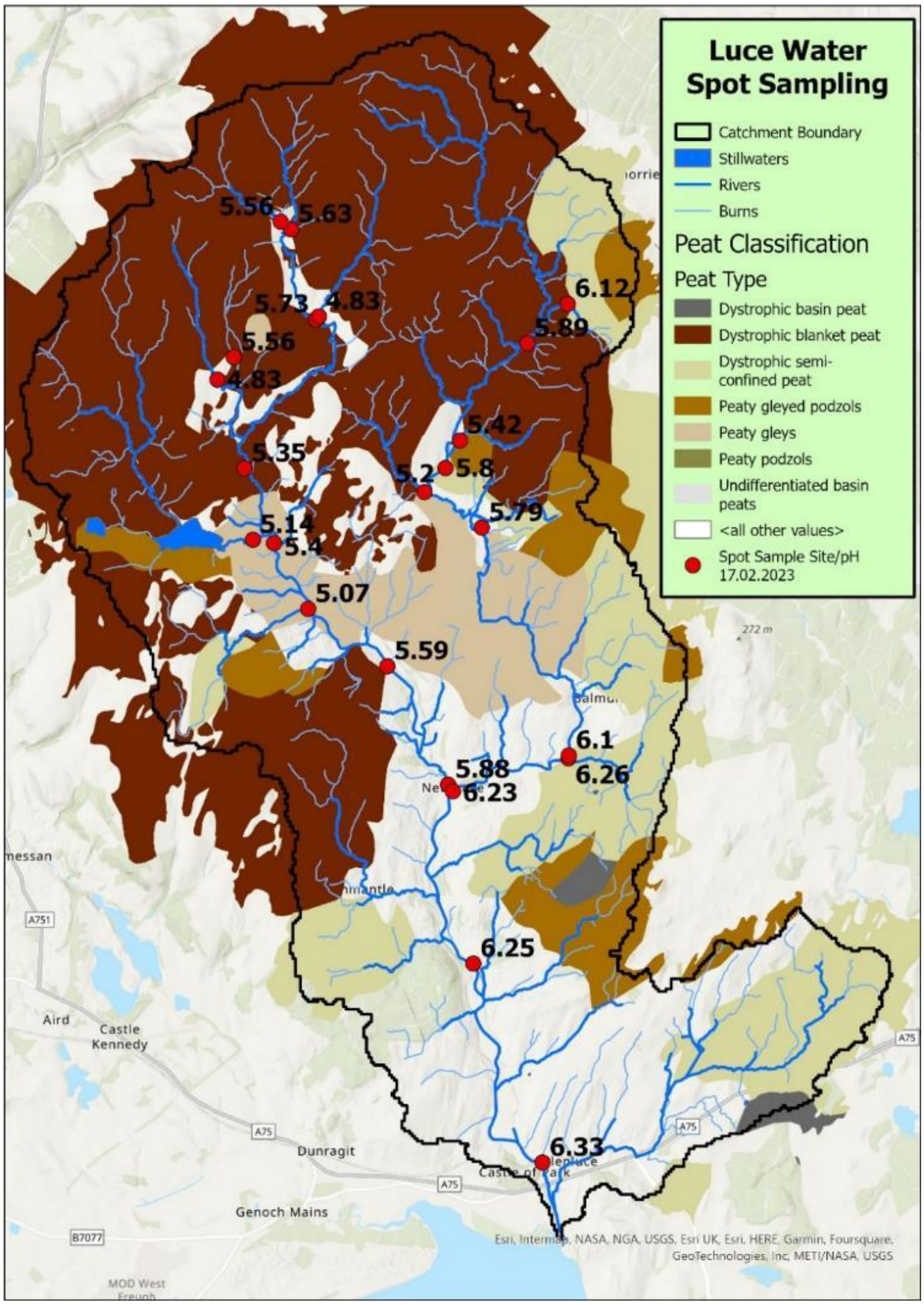
Graph 25: Dissolved Oxygen comparison between the Main Water of Luce monitoring site at Danigap and the Cross Water of Luce site at Miltonise



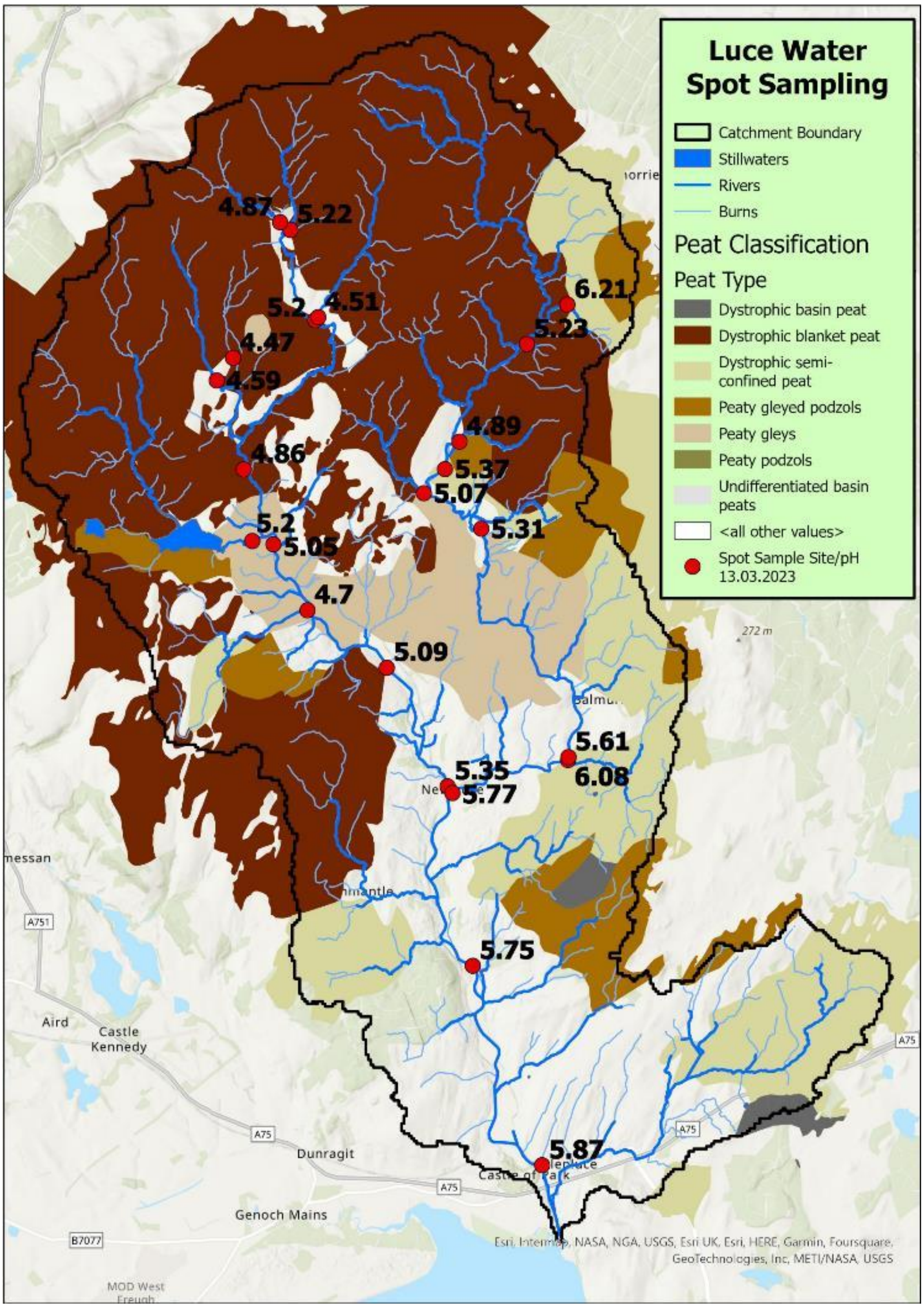
The pH levels recorded during the monitoring stayed above 5 at all times (the level below which there is cause for concern in regards to fish survival). However, as is discussed further in the conclusions section, the likelihood is that the pH sensor from the Main Water of Luce site was reading around 0.4-0.5 of a pH unit less acidic than the actual pH level in the river. As such the lowest recorded pH levels from the Main Water of Luce may have periodically dipped close to pH 5 and are likely to have been very similar to the pH levels recorded from the Cross Water of Luce. As rainfall was well below average for the time of year it is likely that lower pH levels are reached at both sites than were recorded. However, the results give a good indication that whilst pH levels below 5 may be recorded from time to time in both locations the likelihood is that levels do not fall much below 5 and likely recover fairly quickly to safe levels.

For the three other water quality parameter recorded, there was very little difference between conductivity and Dissolved Oxygen for the Main and Cross Waters of Luce, with recorded Dissolved Oxygen levels sitting around saturation point during the entirety of the recording. There was a difference in fDOM levels between the two watercourses with the levels recorded from the Cross Water of Luce being slightly higher than those from the main Water of Luce. This may represent a slightly higher levels of peat erosion from drainage/land use within the Cross Water of Luce catchment.

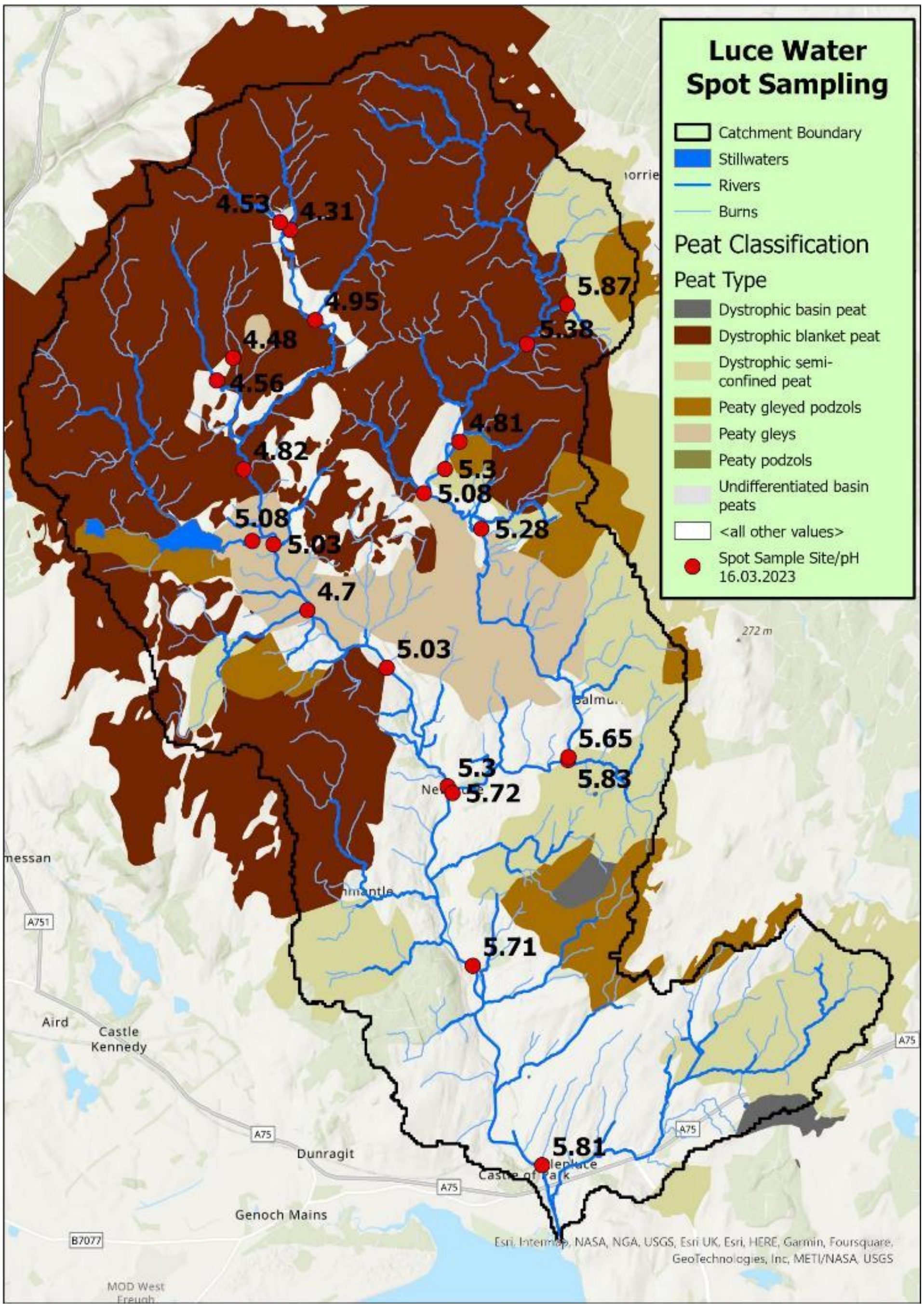
Spot samples were taken across much of the Luce catchment during the 17th February, 13th March and 16th March to show special variation in pH. The results are shown on Maps 16 to 18.



Map 16: pH results from water spot sampling on 17/02/2023



Map 17: pH results from water spot sampling on 13/03/2023



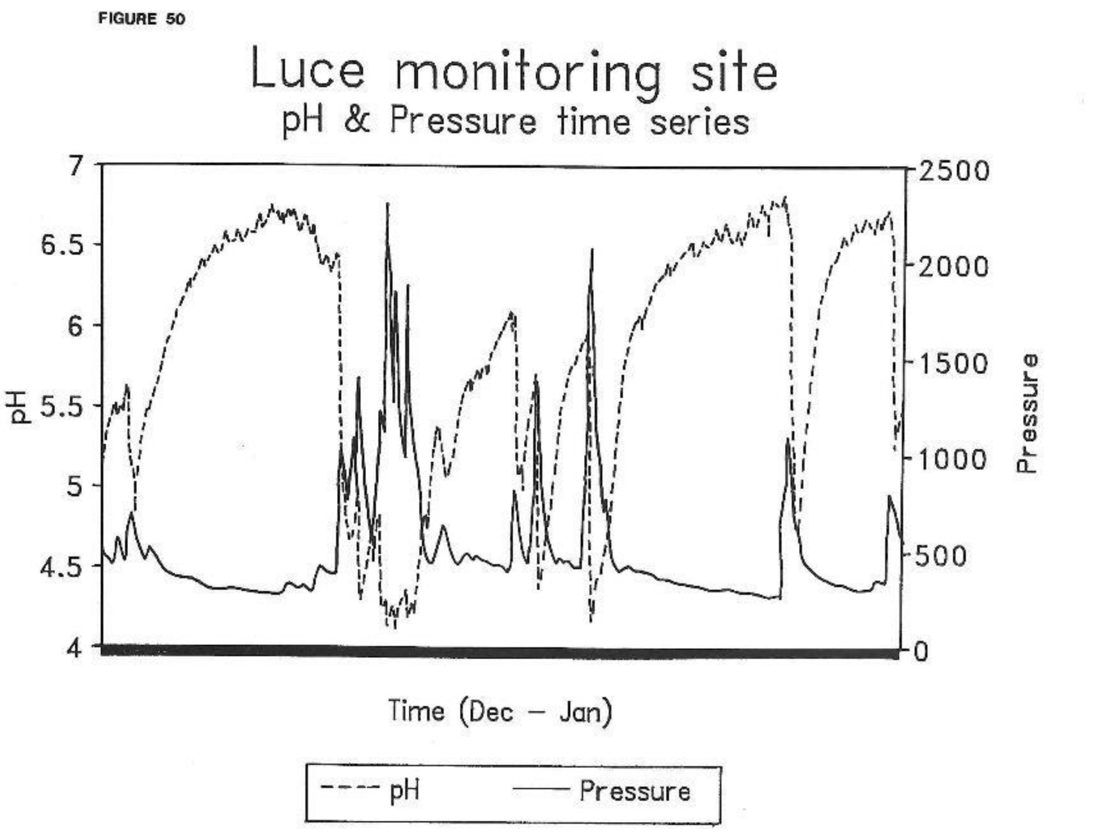
Map 18: pH results from water spot sampling on 16/03/2023

The results from the spot samples show that whilst fish populations are recovering acidification is still an ongoing issue on the upper catchment of the Main Water of Luce, with pH levels below 5 regularly being recorded. Of note is variation in which sites are most acidic at each sampling date. During the first two spot sampling days it is the Laganabeastie and Pilhatchie Burns. However, during the sampling on the 16th March the most acidic pH recorded came from the uppermost sites on the Main Water of Luce and Laggie Burn.

Of particular interest is the variation in pH and the relationship to the to the dominant peat type within burn sub-catchments. Whilst it is difficult to establish any relationship for sites on the main stem of the Main Water of Luce and Cross Water of Luce due to the size of the catchment area above, it is easier to analyse in small sub-catchments. By comparing burns and dominant peat types on the Cross Water of Luce with those on the Main Water of Luce there appears to be a difference in water quality between burns with catchment areas dominated by dystrophic semi-confined peat, when compared to those with catchments dominated by dystrophic blanket peat. As the catchments dominated by semi-confined peat should have a lower percentage of peat cover the results likely show the impacts of blanket peatland degradation on water quality.

In addition to the data recorded within this report some historic data is available for comparison. The first data available is from old West Galloway Fisheries Trust Annual Reports, with pH data from the Main Water of Luce at Dalnigap recorded during December 1991 and January 1992. The results are show in Graph 26. Pressure relates to water pressure at the monitoring site and is a proxy for flow.

Graph 26: pH recorded from the Main Water of Luce at Dalnigap during December 1991 and January 1992 (from Stevens, 1992)



The results from 1991/1992 are not directly comparable with the Dalnigap results from this report due to differences in rainfall patterns (the 1991/1992 recording period was much wetter). However, the results do appear similar, if not slightly more acidic, than those from the present day Laganabeastie Burn shown within this report. As the 2023 pH spot sampling shows the pH at Dalnigap to be less acidic than the pH in the Laganabeastie Burn this does suggest that the Main Water of Luce was more acidic in 1991/1992 and is slowly getting less acidic. As such, the 1990's water pH data backs up the pattern seen within the electrofishing review. The second data available is from the PHD Thesis of Christoph Puhr from 1996 which looked at the impacts of commercial conifer plantations on fish populations and water chemistry. It included some pH data from the Luce catchment taken after high flow events in March 1996. Where comparable results have been compared to the lowest modern record from the 2023 spot sampling in Table 3.

Table 3: Comparisons between modern water quality monitoring spot sampling results and those from 12/03/1996 in the PHD Thesis of Christoph Puhr

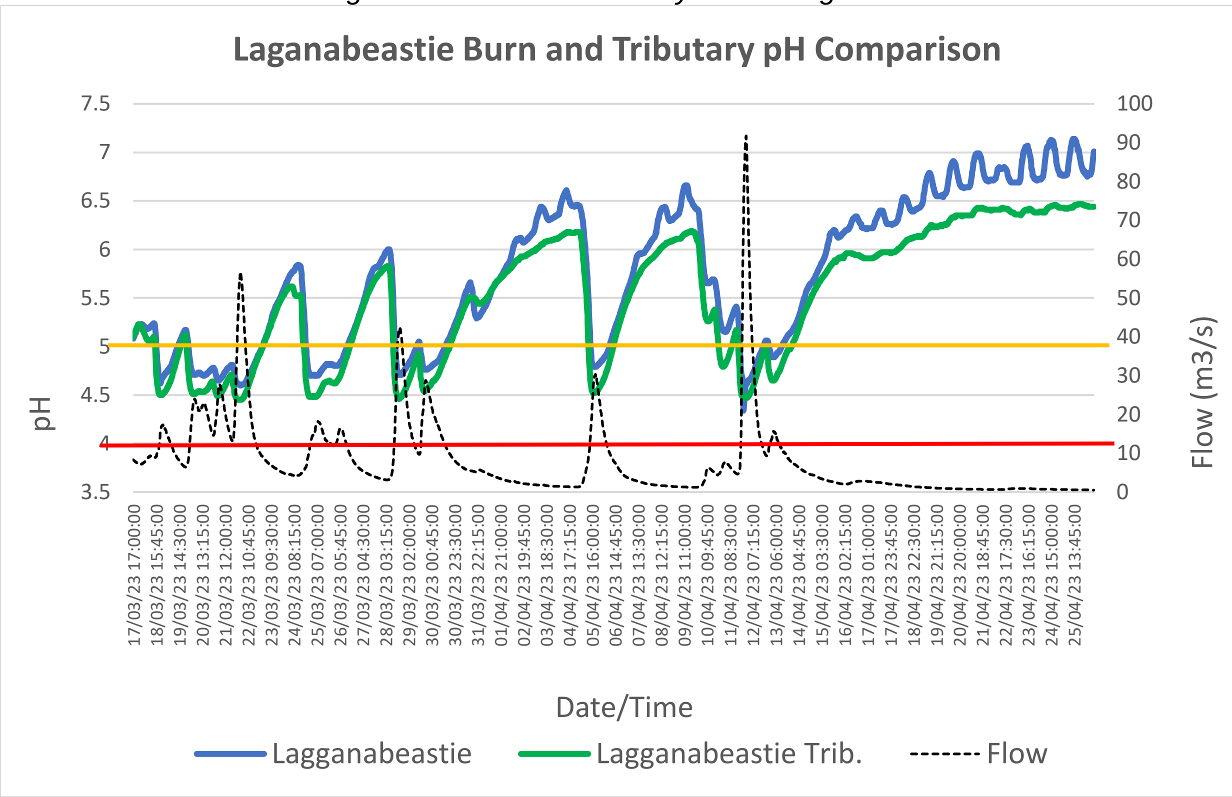
Watercourse	Location 1996	Location 2023	Comments	pH 1996	pH 2023	Change
Laganabeastie Burn	Near road bridge	Above road bridge	Sample sites appear to be in roughly the same location in 1996 and 2023	4.33	4.56	+0.23
Main Water of Luce	Dalnigap	Dalnigap	Sample sites appear to be in roughly the same location in 1996 and 2023	4.50	4.82	+0.32
Main Water of Luce	Little Larg	New Luce	1996 site approx. 1.5km upstream of 2023 site	4.67	5.30	+0.63
Cross Water of Luce	Quarter Farm	Pultadie	1996 site approx. 2km downstream of 2023 site	4.76	5.28	+0.52
Cross Water of Luce	Barnshangen	Draniglover	1996 site approx. 300m dowstream of 2023 site	4.95	5.61	+0.66

Again, the results back up the conclusions from the electrofishing review that pH levels are slowly recovering on the Luce. In this instance the results also suggest that the improvements in pH increase with distance downstream, although this is based on a relatively small amount of data so cannot be stated conclusively.

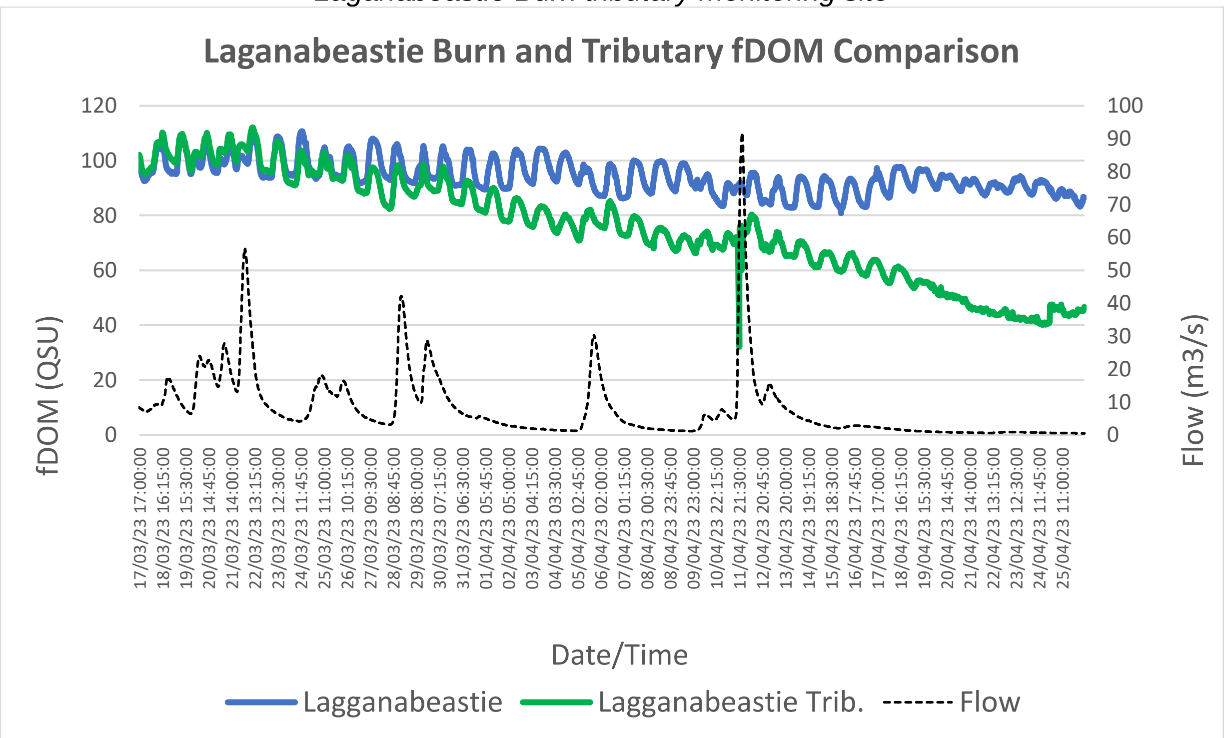
3.4 Additional targeted data collection

The Sondes on the Laganabeastie Burn and the un-named Laganabeastie Burn tributary were deployed on 17/03/2023 and taken out on 26/04/2023. During that time there were significant variation in flow levels. The water quality monitoring data for the two sites can be seen Graphs 27 to 30.

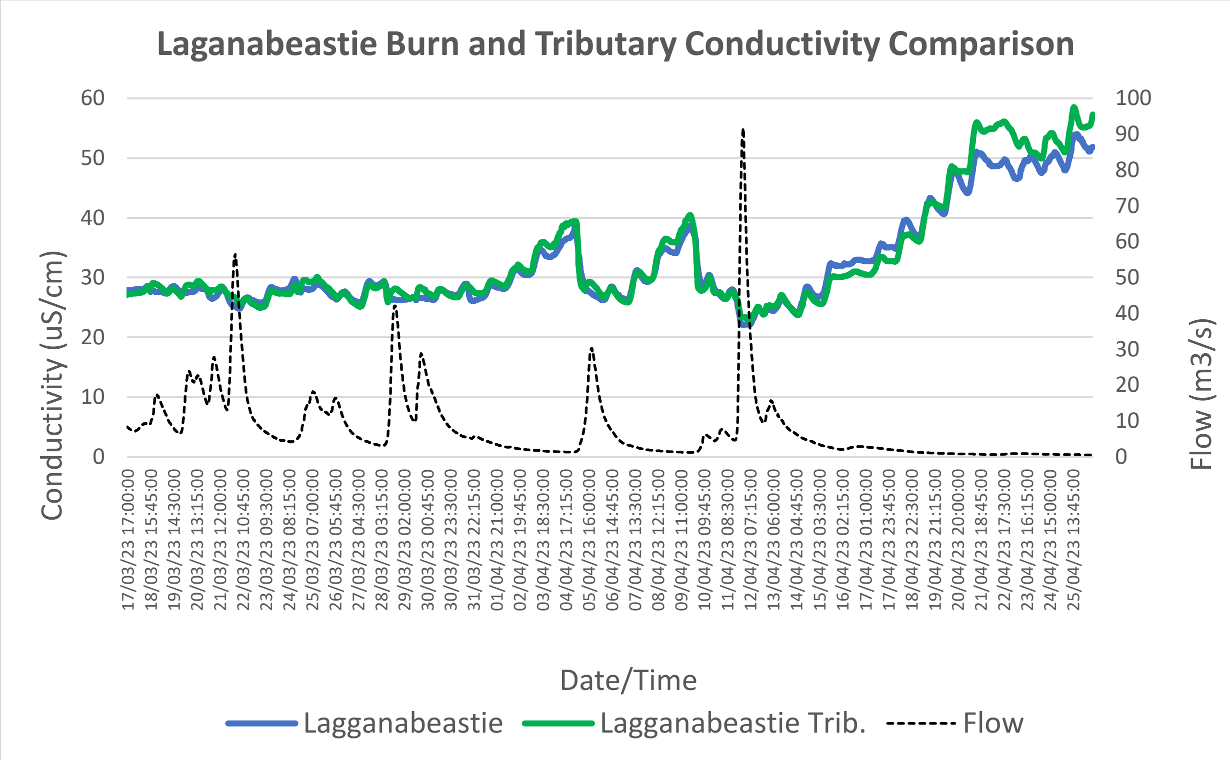
Graph 27: pH comparison between the Laganabeastie Burn monitoring site and the Laganabeastie Burn tributary monitoring site



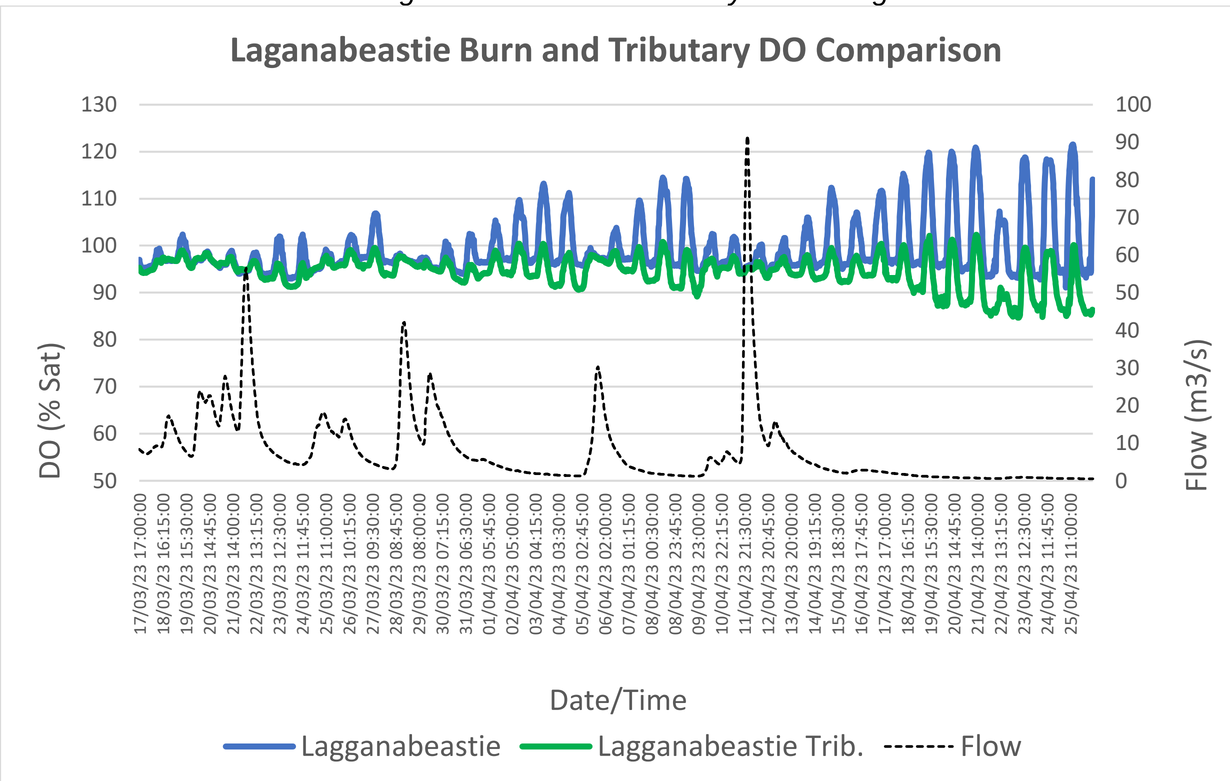
Graph 28: fDOM comparison between the Laganabeastie Burn monitoring site and the Laganabeastie Burn tributary monitoring site



Graph 29: Conductivity comparison between the Laganabeastie Burn monitoring site and the Laganabeastie Burn tributary monitoring site



Graph 30: Dissolved Oxygen comparison between the Laganabeastie Burn monitoring site and the Laganabeastie Burn tributary monitoring site



Given the proximity between the two sampling sites the results are very similar. However, the tributary site does experience slightly lower pH (and therefore is more acidic) and lower levels of Dissolved Oxygen. The latter would appear to be related to increased biological activity within the burn as oxygen levels fall as spring progresses and temperatures are assumed to rise (along with biological activity). The two burns were chosen for additional data collection as they recorded some of the lowest pH within the sites from which spot sampling data is available. As such the data shown is likely indicative of some of the lowest water quality experienced within the Water of Luce catchment.

4 DISCUSSION

4.1 Water of Luce electrofishing data review

The electrofishing results from the Water of Luce show signs of recovery from the low, and sometimes absent, trout and salmon numbers recorded during the earliest recording period. There are some signs of both increases in range and density for both salmon and trout. This is in line with what has been recorded from many hill lochs in the Galloway region as pH levels recover from acidification as a result of improvements in air quality and some changes in land use (e.g. Ferrier et al., 2001, Battarbee et al., 2011). However, such trends in rivers systems have generally been less well recorded. Whilst there are clear indications of recovery from a more acidified state when recording began, juvenile salmonids are still likely being impacted by low pH levels in the upper catchments. Recovery from a more acidified state is clearly a relatively recent phenomenon and some degree of acidification still persists in the upper catchments with some poor or absent results still occurring during the most recent sampling. Whilst the improving water quality will reduce the degree and persistence of low pH, reducing the chances of it coinciding with delicate stages in development, low pH levels will still occur and on occasion will coincide with these sensitive stages. Given the connections between water quality and peatland degradation current land use is likely contributing to reduced water quality, and therefore fish populations, in some locations within the upper Water of Luce catchments.

More data would be helpful in recording trends in fish numbers and the impacts of acidification more clearly. Collecting large amounts of electrofishing data is always difficult due to the time and resources required for its collection. However, as the trout population in the Laganabeastie Burn appears to be the most recent population to show recovery, monitoring trout juvenile numbers within the burn would show the variability in results from year to year and would show if low pH is still on occasion impacting trout numbers, and if so how often. This would have the additional benefit of providing trout data for the Lagafater peatland restoration project as the burn drains from the area being restored.

4.2 Lagafater pre-peatland restoration water quality data collection

Unfortunately, the issues with the EXO1 Sonde deployed in the Main Water of Luce control site are a blow to the data collection. However, there was plenty of data collected from the two other sites. This should still allow changes to be detected between the neighbouring sub-catchments and should still allow significant changes in water quality to be picked up. The low pH levels recorded from both burns show that whilst fish numbers (and therefore pH levels) are recovering, acidification and subsequent periods of low pH remain an issue. As such the recorded pH levels back up results/findings from the fish data. Given the pH levels recorded the Lagafater peatland restoration work has, dependent on the extent of the restoration, the potential to significantly improve water quality, improve conditions for fish populations and improve fish survival/numbers. It is important going forward that all of the potential benefits of the restoration work are covered in the recording. The water quality parameters being recorded should allow many potential water quality gains to be captured.

One gap in the data that needs considered is summer recording as some of the potential benefits of the restoration may not be easily distinguished during the winter recording period. One such variable is high summer water temperatures. Whilst there is little research available on the impacts of peatland restoration on water temperatures there is the potential for a cooling effect resulting from the increased storage, and slower release, of water within fully functioning peatlands. As such four water temperature monitoring loggers were purchased as part of the monitoring programme. They were deployed in spring 2023 at the pre-restoration sites on the Main Water of Luce and Laggie Burn and on the additional data collection sites on the Laganabeastie Burn and Laganabeastie Burn tributary. The data will be collected in late autumn 2023 and for the foreseeable future to provide a record of summer water temperatures for before and after restoration.

4.3 Water of Luce water quality overview

The results from the Water of Luce continual monitoring and for the spot sampling again show that acidification persists within the headwaters of the catchment, further backing up the results from the electrofishing review and the Lagafater pre-restoration monitoring. Whilst the continual monitoring results from the Main and Cross Waters of Luce suggest that acidification is not a major issue (regarding the health of the aquatic environment) at the central locations where sampling took place, the spot sampling from the 16th of March recorded a pH of 4.82 at the Main Water of Luce sampling site. This shows that low levels of pH may still occasionally prove problematic under high flow events, even at these relatively central locations within the catchments. The relationship between pH and flows, in regards to the impact of flood size, should also be noted as small floods don't always result in lowered pH levels to the same degree as larger floods. As rainfall varies from winter to winter, and the impacts of low pH on salmonids are influenced by exposure and timing (in relation to key hatching stages in egg development), fish/egg mortalities will vary from one year to the next based on the frequency/timing of rainfall and the exact timing of egg development/hatching. This has not been looked at in any detail within this report and in future the collection of data that would allow hatching timing to be estimated and compared to pH/flows should be considered. As trout and salmon egg development is heavily influenced by temperature then this may be possible using winter temperature data from temperature loggers which this report has previously recommended.

As with the continual monitoring the spot sampling results show low pH levels that are likely amplified by degraded peatlands. Of the sites sampled the upper sections of the Main Water of Luce consistently show the lowest pH levels and are therefore the most acidified. Burns such as the Laggie, Pilhatchie and Laganabeastie Burns and the very top of the Main Water of Luce (Black Glen Burn) are the main watercourses impacted and are therefore most likely to have impacted fish populations (and freshwater ecology in general). As such the peatland restoration in this area being undertaken by the CCC is ideally located as it covers large sections of the catchment area of two of the four watercourses mentioned (Laggie and Laganabeastie Burns). The more that can be done in regards to restoring full peatland function within the restoration area the better the benefits are likely to be to the whole aquatic environment and, as such, this report supports any work being carried out and supports full restoration where possible. As well as reducing peak pH levels and the duration of such events, peatland restoration has the potential to alter flows and reduce temperatures during low flow/high temperature events.

Of note is the spot sampling results from the Cross Water of Luce. The pH improves on the main stem of both the Main and Cross Waters as they flow downstream away from more acidified uplands. However, the pH on the Main Water of Luce is still significantly lower/more acidic than that of the Cross Water at the point at which the two watercourses merge. The lower pH appears to stem, at least in part, from small sub-catchments that are dominated by semi-confined peat. The pH from a burn (Pilwhirn Burn) that flows from one sub catchment was recorded at 5.87 during high flows on 16th March 2023. By comparison the pH of two burns that flow into the Cross Water of Luce a short distance downstream were 4.81 and 5.08. Both burns flow predominately through blanket peat. A further comparison is the Laganabeastie Burn on the Main Water of Luce. It is at a similar latitude and altitude and flows through blanket peat and recorded a pH of 4.56 on the same day (more than 10 times more acidic). This does suggest that the degraded blanket peat is directly contributing to acidity/water quality as the water coming out of the area of semi-confined peat (essentially an area with a lower percentage of peat) is notably less acidic. As the areas of semi-confined peat in the Luce catchment are a relatively small percentage of the total catchment area the water quality monitoring does not provide enough data to conclusively prove a link between peat/soil types and water quality. However, they do show that a relationship may well be present and more work should be carried out that looks to identify if a relationship exists. This should feature heavily in the planning of all future work. Collecting water samples from the upper section of the Cross Water of Luce should also provide additional data that will help explore this area of research.

One point of note from the spot sampling is that it indicates that the pH readings from the Sonde deployed on the Main Water of Luce at Dalnigap as part of the Water of Luce Water Quality Overview may have been slightly out. One of the spot sampling sites was approximately 200 m downstream from the Sonde deployment site. The Sonde was recording when the spot sampling took place on the 17th of February. The pH recorded during the spot sampling was 5.35, whilst the pH recorded from the Sonde at the same time (approx. 12.30) was 5.81. The Sonde used for spot sampling is calibrated before each spot sampling and spot sampling results generally provided results like those shown in other locations where Sondes were deployed (Laggie Burn, Laganabeastie Burn, etc) suggesting that the issue was with the pH sensor on the continual monitoring Sonde on the Main Water of Luce. As such the pH readings from this Sonde appear to be out by around 0.4 to 0.5 of a pH unit. There is no indications to suggest that there are issues with any of the other sensors and the issues with the pH sensor appeared to stop after re-calibration.

4.4 Additional targeted data collection

The targeted water quality monitoring showed the extent of the low pH levels within the Laganabeastie Burn and the small un-named tributary that flows into it. These results are most likely representative of other burns within the upper Main Water of Luce catchment. The recording period started off fairly wet with several rises in flows and got dryer as the recording period progressed. As wet winters are fairly common in South West Scotland the initial frequency of rises in flow experienced are likely to be fairly common for the Water of Luce during winters. Two points are of note from the pH levels recorded. Firstly, that there was a period of several days at the beginning of the recording period when the pH was continually below 5 (the point below which salmonid populations are potentially impacted). The lowest pH recorded during deployment was 4.34. As such there is the potential for significant impacts on fish populations if particularly wet periods coincide with delicate stages of egg development. Secondly, at no point does the pH get below 4 (the point below which pH is generally lethal to salmonids), although it gets close. Again this data backs up the results from the GFT electrofishing review which shows a recovering population where burns that were previously devoid of fish are now beginning to see signs of recovery. Given the pH levels recorded it is still likely that salmonid egg mortalities are still being experienced. As not all trout within any burn spawn at the same time there could potentially be a significant time difference (potentially up to two months) between early and late spawning fish. As such not all eggs will be at the same stage of development at the same time. This most likely means that acid flushes will kill a percentage of the eggs within a given year, as opposed to all, with more frequent rises in water increasing the percentage of mortalities. Therefore even the areas that are showing recovery in salmonid numbers may still be losing a variable, but significant, percentage of salmonid eggs from year to year and may still experience complete losses during particularly wet winters. This may show up in electrofishing if burns like the Laganabeastie Burn can be surveyed more consistently going forward.

The fDOM graph for the two watercourses initially show very similar results and both show decreases in fDOM levels over time that is increasingly less influenced by flow levels. As the recording period ran from March well into April this may represent vegetation growth in spring reducing the amount of bare, exposed peat within drainage ditches or over the catchment area as a whole, resulting in reduced peatland erosion into watercourses. As the reduction in fDOM in the tributary burn is far greater than in the Laganabeastie Burn this may indicate that drainage is more efficient within this sub-catchment, although it may also possibly represent some other localised difference. Further work to better understand the relationship between peat erosion and fDOM levels should be considered going forward. It was notable that the conductivity chart showed the opposite trend to the fDOM chart (levels increased over time). As conductivity is influenced by more dissolved chemicals/compounds than just DOM this suggests that other factors are driving the levels recorded and suggests that conductivity is unsuitable as a measure of peatland erosion in this instance.

The Dissolved Oxygen levels within the Laganabeastie Burn tributary were of concern to fish populations. Whilst variations in DO levels are expected as the seasons progress, and between night and day due to the biological activity of plants/algae, the levels recorded in this burn show huge variations with levels regularly dropping below 50% saturation overnight. This is despite recording being quite early in spring. Saturation levels below 50% in warm summer temperatures will almost certainly be lethal to salmonids. Given the potential for low oxygen levels to impact fish populations, and other aquatic life, the relationship between peat type/condition and summer oxygen levels needs to be studied in more detail and should be incorporated into future monitoring, or should be explored within additional projects where/if available.

As has already been noted several times in this report the water quality in the Water of Luce is recovering from a more acidified state. However, acidification still persists. Whilst we do not have large amounts of comparable data from the past for comparison we can come to some general conclusions on this recovery. The earliest data available comes from the 1990's. As described in many of the research papers previously referenced in this report air quality (acid rain) was already beginning to improve during this period and so was water quality. Despite this fish numbers did not significantly improve within some of the upper Luce burns until 10-20 years later with potentially damaging pH levels persisting and impacting egg survival. As such recovery from acidification appears to be a very slow process. Given the links between degraded peat and reduced water quality/lower pH there is a significant chance that the degraded blanket peat within the Luce catchment is not only lowering the water quality within sub-catchments but also potentially slowing water quality recovery. Recovery from acidification in some parts of Galloway has been noted as being slower than much of the rest of Scotland within Acid Monitoring Group reports (Shilland et al., 2017).

4.5 Water of Luce catchment management recommendations

- GFT to regularly repeat at least one electrofishing site on the Laganabeastie Burn to monitor trout responses to water quality in general and to any water quality changes associated with the CCC peatland restoration project (which covers a large percentage of the Laganabeastie Burn catchment).

- Lagafater water quality monitoring to be continued during and prior to the peatland restoration work taking place.

- Temperature loggers to be deployed at Lagafater monitoring sites on the Main Water of Luce, Laggie Burn and Laganabeastie Burn (completed spring 2023).

- The gap in data from the upper Cross Water of Luce is to be filled during any future sampling.

- Of the sites samples the upper sections of the Main Water of Luce consistently show the lowest pH levels and are therefore the most acidified. Burns such as the Laggie, Pilhatchie and Laganabeastie Burns and the very top of the Main Water of Luce (Black Glen Burn) are the main watercourses impacted and are most likely to have impacted fish populations, and freshwater ecology in general. As a result this report supports and encourages any peatland restoration that can be carried out within these areas and fully supports the peatland restoration currently being planned by the CCC. This report supports full peatland restoration where possible/practical as full restoration will see the most benefit to water quality and aquatic ecosystems.

- The spot sampling results from the Luce have indicated that there may be a relationship between water quality (particularly pH) and peat type. This should be explored further in future work and any joint project that bring additional expertise into future studies should be encouraged.

- Work should be undertaken to better understand the relationship between DOM and peat erosion.

- More work should be carried out in summer to assess the impact of degraded peatland on Dissolved Oxygen within watercourses that drain through damaged peatlands as it may be significant.

- The data and conclusions from this report should be used within any future management planning within the Water of Luce catchment and should act as a reference point for managing peatland and/or water quality within other areas where applicable.

5 REFERENCES

Battarbee, R.W. (1989). Geographical research on acid rain 1. The acidification of Scottish lochs. *The Geographical Journal, 155 (3),* 353-377.

Battarbee, R.W., Curtis, C.J. and Shilland, E.M. (2011). The Round Loch of Glenhead: Recovery from acidification, climate change monitoring and future threats. *Scottish Natural Heritage Commissioned Report No. 469.*

Brown D.J.A., Howells G.D., Dalziel T.R.K. & Stewart B.R. (1998). Loch Fleet – a research watershed liming project. Water, Air and Soil Pollution, 41, 25-41.

Chapman, S. J., Bell, J., Donnelly, D., & Lilly, A. (2009). Carbon stocks in Scottish peatlands. *Soil Use and Management*, *25*(2), 105–112. https://doi.org/10.1111/j.1475-2743.2009.00219.x

Crisp, D. T. (2000). *Trout and Salmon - Ecology, Conservation and Rehabilitation. 1st Edn. Blackwell Science.*

Driscoll C.T. (1985). Aluminium in Acidic Surface Waters: Chemistry, Transport and Effect. *Environmental Health Perspectives. Vol 63, pp93-104.*

Ferrier, R. C., Helliwell, R. C., Cosby, B. J., Jenkins, A., and Wright, R. F. (2001). Recovery from acidification of lochs in Galloway, south-west Scotland, UK: *1979-1998, Hydrol. Earth Syst. Sci., 5, 421–432, https://doi.org/10.5194/hess-5-421-2001, 2001*.

Fisheries Management Scotland (2022). Annual Report.

Forest and Land Scotland (2016). *Tannylaggie Land Management Plan 2016-2026.*

Galloway Fisheries Trust (2018). *Bladnoch restoration feasibility study* (No. JRJRAD22).

Godfrey, J. D. (2006). *Site Condition Monitoring of Atlantic Salmon SACs: Report by the SFCC to Scottish Natural Heritage, Contract F02AC608,* https://www2.gov.scot/resource/doc/295194/0096508.pdf

Gensemer, R. W., & Playle, R. C. (1999). The bioavailability and toxicity of aluminum in aquatic environments. *Critical Reviews in Environmental Science and Technology*, *29*(4), 315–450.

Harenda, K. M., Lamentowicz, M., Samson, M. & Chojnicki, B. H. (2018). The role of Peatlands and their carbon storage function in the context of climate change. In T. Zielinski, I. Sagan, & W. Surosz (Eds.), *Interdisciplinary Approaches for Sustainable Development Goals* (pp. 169–187). Springer International Publishing.

Harriman, R, & Morrison, B. R. S. (1982). Ecology of streams draining forested and non-forested catchments in an areas of central Scotland subject to acid precipitation. *Hydrobiologia, 88,* 251-263.

Harrison, Hutton, Baars, Cruikshanks, Johnson, Juhel, Kirakowski, Matson, O'Halloran, Phelan, & Kelly-Quinn. (2014). Contrasting impacts of conifer forests on brown trout and Atlantic salmon in headwater streams in Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy*, *114B*(3), 219.

Hesthagen, T. (1988). Movements of Brown trout, *Salmo trutta*, and juvenile Atlantic Salmon, *Salmo salar*, in a costal stream in Northern Norway. *Journal of Fish Biology, 32 (5),* 639-653.

Howells, G. & Dalziel, T. R. K. (1992). *Restoring Acid Waters: Loch Fleet 1984-1990.* Elsevier Applied science Publishers Ltd.

Kroglund, F., Rosseland, B. O., Teien, H.-C., Salbu, B., Kristensen, T., & Finstad, B. (2008). Water quality limits for Atlantic salmon (*Salmo salar* L.) exposed to short term reductions in pH and increased aluminum simulating episodes. *Hydrology and Earth System Sciences*, *12*(2), 491–507.

Maitland, P. S., Lyle, A. A. & Campbell, R. N. B. (1987). *Acidification and Fish in Scottish Lochs. Cambrian News Ltd.*

Malcolm, I. A., Millidine, K. J., Jackson, F. L., Glover, R. S. and Fryer, R. J. (2019). Assessing the status of Atlantic salmon (*Salmo salar*) from juvenile electrofishing data collected under the National Electrofishing Programme for Scotland (NEPS). *Scottish Marine and Freshwater Science, Vol 10, No. 2.*

Peacock, M., Jones, T. G., Futter, M., Freeman, C., Gough, R., Baird, A. J., Green, S. M., Chapman, P. J., Holden, J. & Evans, C. D. (2018). Peatland ditch blocking has no effect on dissolved organic matter (DOM) quality. *Hydrological Processes, 32(26), 3891-3906.*

Puhr, C. B., *Catchment afforestation, surface water acidification, and salmonid populations in Galloway, South West Scotland.* PHD Thesis, Department of Geography, University of Durham.

Puhr, C. B., Donoghue, D. N. M., Stephen, A. B., Tervet, D. J. & Sinclair, C. (2000) Regional patterns of streamwater acidity and catchment afforestation in Galloway SW Scotland. *Water, Air and Soil Pollution, 120(1/2), 47-70.*

Scottish Fisheries Co-ordination Centre (2021). *Team Leader Electrofishing Training Manual.*

Stevens, A. (1992). *Annual Report 1991 – 1992*. West Galloway Fisheries Trust.

Shilland E.M., Monteith D.T., Millidine K & Malcolm I.A. (2017). UK Upland Waters Monitoring Network Annual Summary Progress Report to Forest Research. April 2016 to March 2017.

Waiwood, B. A. & Haya, K. (1983) Levels of chorionase activity during embryonic development of *Salmo salar* under acid conditions. *Bulletin of Environmental Contimination and Toxicology, 30*, 511-15.

Whitehead, P. G., Wilbey, R. L., Battarbee, R. W. & Wade, A. J. (2008). A review of potential impacts of climate change on surface water quality. *Hydrological Sciences Journal. 54 (1),* 101-123.