A Scottish Registered Charity
No. SC 020751

Galloway Fisheries Trust / Peatland Action annual water quality monitoring report Winter 2021/2022

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This report should be quoted as:

Galloway Fisheries Trust. September 2022. GFT's annual water quality monitoring report on behalf of Peatland Action.
Galloway Fisheries Trust Report No. – GFT_PA_WQM0123

Summary

GFT's annual water quality monitoring report on behalf of Peatland Action

Year of publication: September 2022

Keywords

Peatland Restoration; pH; EXO 1 Sonde; salmonids; Water of Fleet; River Bladnoch; acidification; Tannylaggie.

Galloway Fisheries Trust (GFT) have been actively involved in recent years 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 degraded fish populations. In November 2019, Peatland Action (PA) agreed to fund an annual Water Quality Monitoring (WQM) program monitoring peatland restoration sites within the Galloway region under the guidance of Emily Taylor, Galloways' local Peatland Officer.

Following felling of commercial Sitka spruce Forest and Land Scotland (FLS) decided not to replant in an area of deep peat surrounding the Dargoal Burn (River Bladnoch catchment) at Tannylaggie Flow, and instead put the land aside for peatland restoration. Restoration plans have been drawn up and agreed with the work being out to tender at the time of writing. As a result of poor buffering capacity in the underlying geology and past land use practices, including the drainage and afforestation of deep peat, the Dargoal Burn suffers from chronic acidification. The GFT/PA have been monitoring a number of water quality parameters to assess the impact the planned restoration of degraded peatland may have on water quality within the burn. Pre restoration data collection began during winter 2019/2020 and continued during both winter 2020/2021 and the most recent winter (2021/2022). Data has been collected from watercourses in three locations within the planned restoration area. Water quality parameters were recorded at 15 m intervals using EX01 Sondes during periods of deployment. 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 data collected to date provides a large volume of pre-restoration data for comparison with any data recorded post-monitoring. One of the recommendations of this report is summertime recording of temperature and DO when readings should be at their highest and lowest respectively.

In addition to the peatland pre-restoration monitoring on the Dargoal Burn, a general

water quality overview was recorded for the Water of Fleet during January, February and March 2022. The upper Water of Fleet catchment lies on granite bedrock, contains large areas of peat (much of it degraded) and has a high percentage of afforestation with commercial Sitka spruce. The upper catchment suffers from widespread acidification with subsequent impacted aquatic ecosystems.

As a pre-cursor to the water quality monitoring the GFT undertook a review of their (electrofishing) fish survey data to look at the current status of salmonid fish stocks in the Fleet, and their trends over time. To record water quality EX01 Sondes were deployed at a site on the Big Water of Fleet and Little Water of Fleet to gain an overview of water quality variations for each sub-catchment (recording interval and parameters were as they were on the Dargoal Burn). In addition an upper catchment wide pH spot sampling program was initiated in late January 2022 and repeated on a number of occasions within the monitoring period. The aim of the spot sampling was to show spatial variation in water quality across the catchment with sampling carried out after periods of high flow to catch lowest pH levels.

The GFT fish data review showed that there has been some recovery in fish numbers and distribution in the Fleet since the late 90's when salmonid populations were in a state of severe depletion as a result of chronic acidification. The improvements most likely relate to improvements in air quality and changes in land practices. However, fish populations remain depleted in many areas and acidification is clearly still a problem. Whilst most burns in the Fleet headwaters contain juvenile trout numbers are significantly depleted in some areas, with the Little Water of Fleet being particularly heavily impacted.

Water quality data backed up the electrofishing results and showed low pH levels consistent with the impacts of acidification across much of the upper Fleet catchment. The Sonde data showed pH levels in both the Big Water of Fleet and Little Water of Fleet fall below pH 5 after periods of heavy rainfall and as such reach levels that are potentially harmful to sensitive stages in trout and salmon development. However, the Little Water of Fleet reaches a lower pH than the Big Water of Fleet with low pH levels taking longer to recover – indicating a more acidified state. As a result of the lower pH, and greater persistence of low pH, periods of low pH on the Little Water of Fleet are more likely to coincide with pH sensitive stages in trout and salmon lifecycles, as represented in the results from the GFT fish data review. Catchment wide pH spot sampling after periods of rainfall showed that low pH levels recorded at the Big and Little Water of Fleet Sondes sample sites are common throughout the upper Fleet catchment. As with the results from the Sondes the spot sampling showed widespread low pH levels on the Little Water of Fleet, with recovery not starting to kick in until the lower reaches of the commercially planted headwaters (a similar trend in pH recovery was recorded on the Big Water of Fleet but with slightly higher pH). Although pH levels were generally better on the Big Water of Fleet a number of burns that flow into it through commercial forestry showed pH/acidification levels as bad as, or worse, than those recorded on the Little Water of Fleet (e.g. the Cleuch of Eglon Burn and the Craiglowrie Burn). The better water quality in the Big Water of Fleet originates from the unplanted section covering much of the Cardoon Burn and Mid Burn. This unplanted area consistently showed the best results for pH and fish numbers and has been the subject of peatland restoration within the Cairnsmore of Fleet Nature Reserve.

Main findings

Tannylaggie Flow Peatland Restoration Water Quality Monitoring

- The Tannylaggie peatland restoration project is still in the pre-restoration phase. The water quality monitoring data collected from the Dargoal Burn, which flows through Tannylaggie, provides a large amount of baseline data for comparison post-restoration.

- The pH in the Dargoal Burn consistently falls to levels that can cause mortalities in fish. The burn flows into the Polbae Burn, which in turn flows into the River Bladnoch. Both are part of the River Bladnoch Special Area of Conservation and it is likely that the low pH in the Dargoal Burn is having a knock on effect within both watercourses.

- This report recommends that future monitoring on the Dargoal Burn should consider recording dissolved oxygen levels and water temperatures during the summer, should look to relocate the furthest upstream sample site and should explore whether analysis of labile Aluminium levels are possible.

Water of Fleet Water Quality Monitoring and Electrofishing Data Review

- The headwaters of the Water of Fleet lie on base-poor geology with poor buffering capacity and have been extensively planted with conifers, large sections of which are planted on peat. Acidification, to varying degrees, resulting from land use and atmospheric deposition is impacting most of the upper catchment with the impacts extending downstream beyond the source of the acidification problems.

- A review of GFT electrofishing data shows that there have been improvements in fish numbers and range since recording began in the late 1990's, but acidification is still impacting fish populations on a catchment scale, with both salmon and trout populations being impacted.

- More electrofishing data would assist in seeing trends in fish numbers and the impacts of acidification more clearly. It is recommended that going forward all of the electrofishing sites which have had multiple visits should be continued in the future. It is also recommended that there should be an annual timed electrofishing programme on the Big Water of Fleet to look at the variations in salmon fry distribution and relative abundance from one year to the next.

- Water quality monitoring shows the Little Water of Fleet is more acidic than the Big Water of Fleet and this is reflected in the fish data recorded. The Little Water of Fleet catchment has a greater percentage of peat overplanted with conifers and this is likely the cause of the lower pH levels and subsequent lower salmonid survival.

- The acidification issues within the headwaters of the Water of Fleet are as a result of land use practices on a catchment scale. However, the removal of trees and restoration of peatlands can benefit water quality and fish populations. If they can be rolled out on a larger scale they could result in a significant recovery of the Water of Fleet trout and salmon populations within the upper catchment, in addition to the numerous other environmental benefits. As such this report likely contains data which would support peatland restoration from any afforested areas of deep peat which can be identified within the Fleet headwaters.

- The catchment area surrounding the Cardoon Burn lies largely on deep peat, has a lower level of conifer planting than many other headwater burns and is subject to ongoing peatland restoration. The results for both pH and fish numbers are consistently better than in other burns within the Fleet headwaters.

- Water flows into the Cardoon Burn from a small gully which connects to a number of drainage ditched that drain a section of forestry planted on peat on the burns South bank. Spot sampling after flood events recorded the pH in the gully as being ten times more acidic than the water in the Cardoon Burn and is impacting water quality downstream of where it entered the burn. It is a recommendation of this report that the impact on water quality from the gully needs addressing.

- Opportunistic sampling of forestry drainage ditches during spot sampling indicated that the situation on the Cardoon Burn, with low pH water entering from a gully connected to forestry drainage ditches, is likely to be happening in other locations throughout the Fleet headwaters. This report recommends that there should be a focus on finding such locations in future sampling and working to address the issues.

- Although this study primarily focuses on pH, it is recommended that recording levels of labile Aluminium should be considered for any area where acidification may be a problem, if funding allows.

- Climate change is considered a major threat to water quality around the globe. In particular, given the findings of this report, forecasts of wetter and more stormy winters could lead to conditions where low pH events are more common and pH levels are held at lower values for longer periods. This could increase the chances of low pH events coinciding with vulnerable stages in trout and salmon life cycles.

- It is a recommendation of the report that the data it contains should be fed into Forestry Management Plans, should be shared with interested parties and should be made generally available.

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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).

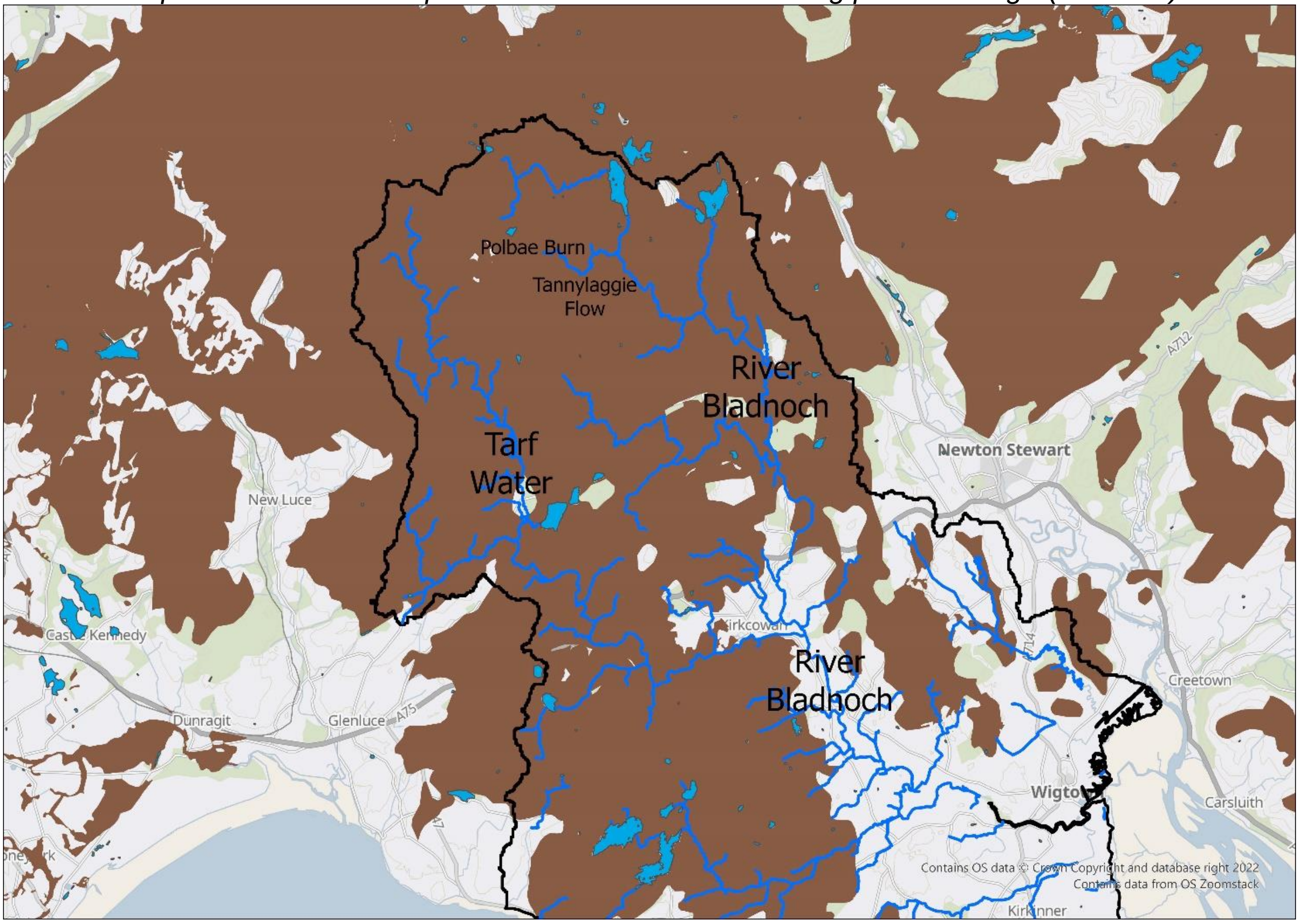
The two main native fish species within these areas are Brown trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*). Low pH can have significant impacts to both trout and salmon at critical stages within their lifecycle. At the time of hatching pH below 4.5 can block the action of the hatching enzyme 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. 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 on fish (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 11 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 (as shown in the electrofishing review for the Water of Fleet discussed later).

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, 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, increase in toxic metals, increase in ammonia, increase in DOC and increase in turbidity (Harrison et al., 2014; Puhr et al., 2000).

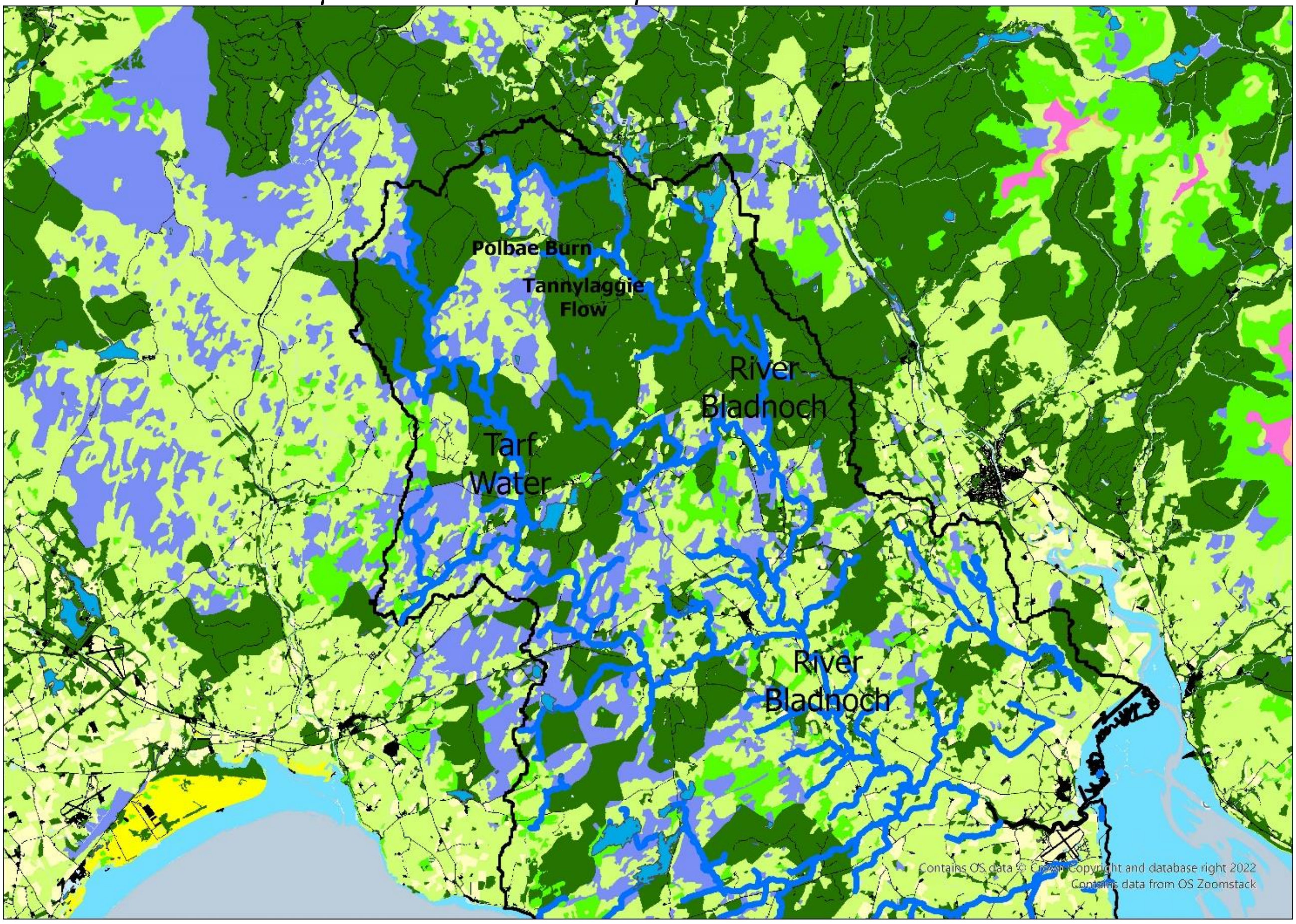
The identification of areas where acidification impacts fish populations and working to address, mitigate or inform land management practice, forms a large part of the work carried out by the GFT. Within this the identification of areas of degraded peatlands (and in particular areas where conifers are 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, including carbon storage, repopulating unique peatland flora and fauna and improved water quality with resulting benefits for fish populations. For that purpose the GFT has been working in partnership with Peatland Action (PA) since 2019 to monitor water quality in sections of Galloway rivers that are impacted by acidification, paying particular attention to watercourses that drain peat, and looking for opportunities for restoration. The collaboration between GFT and PA is funded by NatureScot (NS) with funding being secured in Autumn in 2021 to monitor water quality over the winter 2021/22. Winter is the period when rainfall is typically highest resulting in more frequent acid flushes into watercourses. This report covers the work carried out during that period but also includes the data from winter 2019/20 and 2020/21.

Work in 2021/2022 centred on two areas. The first is the Dargoal Burn, an upland burn within the River Bladnoch catchment which flows through an area known as Tannylaggie. The River Bladnoch is a medium sized, low lying catchment which has been designated a Special Area of Conservation (SAC) under the European Commission's Habitats Directive for Atlantic salmon. The river flows out of Loch Maberry and gently weaves its way over moors, forestry and farmland before entering the Solway at Wigtown Bay. With a catchment area of approximately 342 km^2, the Bladnoch is a spate river whose character changes dependent upon its water level. The Tarf Water is the largest tributary which joins the Bladnoch near Kirkcowan. There are various sub-stocks of salmon found in the river resulting in fish entering the rivers during nearly every month of the year, as shown by rod catches. There are only three settlements along the length of the river - Bladnoch village, Wigtown and Kirkcowan. There has been a decline in abundance of Atlantic salmon in the upper River Bladnoch catchment. Rod catches for the River Bladnoch have fluctuated over the last decade, however catches from the upper River Bladnoch catchment have declined over the last decade, which may be as a result of acidification. There is a big difference in land use between the upper and lower Bladnoch catchment. In the upper catchment land use is primarily commercial conifer plantations and there have been multiple windfarm sites erected in recent years. In the lower catchment land use is primarily rough and improved grassland used for grazing livestock. Peat is very common within the Bladnoch system and covers most of the catchment, shown in Map 1. As a result of man-made alterations to the landscape much of the peat within the Bladnoch catchment is degraded. Map 2 shows the land use map for the Bladnoch catchment. As Map 2 shows conifer plantations in the river headwaters and grassland (mostly for livestock) in the lower catchment are the dominant land uses. Both require significant drainage and lowering of the water table, combined with changes in vegetation from natural systems to ones dominated by Sitka spruce and grasses respectively. As discussed previously where peat is present this will have resulted in widespread degraded ecology, release of CO^2, peat erosion and acidification of watercourses in areas of base-poor geology. These impacts are significantly greater in areas of deep peat. Along the River Bladnoch catchment there are multiple designated sites. In addition to the River Bladnoch SAC for Atlantic salmon Kirkcowan Flow (SAC, SSSI) and Ring Moss (SSSI) in the upper catchment are designated for their bog habitats. In the lower catchment there is the small Cotland Plantation SSSI designated for its upland mixed ash woodland. SEPA's water classification hub showed the lower River Bladnoch catchment and the Black Burn have a good status. The mid reaches of the River Bladnoch catchment and lower Tarf Water sub-catchment have a moderate status which has been downgraded due to degraded morphology and iron pollution. The upper River Bladnoch catchment and upper Tarf Water sub-catchment have a poor status and have been downgraded due to poor water quality (pH), fish ecology, invertebrates and iron pollution.

Map 1 – Catchment map of the River Bladnoch showing peat coverage (in brown)



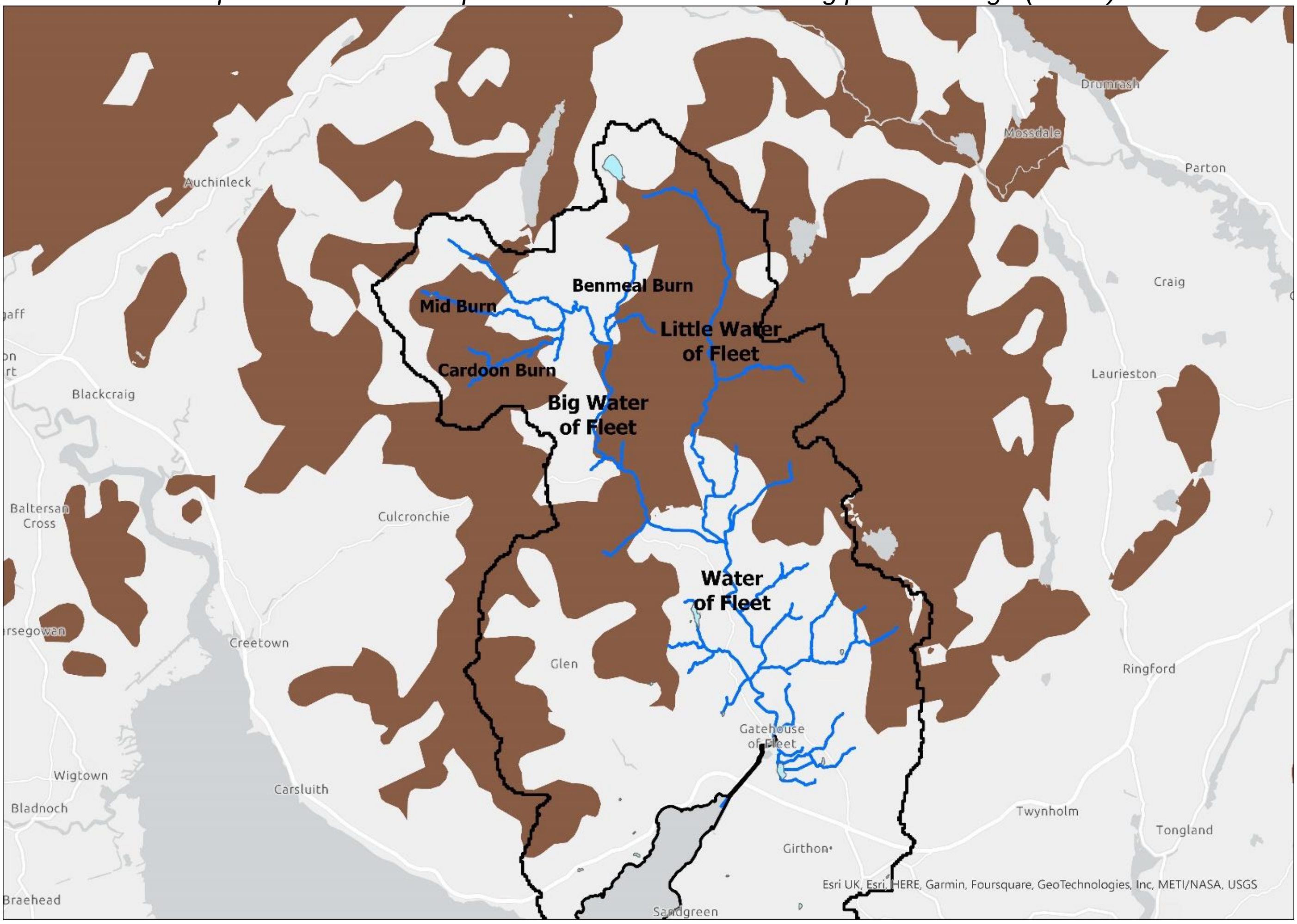
Map 2 – Eunis land use map for the Bladnoch catchment



(Dark green = Conifer Plantations; Bright green = Heathland, Scrub and Tundra; Pale Green = Grasslands; Purple = Mires, Bogs and Fens; Pink = Montane Habitats; Peach = Inland Unvegetated or Sparsely Vegetated Habitats; Yellow = Coastal Habitats; Blue = Watercourses)

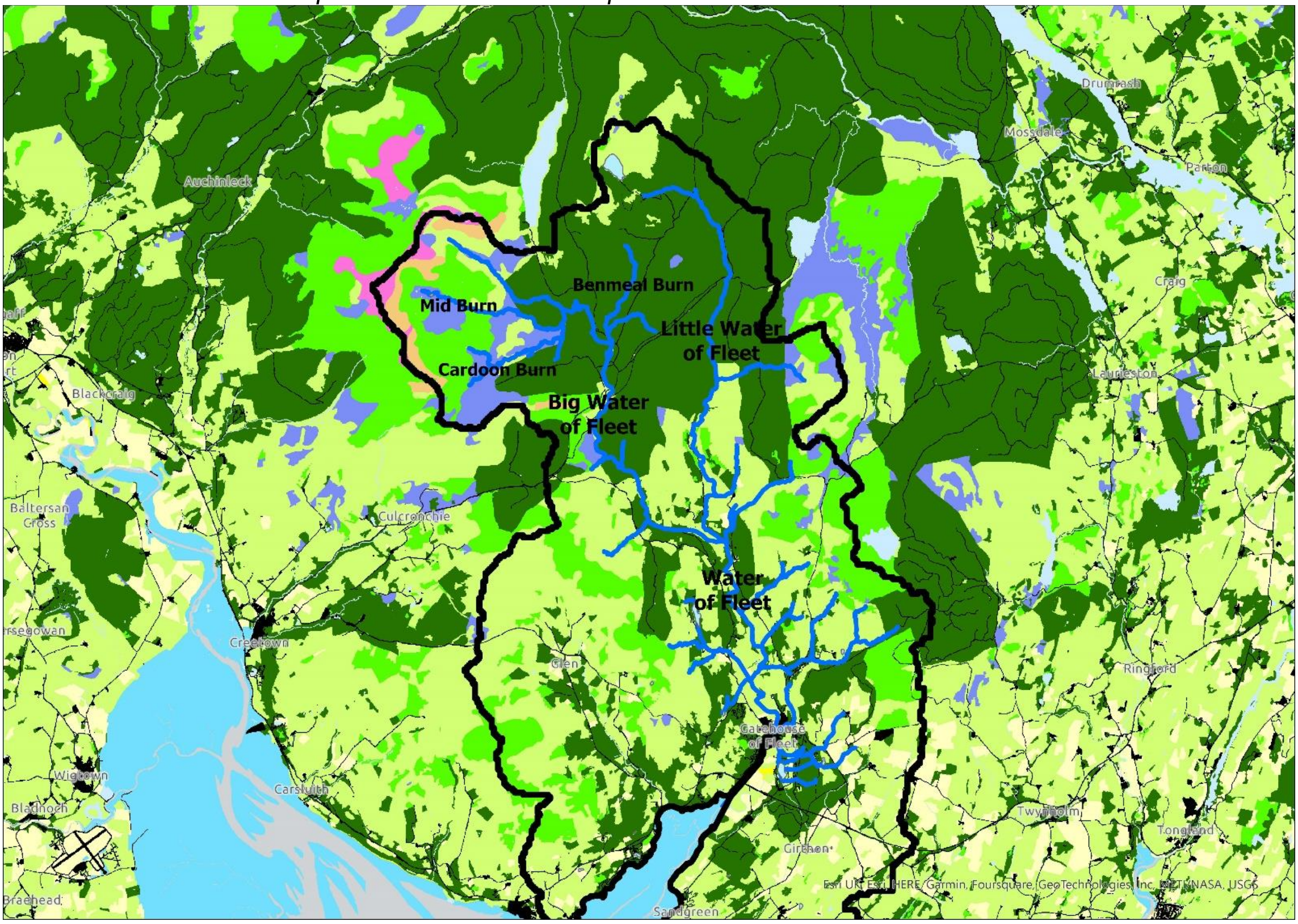
The second area covered during Winter 2021/2022 is the headwaters of the Water of Fleet. The Water of Fleet is a small river catchment, covering 144 km^2. The river sources in the Cairnsmore of Fleet hills and meanders south for over 25 km before flowing into the Solway. The upper river drains two main sub-catchments; the Big Water of Fleet and the Little Water of Fleet and the surrounding land use is dominated by commercial Sitka spruce forestry. As with the Bladnoch, the Water of Fleet catchment contains a significant coverage of peat (Map 3). In addition to the peat map some work has been carried out to record peat depths within the Fleet headwaters. Maps from work carried out by PA and NatureScot showing recorded peat depths for a number of areas are listed in Appendix 1. As can be seen from the Map 3 the highest concentrations of peat are located within the headwaters of the system. A massive land use change took place over much of these headwater areas during a relatively short period of time with extensive drainage and planting with a monoculture of Sitka spruce (shown on Map 4). As can be seen by comparing Maps 3 and 4 much of the forestry is planted over peat which has resulted in significant degradation. As an added complication much of the peat, and afforestation, lie on granite bedrock which has poor pH buffering capacity and has resulted in significant levels of acidification.

Map 3 – Catchment map of the Water of Fleet showing peat coverage (brown)



Local anecdotes indicate the Little Water of Fleet, including its source Loch Fleet, was recognised historically as an impressive Brown trout fishery. A large natural waterfall in the lower reaches meant no migratory salmonids could utilise these habitats resulting in only Brown trout being present above the falls. The Big Water of Fleet is accessible to migratory salmonids and offered particularly good spawning and juvenile habitats. By all accounts these habitats were able to support an impressive Sea trout population with annual rod catches peaking at nearly 1,200 fish in the mid 1960's (catch data available from Marine Science Scotland). Through the 1970's and 1980's these trout populations underwent a marked decline. By the mid 1980's the entire Little Water of Fleet catchment (including Loch Fleet) trout population was considered extinct. The sea trout rod fishery, which was reliant on high smolts production from the upper Big Water of Fleet burns, dropped suddenly from the high of nearly 1,200 trout in the mid 1960's to only between 20 - 70 trout caught in most years since the early 1970's. This sudden extensive collapse of these abundant trout fisheries is largely believed to be due to acidification with the Fleet headwater burns being some of the most acidified in Britain. The Solway Tweed River Basin Plan 2009 concluded that over 28 km of watercourses were acidified in the upper Fleet.

Map 4 – Eunis land use map for the Water of Fleet catchment



(Dark green = Conifer Plantations; Bright green = Heathland, Scrub and Tundra; Pale Green = Grasslands; Purple = Mires, Bogs and Fens; Pink = Montane Habitats; Peach = Inland Unvegetated or Sparsely Vegetated Habitats; Yellow = Coastal Habitats; Blue = Watercourses)

In contrast to the conifer plantations a section of un-planted headwater lies within the Cairnsmore of Fleet National Nature Reserve which is managed by NatureScot and has been subject to peatland restoration. Designations within the Fleet catchment include the Cairnsmore of Fleet SSSI and nature reserve, Lea Larks SSSI, Laughenghiegie and Airie Hills SSSI, Fleet Valley NSA, Castramont Woods SSSI, Galloway Oakwoods SAC, Ardwell Hill SSSI, Killiegowan Wood SSSI and the whole catchment forms a core section of the Galloway and Southern Ayrshire Biosphere. SEPA's water classification hub gives the upper Water of Fleet poor status, downgraded as a result of its poor fish ecology and macroinvertebrates due to acidification.

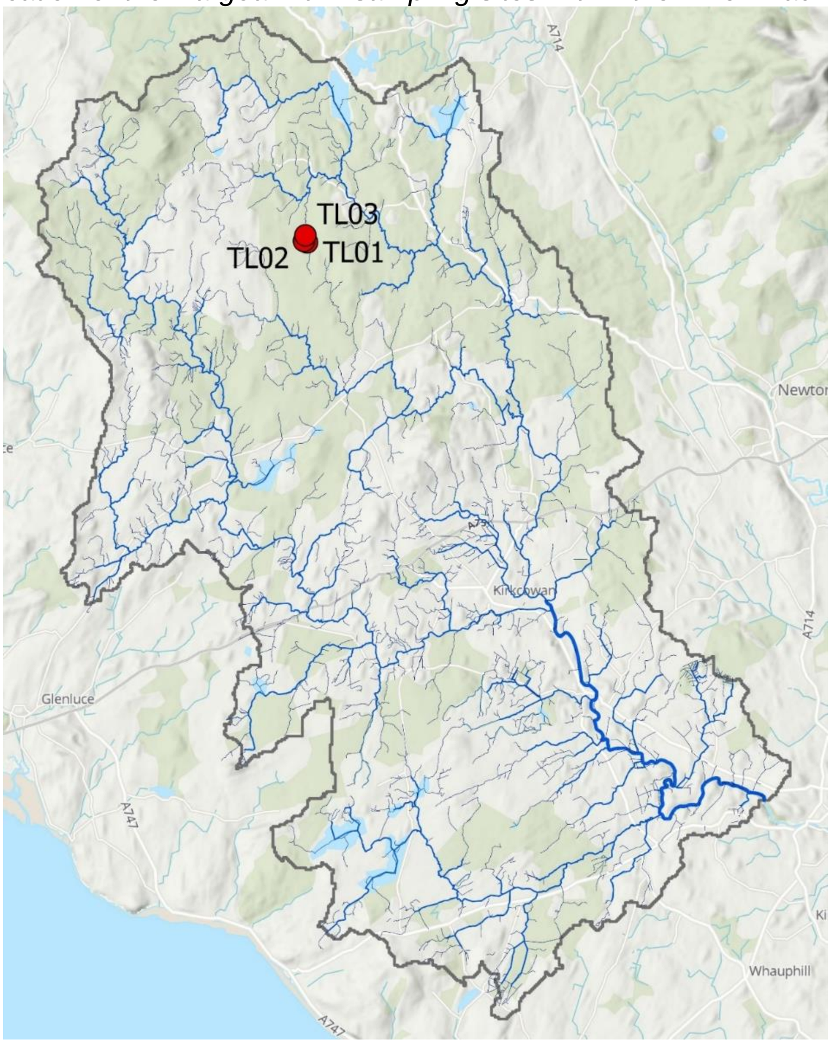
In addition to the water quality monitoring this report includes a review of the GFT electrofishing (fish survey) data from the Water of Fleet to identify areas where fish populations are still being impacted and overall trends in numbers.

2 METHOD

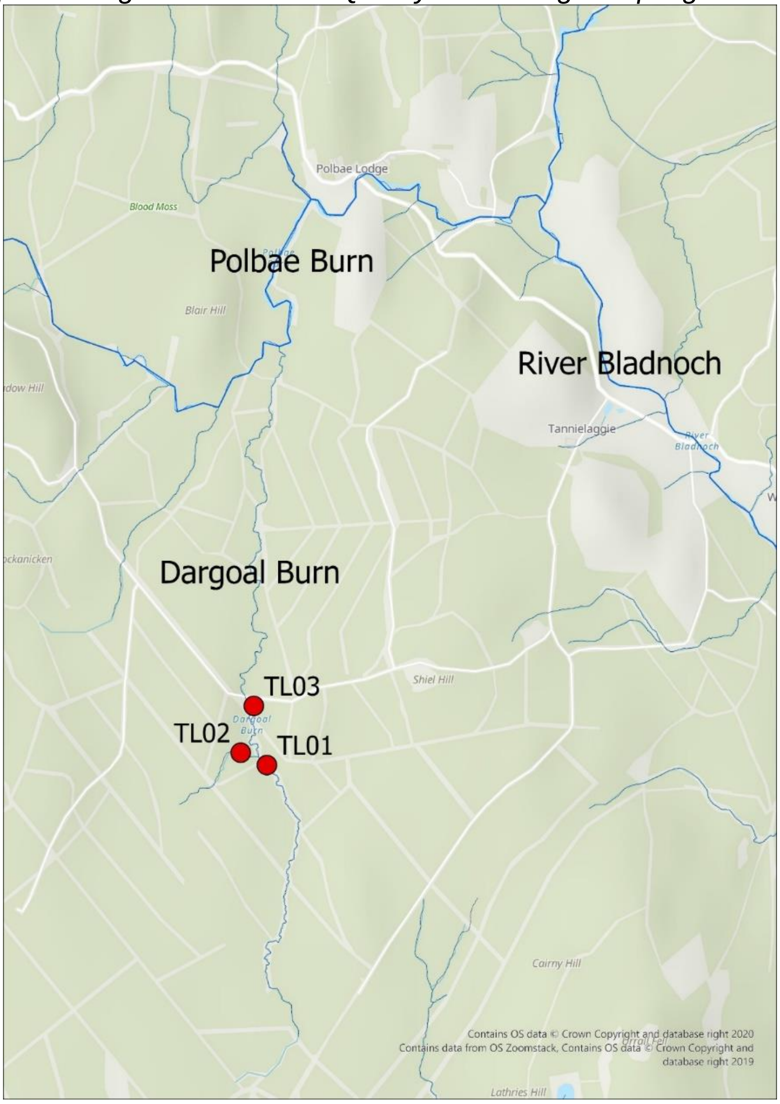
2.1 Tannylaggie Flow Peatland Restoration Water Quality Monitoring

The Dargoal Burn within the Tannylaggie sample area is surrounded by deep peat, with the peat being subject to extensive historic draining and planting with Sitka spruce. This has resulted in the burn experiencing some of the lowest pH values within the Galloway region and having a knock-on effect downstream on the pH levels of the Polbae Burn and the River Bladnoch, both of which form part of the River Bladnoch Special Area of Conservation for Atlantic salmon. Within the last forestry management plan for the Tannylaggie forest the decision was taken by FLS not to replant some of the areas of deep peat post felling and to leave them aside for Peatland restoration (Forest and Land Scotland, 2016). This includes much of the area around the burn. Felling began in 2016 and whilst no peatland restoration has taken place to date a restoration plan has been agreed and is out to tender with the aim of being carried out at the first possible opportunity. The water quality monitoring in the Dargoal Burn therefore centres on monitoring pre and post restoration to look at the water quality benefits of Peatland restoration, with the monitoring to date covering the pre-restoration phase. Recording started in winter 2019/2020, continued in winter 2020/2021 and ran again during the current recording period (winter 2021/2022). Tree felling within the restoration area was underway by the time the monitoring began in 2019, although there has been significant regeneration of Sitka since the felling took place (author, personal observation). The monitoring sites in the Dargoal Burn centres around a small burn/gully into which a number of forestry ditches drain. Sites are located above the gully (TL01), within the gully itself (TL02) and below the gully (TL03). The sites were chosen to show the overall condition of the burn, localised variations within the gully and if the water from the gully is having any significant impact on water quality within the Dargoal Burn. Maps 5 and 6 show the locations of the sample sites within the Bladnoch catchment whilst Maps 7 and 8 show peat occurrence and recorded peat depths around the Dargoal Burn.

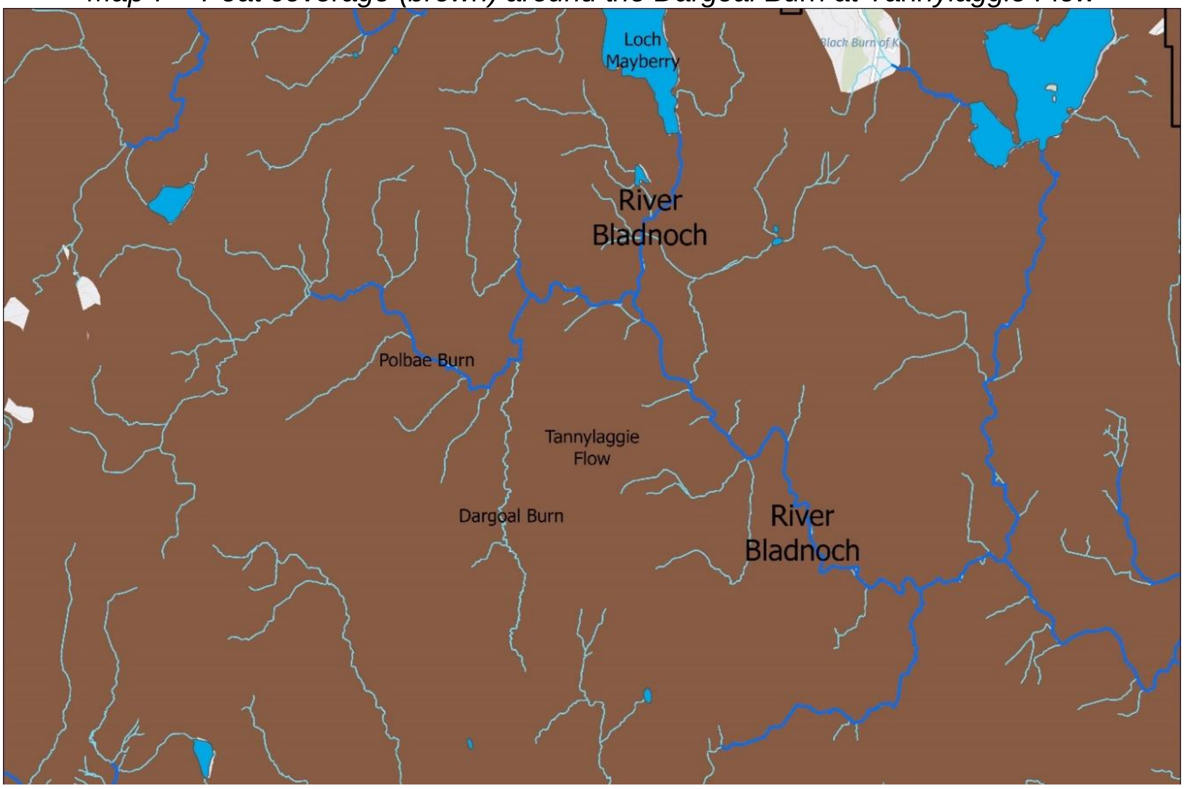
Map 5 – The location of the Dargoal Burn sampling sites within the River Bladnoch catchment



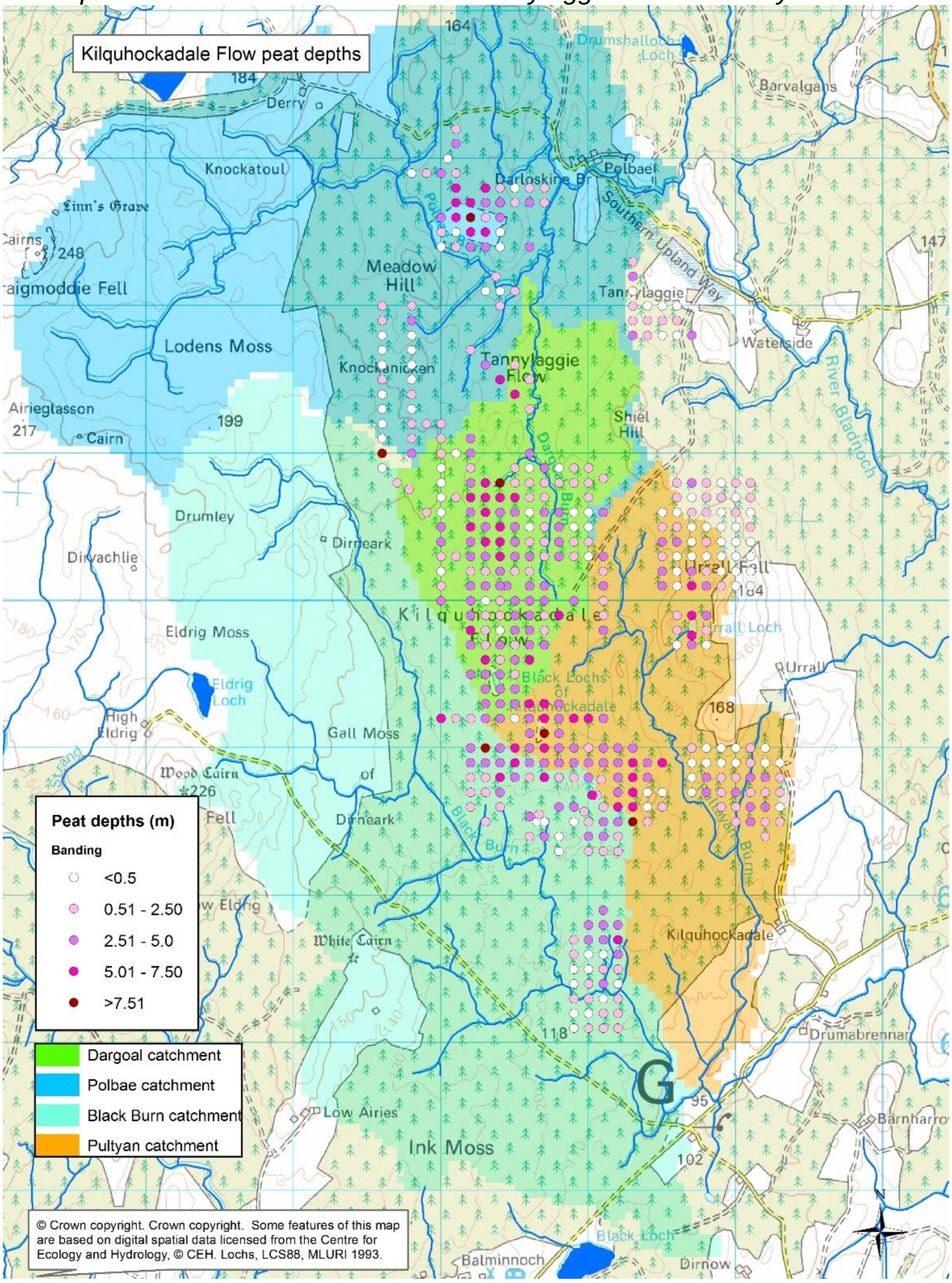
Map 6 – Dargoal Burn Water Quality Monitoring sampling locations



Map 7 – Peat coverage (brown) around the Dargoal Burn at Tannylaggie Flow



Map 8 – Peat Depth Measurements from around Tannylaggie Flow taken by GFT and funded by PA



Water quality was recorded using EXO1 Sondes. The Sondes record water quality parameters at 15 minute intervals after deployment. After an initial trial in in the first year of the project 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, the impacts are amplified by increase run-off after rainfall and increased scavenging of acidic particles in the air by non-native conifers. Both are heavily associated with areas of degraded Peatland within Galloway.
- 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.

The Sondes were held in place submerged within the burn using frames constructed out of drainpipe and supported wooden stobs as shown in Figure 1.

Figure 1 – Frame designed to support the EXO1 Sonde within the Cleuch of Eglon Burn (Fleet catchment)

The Sondes are located within the lower, submerged sections of pipe, which are perforated to allow water to flow through. During Winter 2019/2020 the Sondes were deployed at all three sites from 30.12.2019 to 17.03.2020. Data from the top monitoring site during winter 2019/2020 was highly variable and at times differed greatly from the other two sampling sites. It was concluded that there was insufficient depth for the Sonde to remain submerged during low flows. As a result only the gully and the lower site were monitored during winter 2020/2021 with the Sondes in place between 04.12.2020 to 12.01.2021 and 04.12.2020 to 29.01.2021 respectively. The third available Sonde was used for spot sampling (discussed later) during this recording period. For Winter 2021/2022 the decision was taken to revisit the top site as site visits in Autumn 2021 indicated that it could be placed so that it remained submerged at all times. Sondes were deployed at the top site and bottom site from 15.12.2021 to 14.01.2022. The third available Sonde was retained for spot sampling, although circumstances dictated that no spot sampling actually took place during this recording period. The water quality monitoring for the Dargoal Burn is summarised in Table 1.

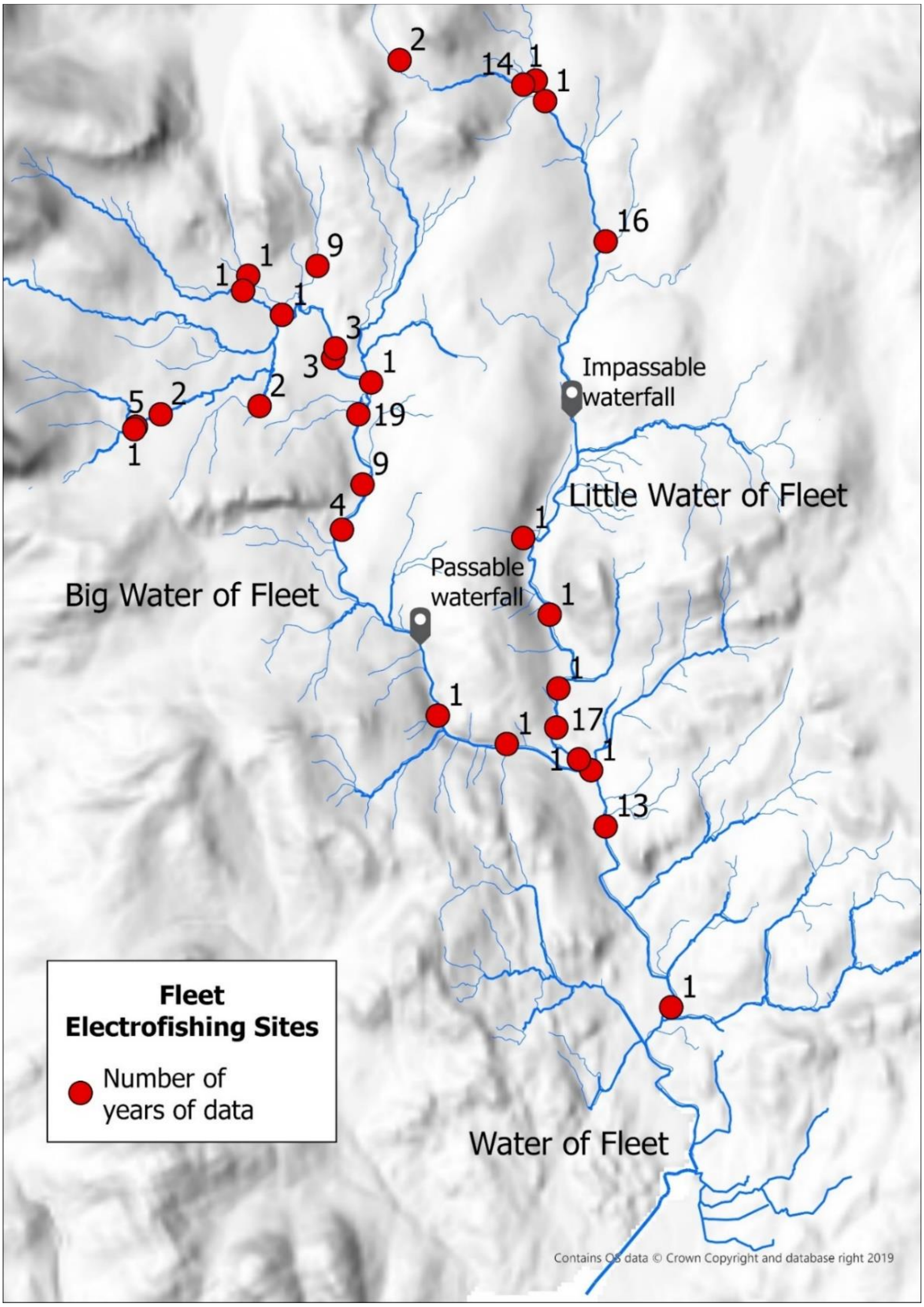
Table 1 – EXO1 Sonde Water Quality Data Collection Summary for the Dargoal Burn

Sample Location	2019/20 Recording Period	2020/21 Recording Period	2021/22 Recording Period
Top (upstream)	30.12.2019 to 17.03.2020	n/a	15.12.2021 to 14.01.2022
Gully	30.12.2019 to 17.03.2020	04.12.2020 to 12.01.2021	n/a
Bottom (downstream)	30.12.2019 to 17.03.2020	04.12.2020 to 29.01.2021	15.12.2021 to 14.01.2022

2.2 Water of Fleet Electrofishing Review and Water Quality Monitoring

GFT has been carrying out electrofishing surveys of the Water of Fleet since the late 1990's, with sampling sites located within the Fleet catchment having been visited on and off between 1997 and 2019. Fleet electrofishing sites were chosen/visited for a number of purposes, these include general monitoring of fish populations, 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 Big and Little Waters of Fleet (to see how far the impacts of the acidified headwaters extend downstream) have been reviewed. Map 9 shows the location of these sites within the Fleet catchment and lists the number of times each site has been visited annually.

Map 9 – Map of the Water of Fleet catchment showing the location of the GFT electrofishing sites and the number of site visits for the main stem of the Fleet and acid sensitive areas

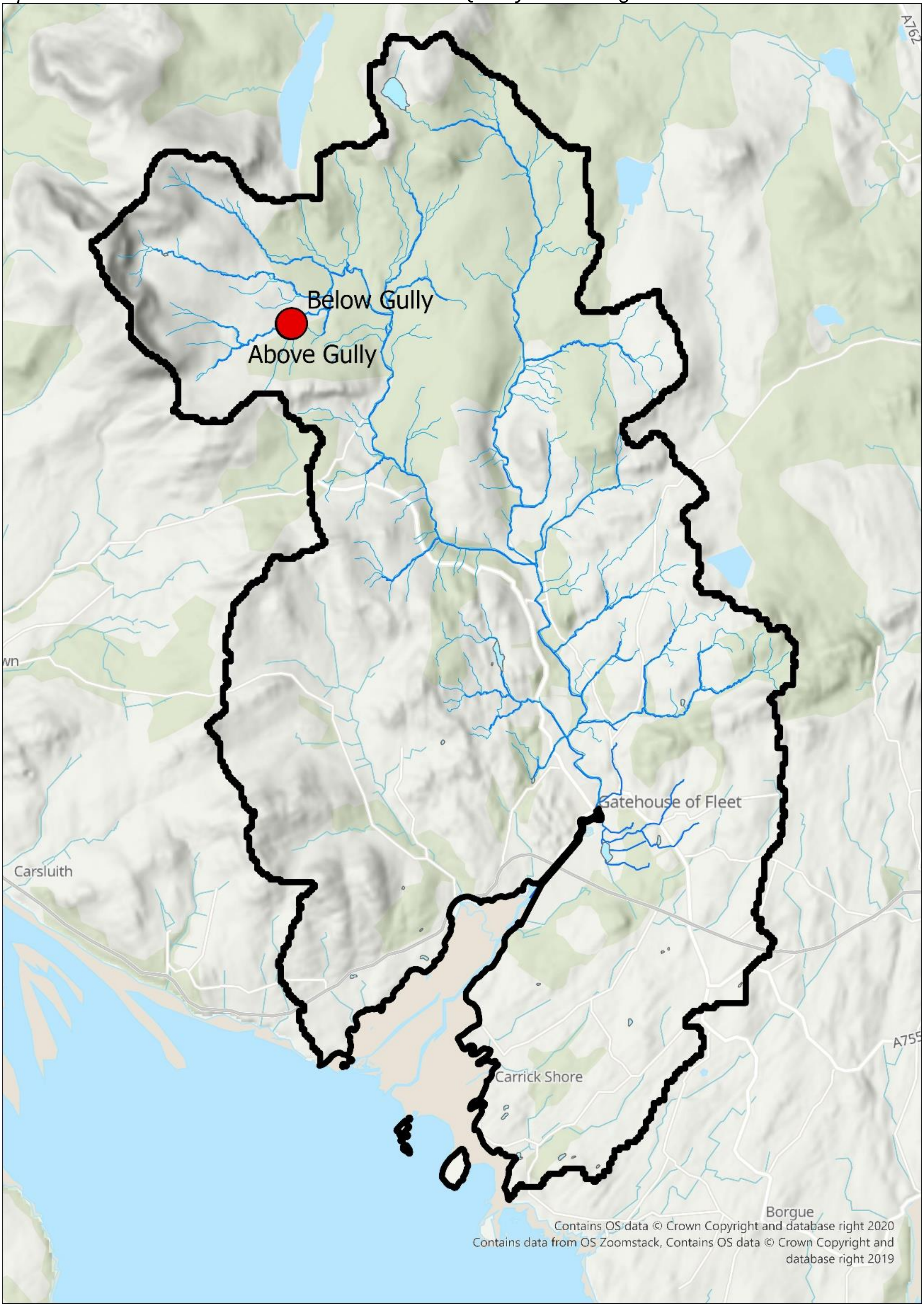


The electrofishing sampling methodology adopted for all sample sites is one to three run sampling following the Scottish Fisheries Co-ordination Centre (SFCC) methodology (Scottish Fisheries Co-ordination Centre, 2021). This gives a minimum estimate of fish density per 100 m^2 for each site and allows, at a minuimum, the first run fish density to be compared between sites, which has been done in this report. Due to the practical limitations of electrofishing the fish habitat sampled is typically shallow riffle and run habitat which is typically dominated by juvenile salmon and trout, with salmon and trout being both the target species and the main native fish species present. Sites are normally visited within in July, August or September (when fry have grown big enough to be influenced by the electrofishing process). The results given 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). 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. As can be seen from Map 9 many of the Fleet electrofishing sites only have data for one or two electrofishing visits. Where sites have been visited on multiple occasions the individual results 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 results have been assigned into three roughly equal time periods – 1997 to 2004; 2005 to 2012 and 2013 to 2019. 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 times with salmon spawning in wider channels and trout in narrower, and that this tends to be represented in the electrofishing results. The exact channel width at which salmon spawning changes to trout 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 shallow riffles and runs in larger channels dominated by salmon fry. As stated earlier in the report there is a waterfall on the Little Water of Fleet that is completely impassable to migratory fish (shown on relevant maps). As such no salmon of any age should be present above these falls as, unlike Brown trout, they cannot complete their life cycle without access to the marine environment.

In combination with the electrofishing review the headwaters of the Water of Fleet were monitored for water quality during winter 2021/22. The Fleet headwaters are amongst the most acidified in the Galloway region (Battarbee, 1989) with fish populations significantly impacted (as shown later in the electrofishing review results). Prior to winter 2021/22 water quality monitoring undertaken as part of this project had been based around Peatland Restoration at Cairnsmore of Fleet in a large area of deep peat around the Cardoon Burn (a major Water of Fleet headwater burn). Much of the peatland was historically drained and grazed. The area is now controlled by NatureScot and two phases of restoration are well underway in the form of ditch blocking and hag re-profiling. However, a large percentage of the peat area on the Southern side of the burn valley is managed as a conifer plantation. A number of drainage ditches within this plantation flow into an actively eroding gully (Figure 2) which, in turn, flows directly into the Cardoon Burn. Water quality monitoring sites were previously put in place directly above and below the gully to look at the overall water quality within the burn and any localised impact that the water from the gully may be having. EXO1 Sondes were deployed from 30.01.2021 to 23.03.2021 (upstream site) and from 03.02.2021 to 23.03.2021 (downstream site).

Figure 2 – Actively eroding gully approx. 100 m upstream from where it enters the Cardoon Burn, resulting in degraded and ineffective deep peatland upstream as a result of the lowered water table

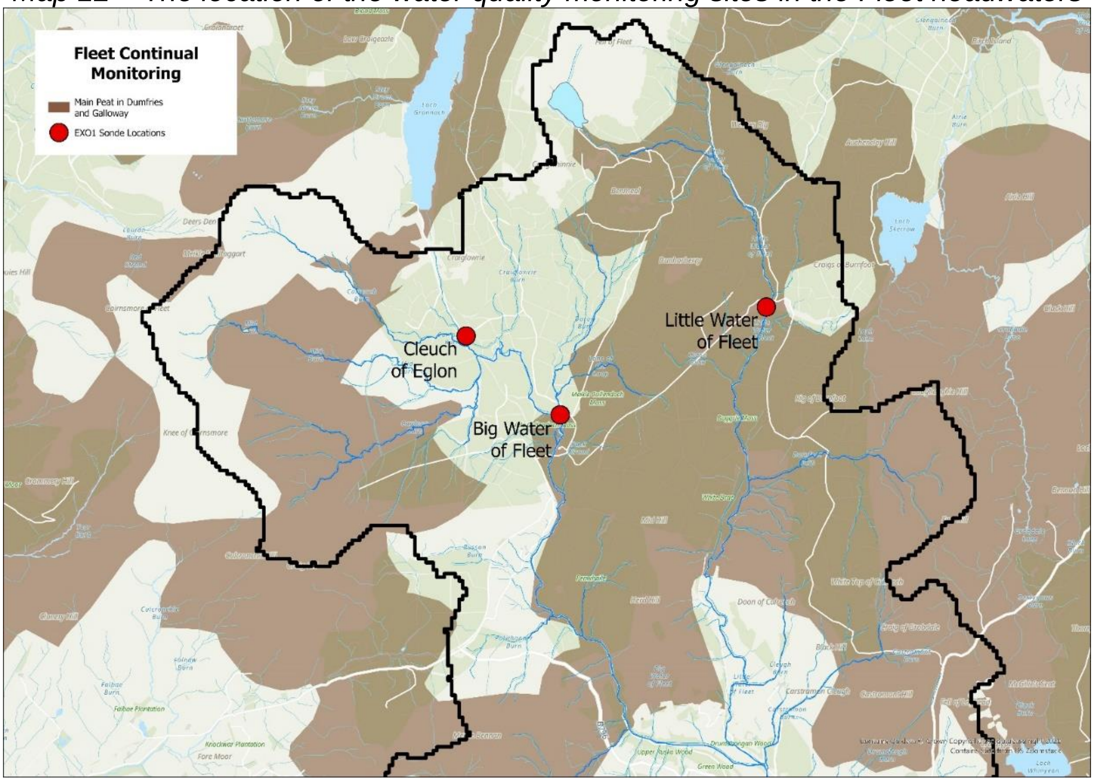
Map 10 – The location of the Cardoon Burn Water Quality Monitoring sites within the Fleet Catchment



Map 11 – The Cardoon Burn showing the location of the water quality monitoring sites

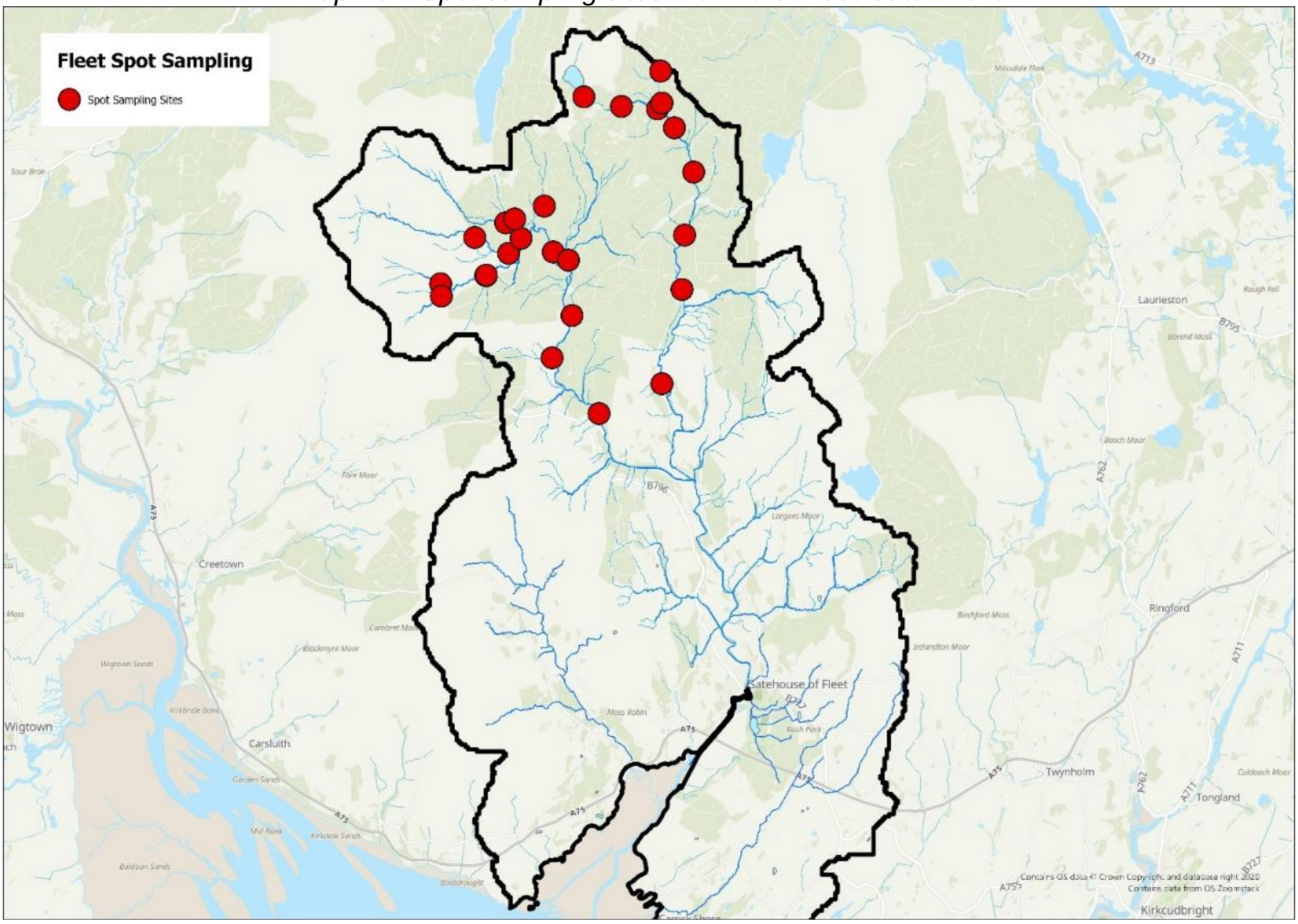
For the winter 2021/22 recording period the decision was taken to expand the Water of Fleet water quality monitoring beyond just the Cardoon Burn to record an overview of the whole upper river catchment. Sites for EXO1 Sonde deployment were chosen on the main stem of the Big and Little Waters of Fleet within the heart of the conifer plantations covering the Fleet headwaters. This was to give an indication of the overall condition of each watercourse and any variations in water quality. The Sondes were deployed at both sites between 21.01.2022 and 29.03.2022. During this monitoring period an additional Sonde funded by NatureScot became available. It was deployed within the Cleuch of Eglon Burn between 03.03.2022 and 29.03.2022. The burn was chosen as low pH spot sampling results combined with low fish numbers from electrofishing data indicated it would be a good monitoring site. The monitoring sites are shown on Map 12.

Map 12 – The location of the water quality monitoring sites in the Fleet headwaters



In addition to the EXO1 Sonde monitoring a number of spot water samples were taken from sites spread around the upper Fleet catchment. This involves collecting water samples from locations within watercourses after periods of high flows to catch pH at its lowest levels. Once collected water samples were quickly taken back to the GFT office and pH was 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 that 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 identified and allowing areas to be identified for further, more detailed investigation.

Map 13 – Spot sampling sites within the Fleet Catchment



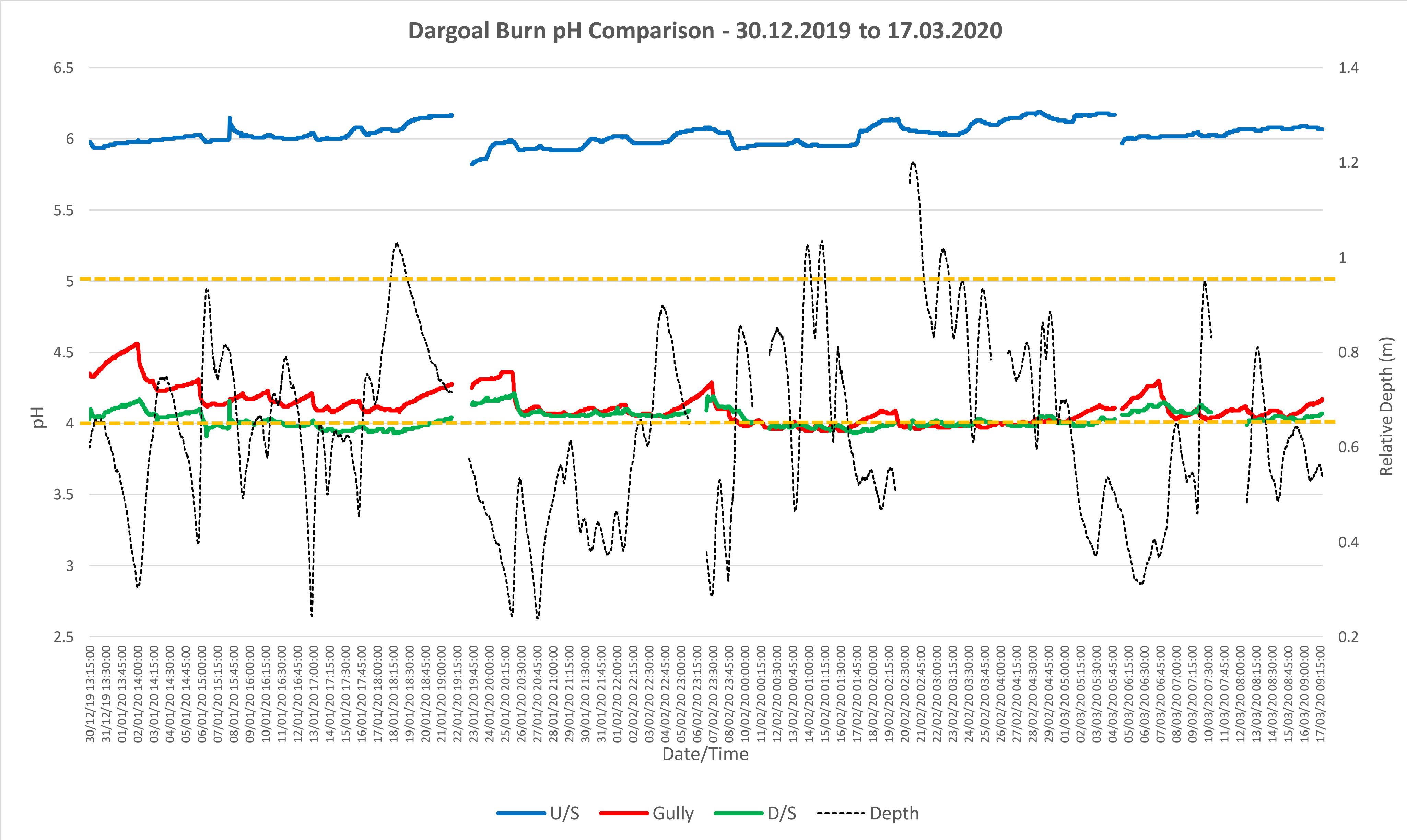
Map 13 shows the spot sampling sites for the Upper Fleet catchment. They were chosen to give the maximum coverage possible within the time available before water levels drop. Spot sampling was carried out after periods of heavy rainfall on 04.02.2022, 14.02.2022, 21.02.2022, 01.03.2022 and 02.03.2022. Whilst the intention was to sample every sample site during each visit the storms that occurred during February/March 2022 resulted in numerous trees being blown down over forestry tracks, preventing access to large numbers of sites during some visits. In addition to the pre-chosen sites some additional water samples were taken on an opportunistic basis when collecting samples. The results from these sites are included within the report, as are the results from spot sampling sites on the Cardoon Burn recorded prior to winter 2021/2022. Some spot samples were also taken from sites on the Rivers Luce and Bladnoch in 2020/2021 and River Cree in 2019/2020, 2020/2021 and 2021/2022 but have not been shown in this report.

3 RESULTS

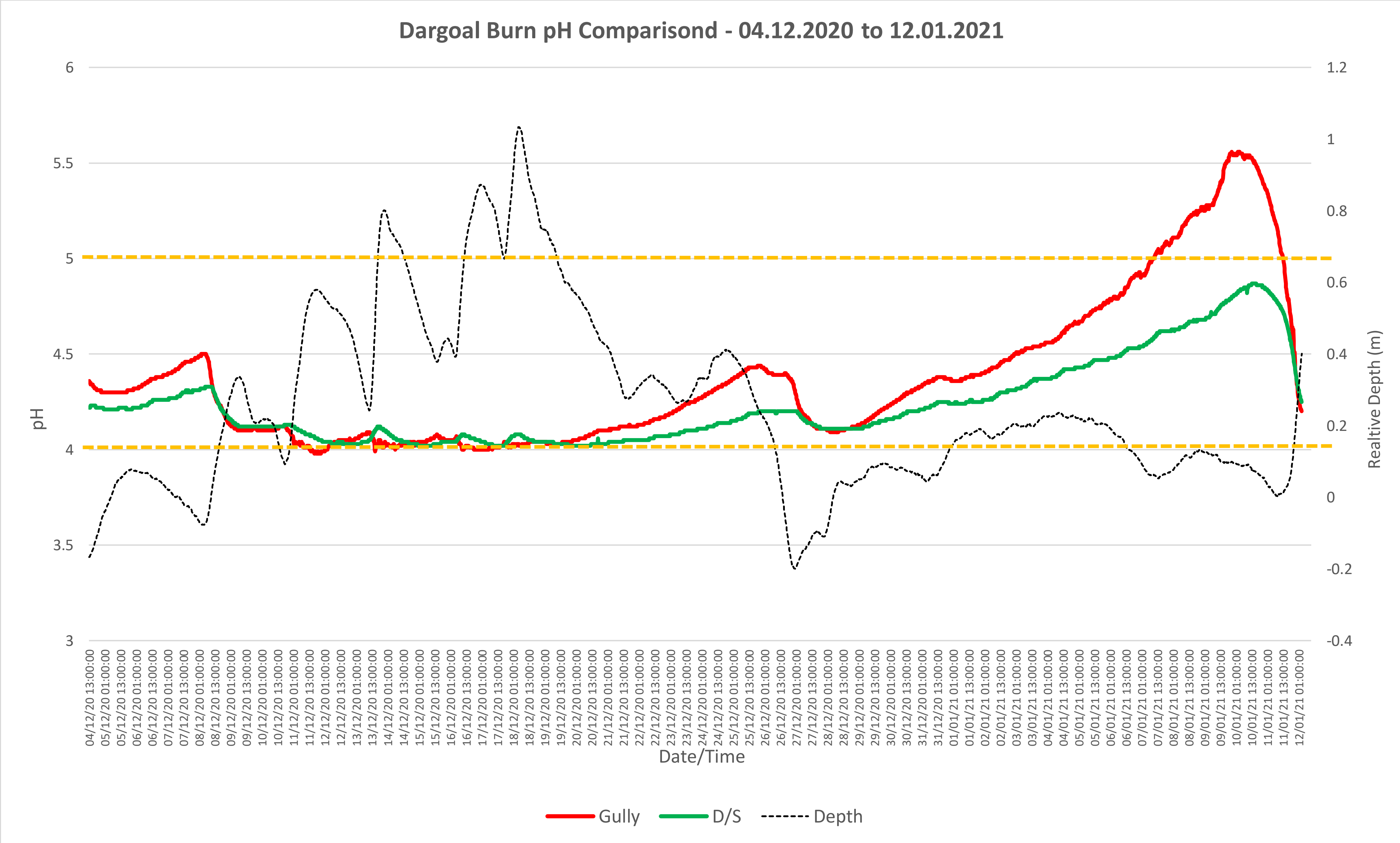
3.1 Tannylaggie Flow Peatland Restoration Water Quality Monitoring

The data collected in 2021/2022 adds to the pre-restoration data collection from 2019/2020 and 2020/2021. The pH data for all three time periods are displayed in Graphs 1, 2, and 3. What is clear from the data is that there is an issue with the furthest upstream water quality monitoring site. Although pH levels in 2021/2022 are much closer to those recorded in the furthest downstream logger, the readings at times are diverging significantly and it is clear that the pH levels being recorded are, during these periods, not representative of the burn in this area. It is believed that the EXO1 Sonde at this site was submerged at all times and was functioning correctly. The exact location of the Sonde is within a large backwater (shown in Figure 3) and it is possible that the water surrounding the Sonde is being cut off from the main flow and stagnating, potentially causing the divergence we see in pH levels during these periods. Graph 3 shows a clear relationship between the relative depth recorded by the Sonde (as a proxy for flow) and the periods in which the pH appears to vary from the typical pH levels recorded at the other two sites. Any future monitoring would require this site to be moved to a location that retains a flow at all times.

Graph 1 – Comparison between pH and relative water depth (m) at all three recording sites on the Dargoal Burn during winter 2019/2020 with pH 5 and pH 4 highlighted (below 5 is likely harmful to Salmonids with below 4 likely being lethal)



Graph 2 – Comparison between pH and relative water depth (m) at the gully site and downstream site on the Dargoal Burn during winter 2020/2021 with pH 5 and pH 4 highlighted (below 5 is likely harmful to Salmonids with below 4 likely being lethal)



Graph 3 – Comparison between pH and relative water depth (m) at the upstream site and downstream site on the Dargoal Burn during winter 2021/2022 with pH 5 and pH 4 highlighted (below 5 is likely harmful to Salmonids with below 4 likely being lethal)

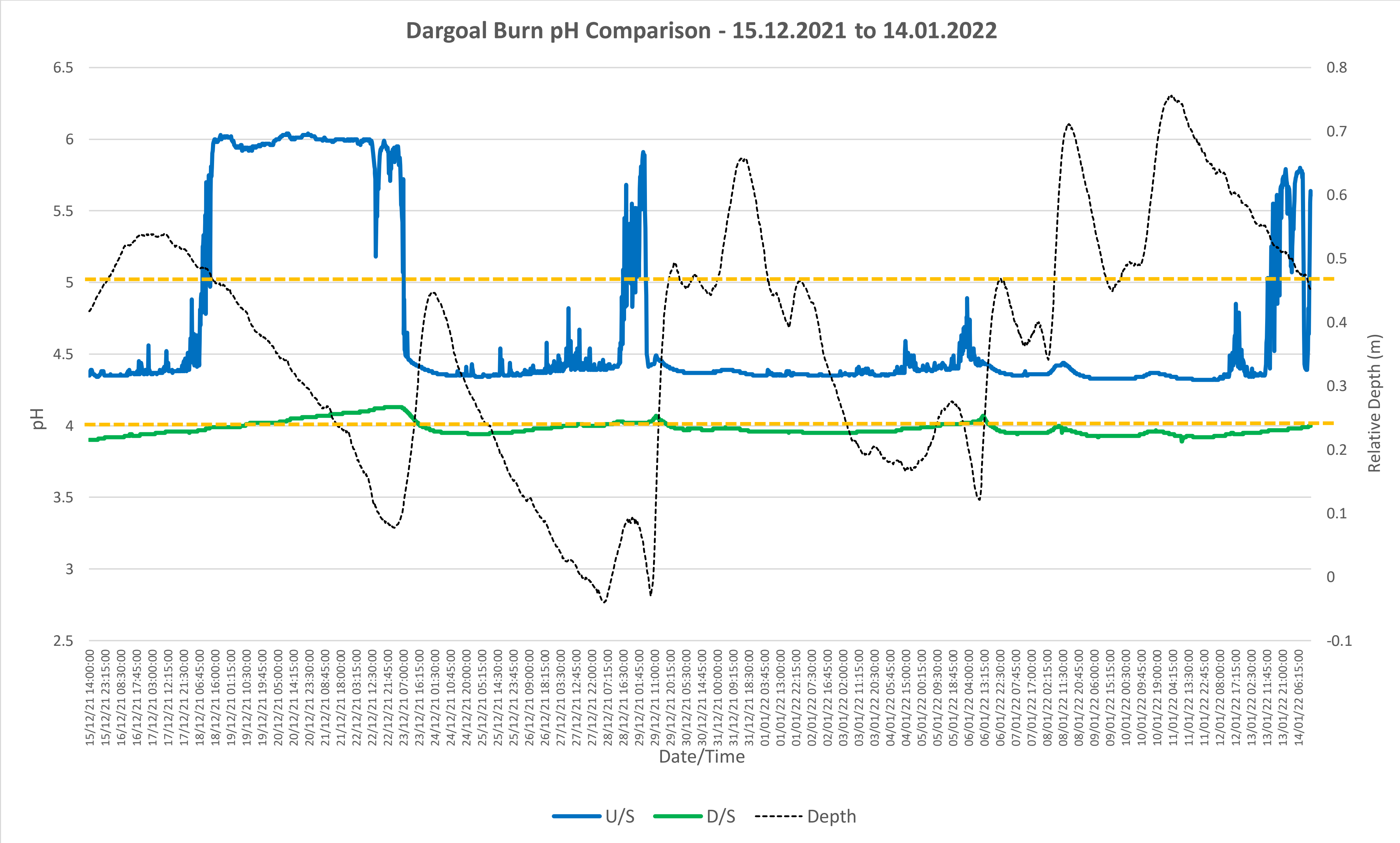
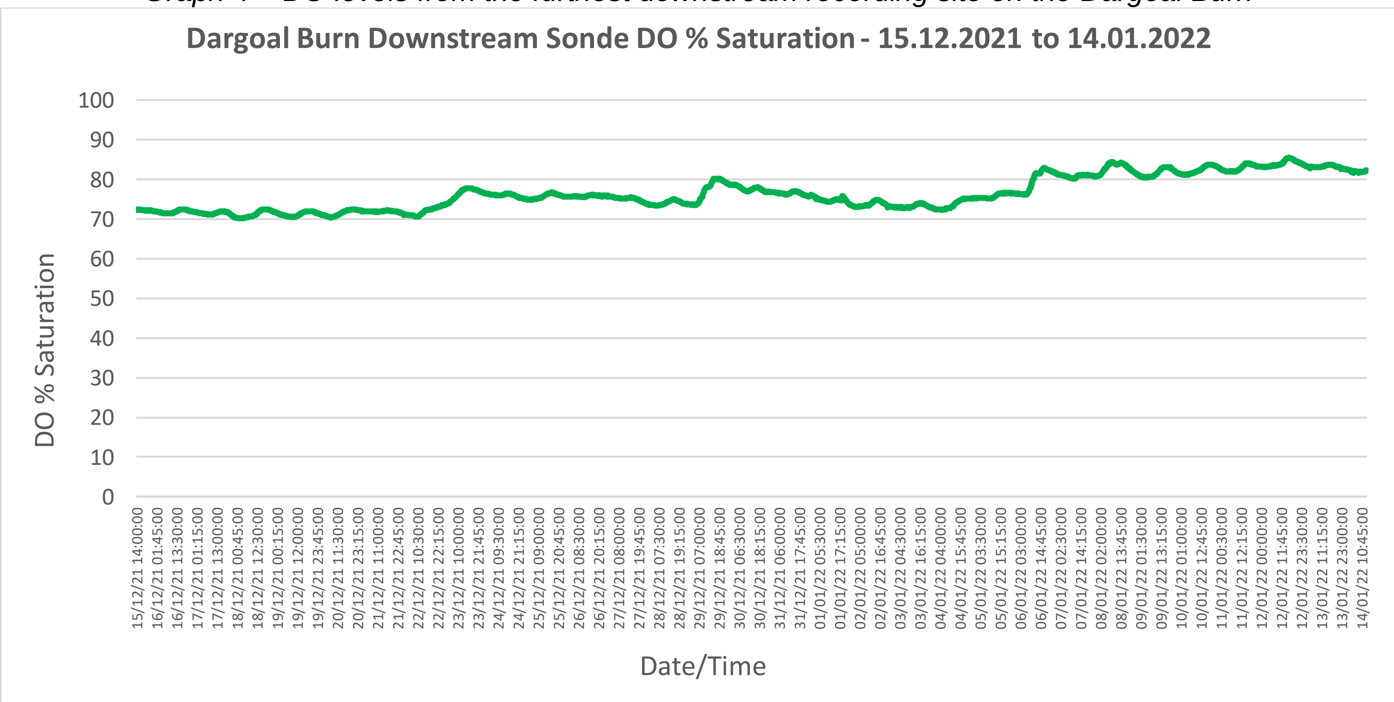


Figure 3 – Location of the furthest upstream EXO1 Sonde (TL01) in the Dargoal Burn

The pH in the Dargoal Burn at the current pre-restoration stage is clearly at a level within which fish populations are unlikely to survive. All three sites recorded pH levels well below 5 with the gully and downstream sites occasionally dropping below 4. Given the close relationship between the pH levels in the Gully and furthest downstream site the results suggest that the low pH levels are as a result of the degraded state of the peatland across the whole burn catchment area, as opposed to being caused by a few problem drainage ditches and direct surface run off. Although the pH levels in the gully react quicker to rainfall than the downstream site, and reach a slightly lower level, the pH at the downstream site persists at a lower level after rainfall indicating acidification beyond primarily surface water flows.

Of the other parameters recorded by the Sondes Dissolved Oxygen (DO) saturation levels are of note. The DO saturation levels recorded were well below 100% in the Dargoal Burn. Graph 13 shows the results from the Winter 2021/2022 recording period. Records from 2019/2020 and 2020/2021 are not shown but similar saturation levels were recorded. The burn within the sample area is slow and deep and DO levels below 100% saturation should be expected. However, given the levels recorded there may be some cause for concern in summer/warmer water temperatures when oxygen levels are potentially at their lowest.

Graph 4 – DO levels from the furthest downstream recording site on the Dargoal Burn

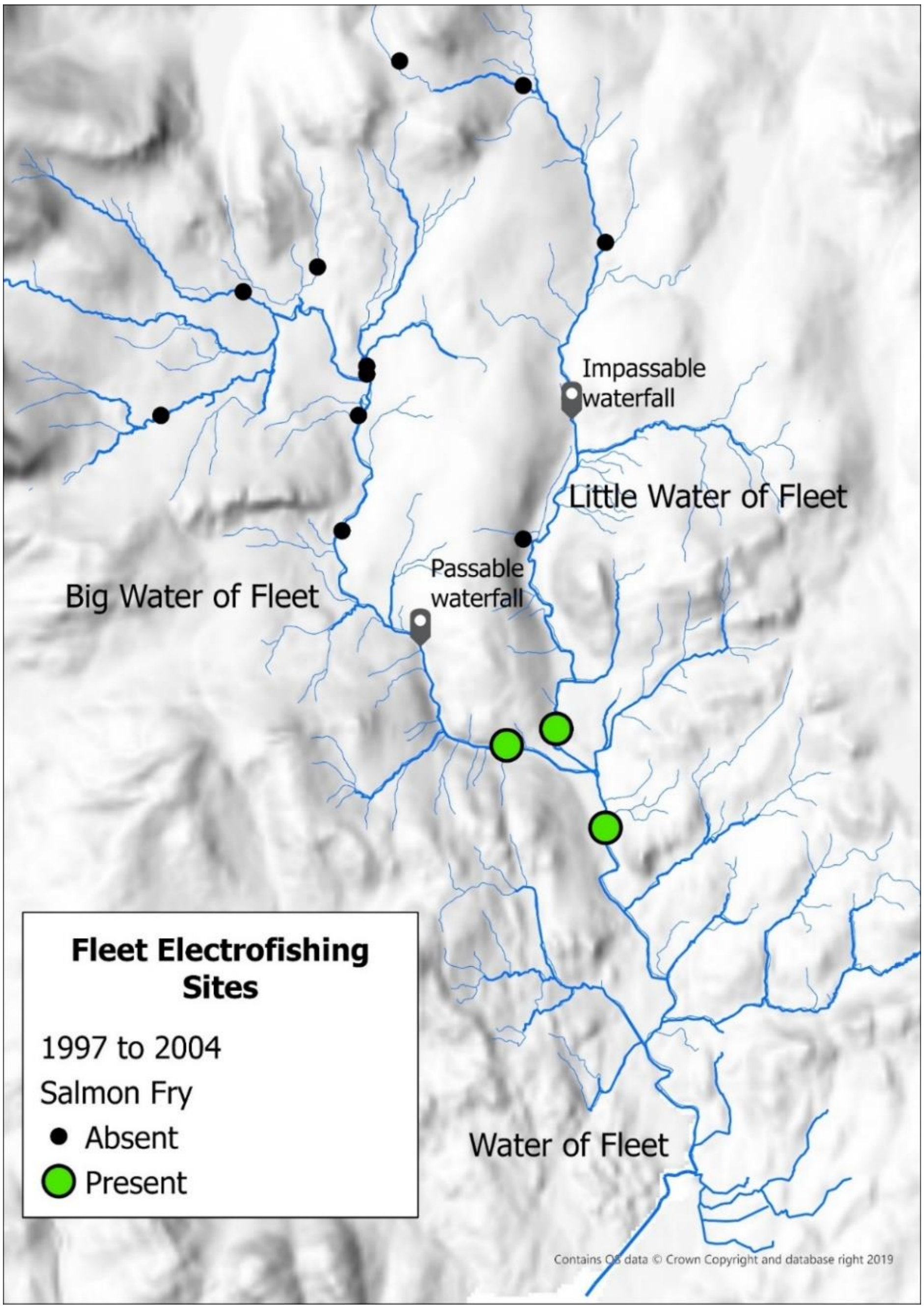


3.2 Water of Fleet Electrofishing Review and Water Quality Monitoring

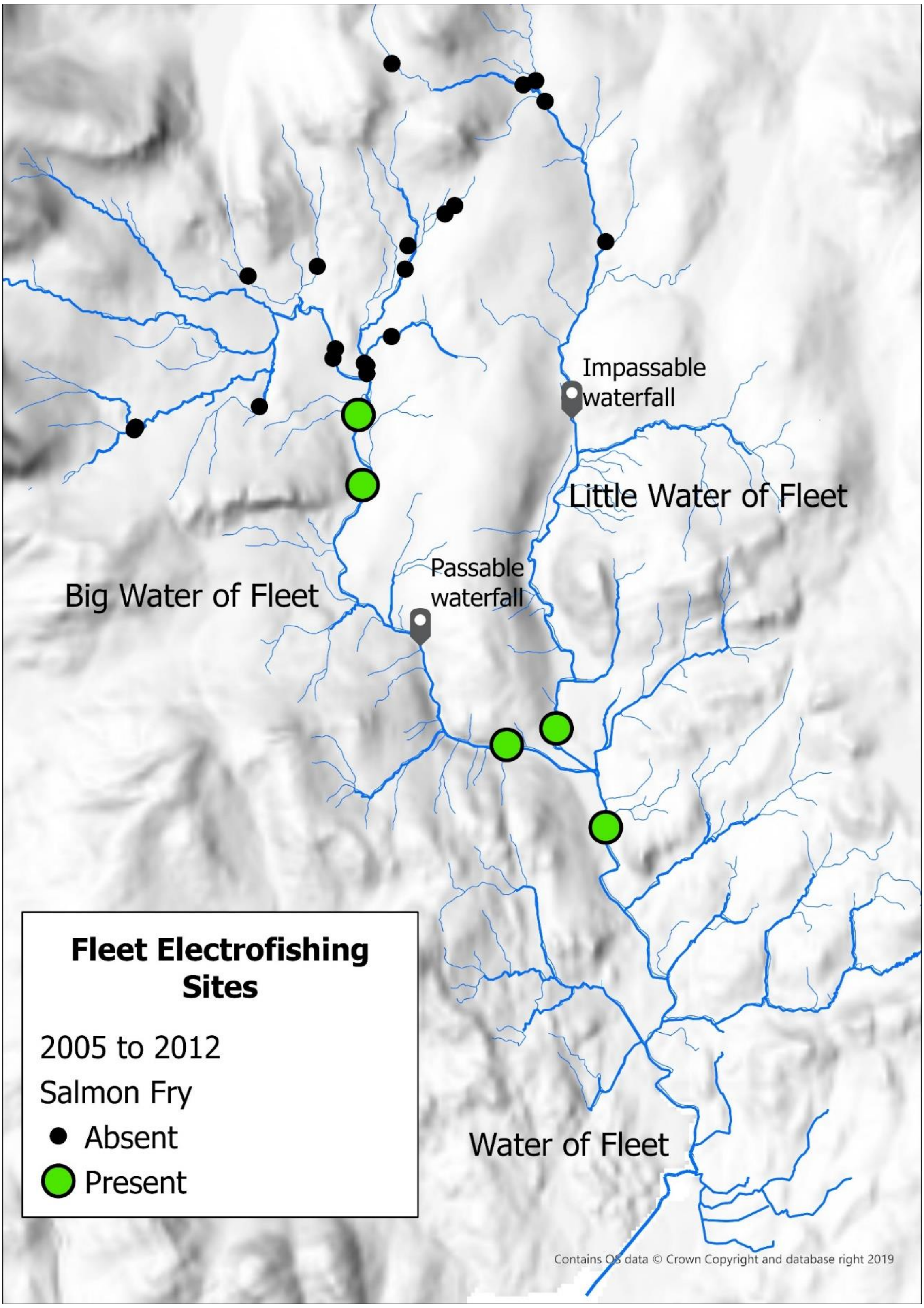
3.2.1 Water of Fleet Electrofishing Review

The electrofishing results from the Water of Fleet generally recorded low, or absent, fish numbers from the headwaters of the Fleet, particularly in the earlier years of recording. To highlight this, simple presence and absence maps for trout and salmon for the three time periods have been produced to give an idea of the spatial variation within the Upper Fleet catchment.

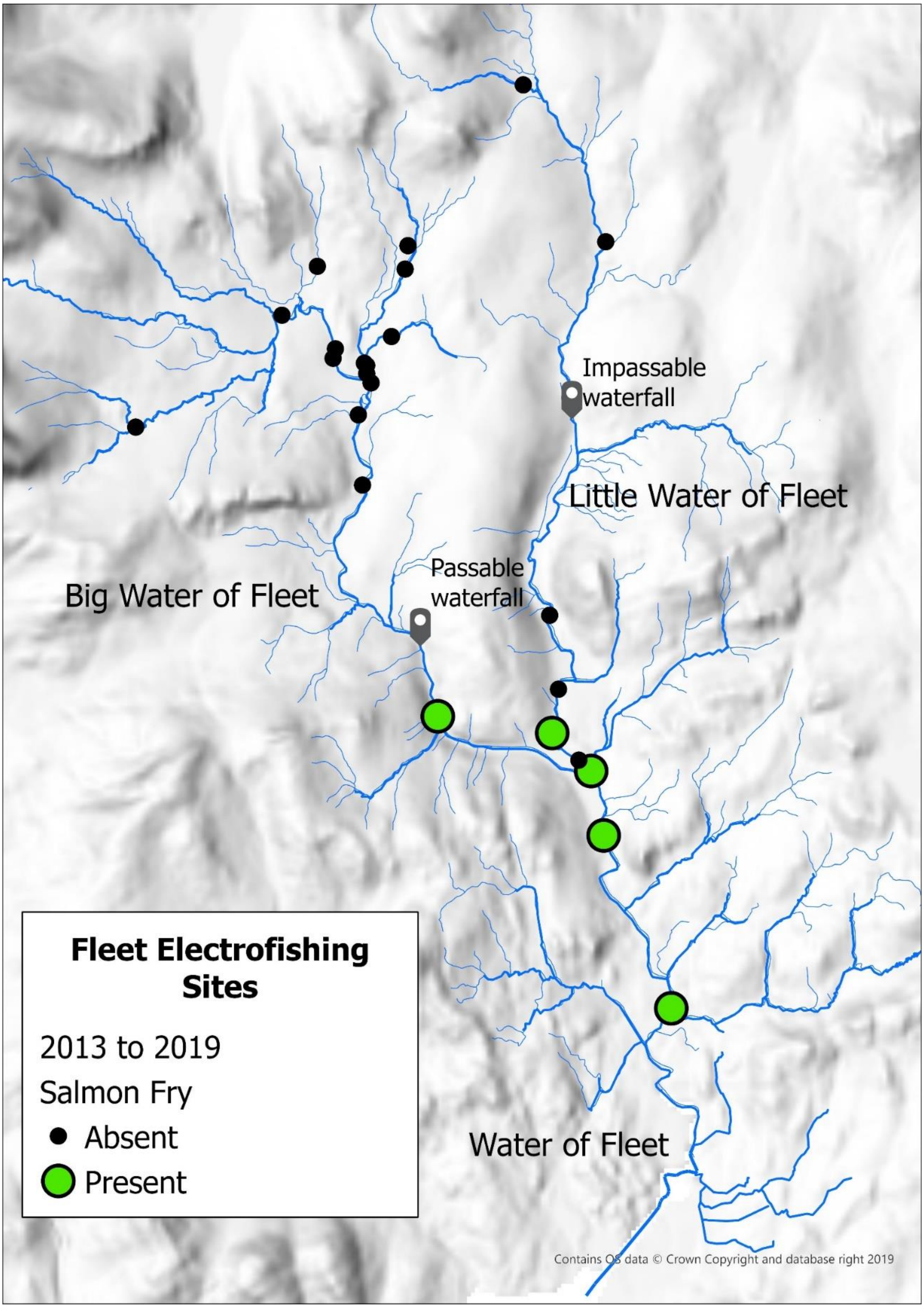
Map 14 – Salmon fry presence and absence for electrofishing sites in the Fleet headwaters sampled between 1997 and 2004



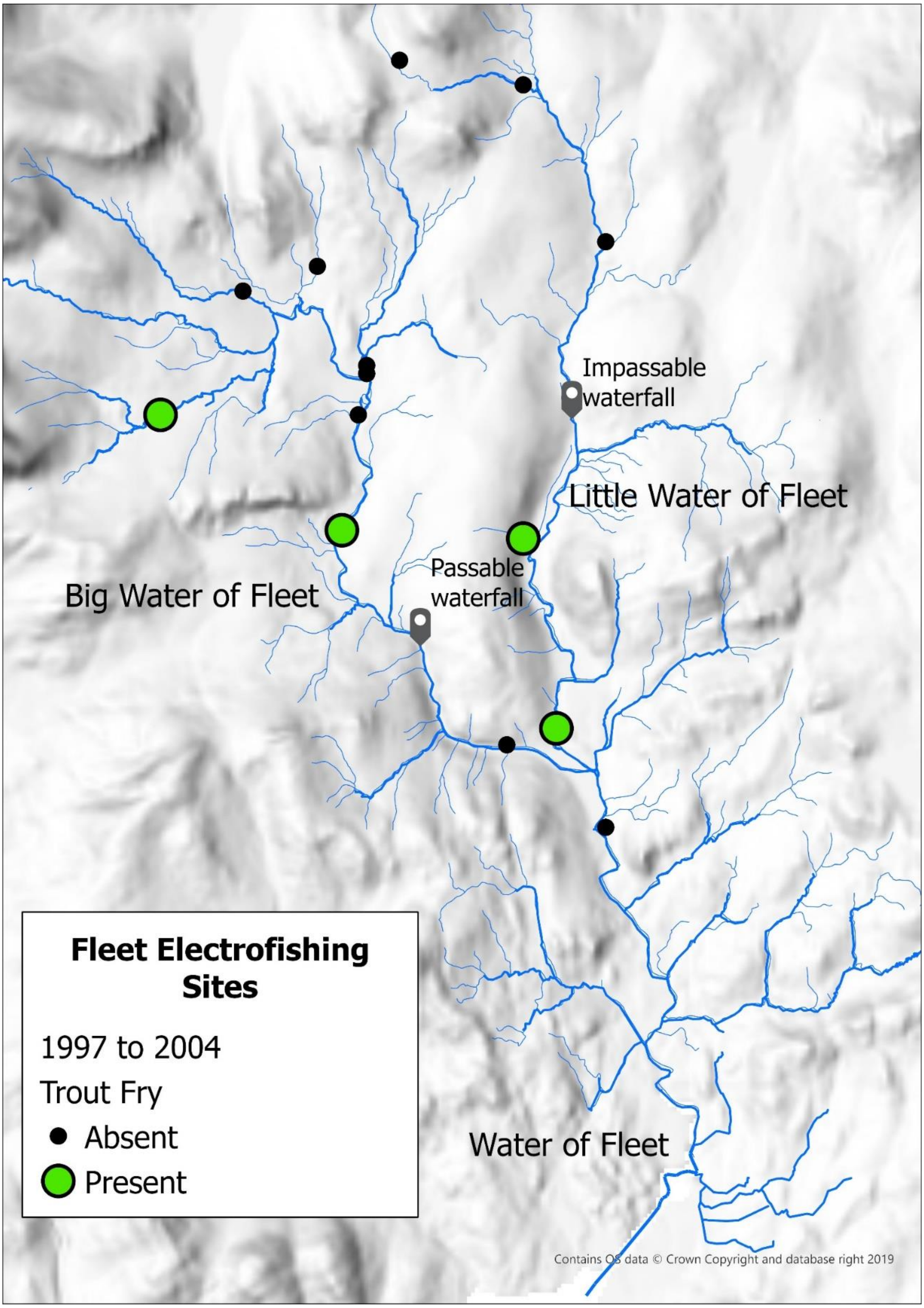
Map 15 – Salmon fry presence and absence for electrofishing sites in the Fleet headwaters sampled between 2005 and 2012



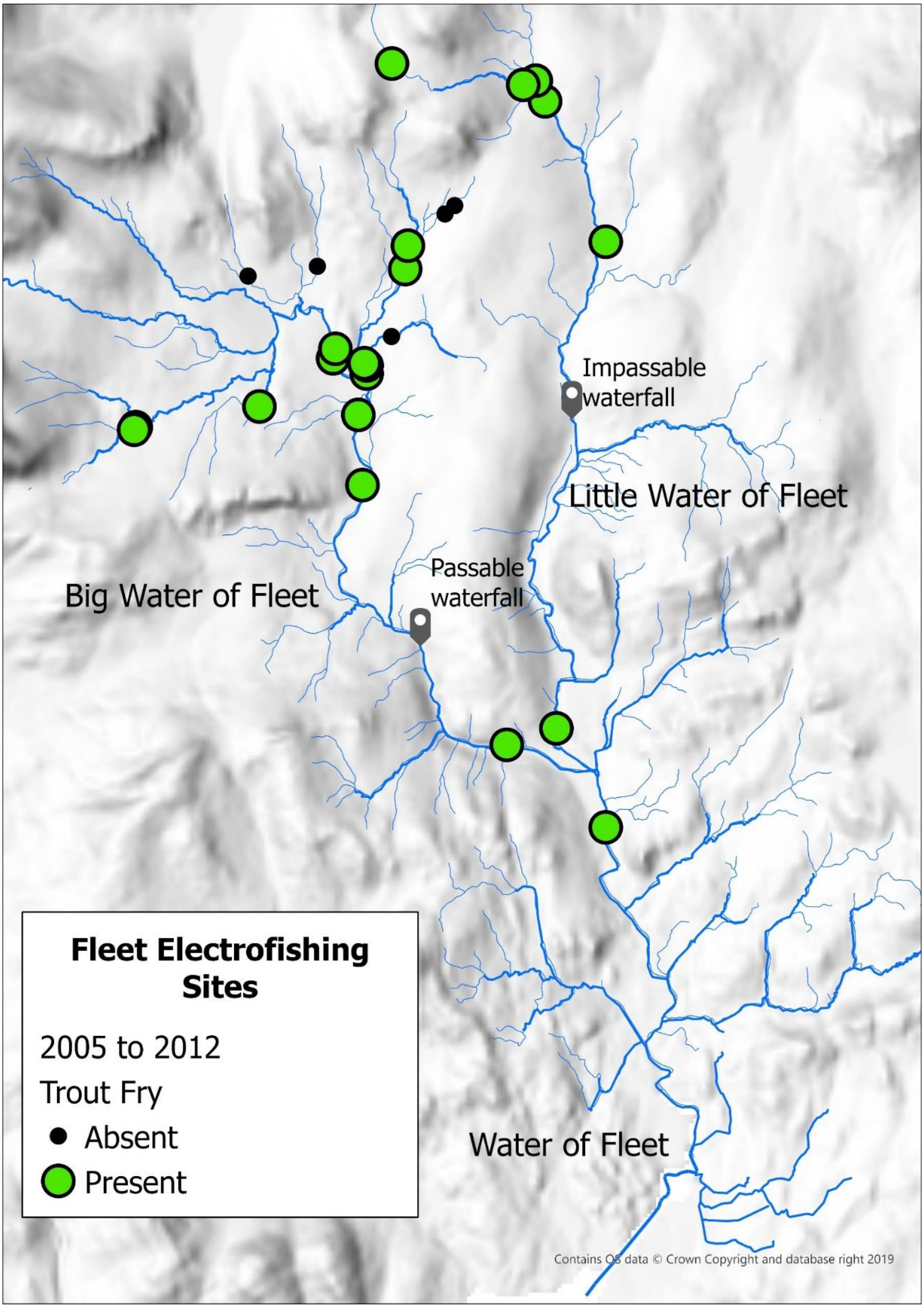
Map 16 – Salmon fry presence and absence for electrofishing sites in the Fleet headwaters sampled between 2013 and 2019



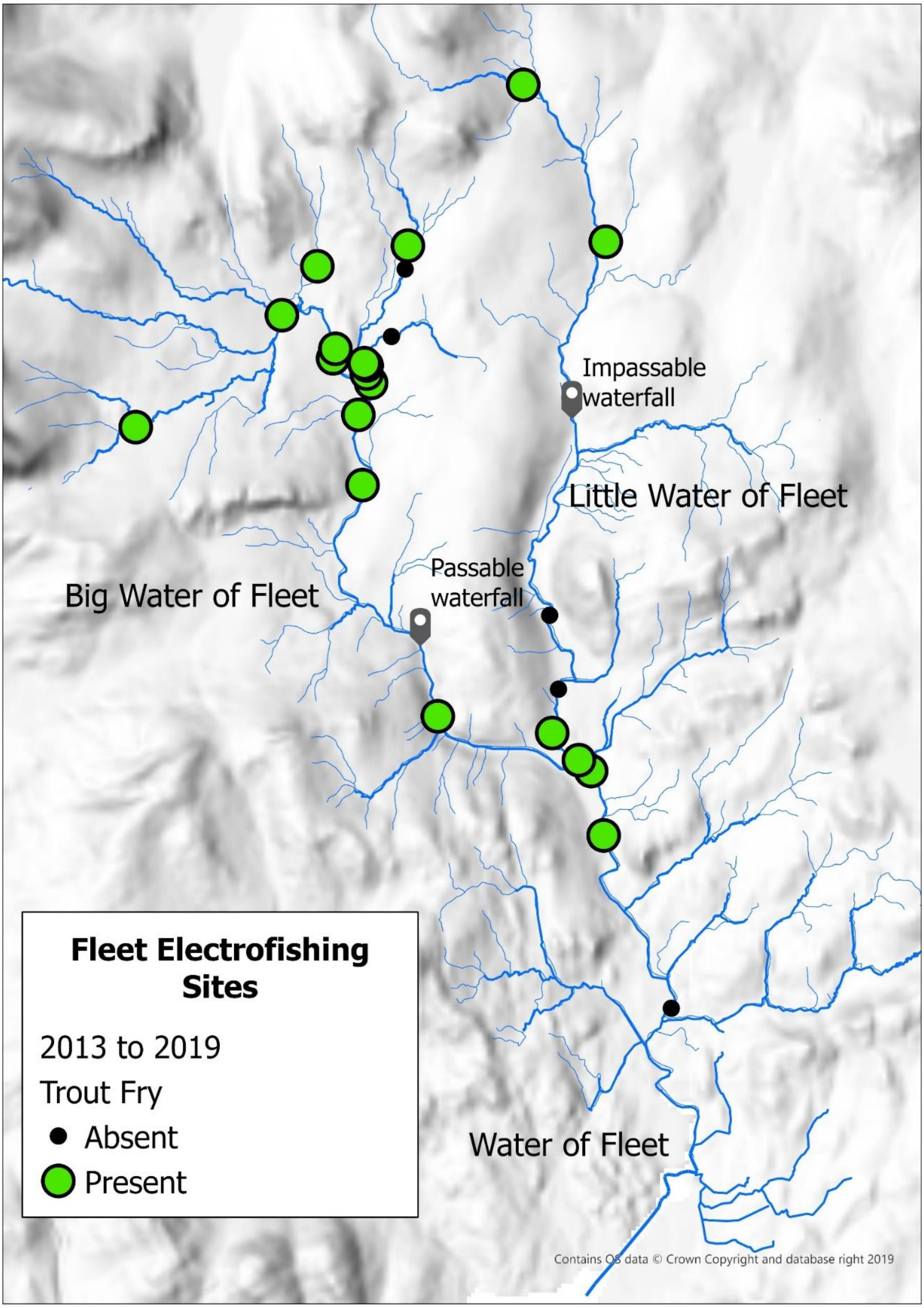
Map 17 – Trout fry presence and absence for electrofishing sites in the Fleet headwaters sampled between 1997 and 2004



Map 18 – Trout fry presence and absence for electrofishing sites in the Fleet headwaters sampled between 2005 and 2012



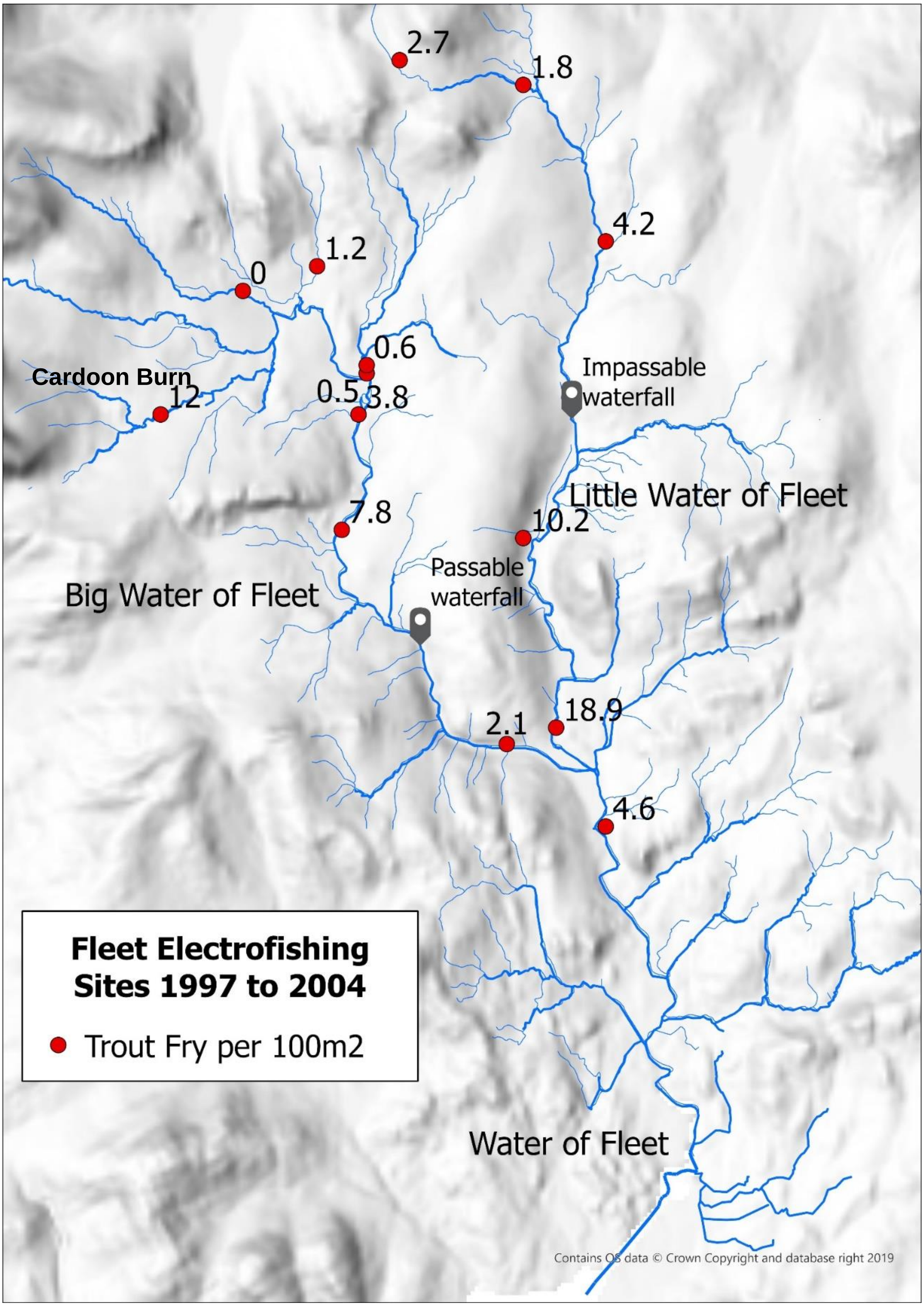
Map 19 – Trout fry presence and absence for electrofishing sites in the Fleet headwaters sampled between 2013 and 2019



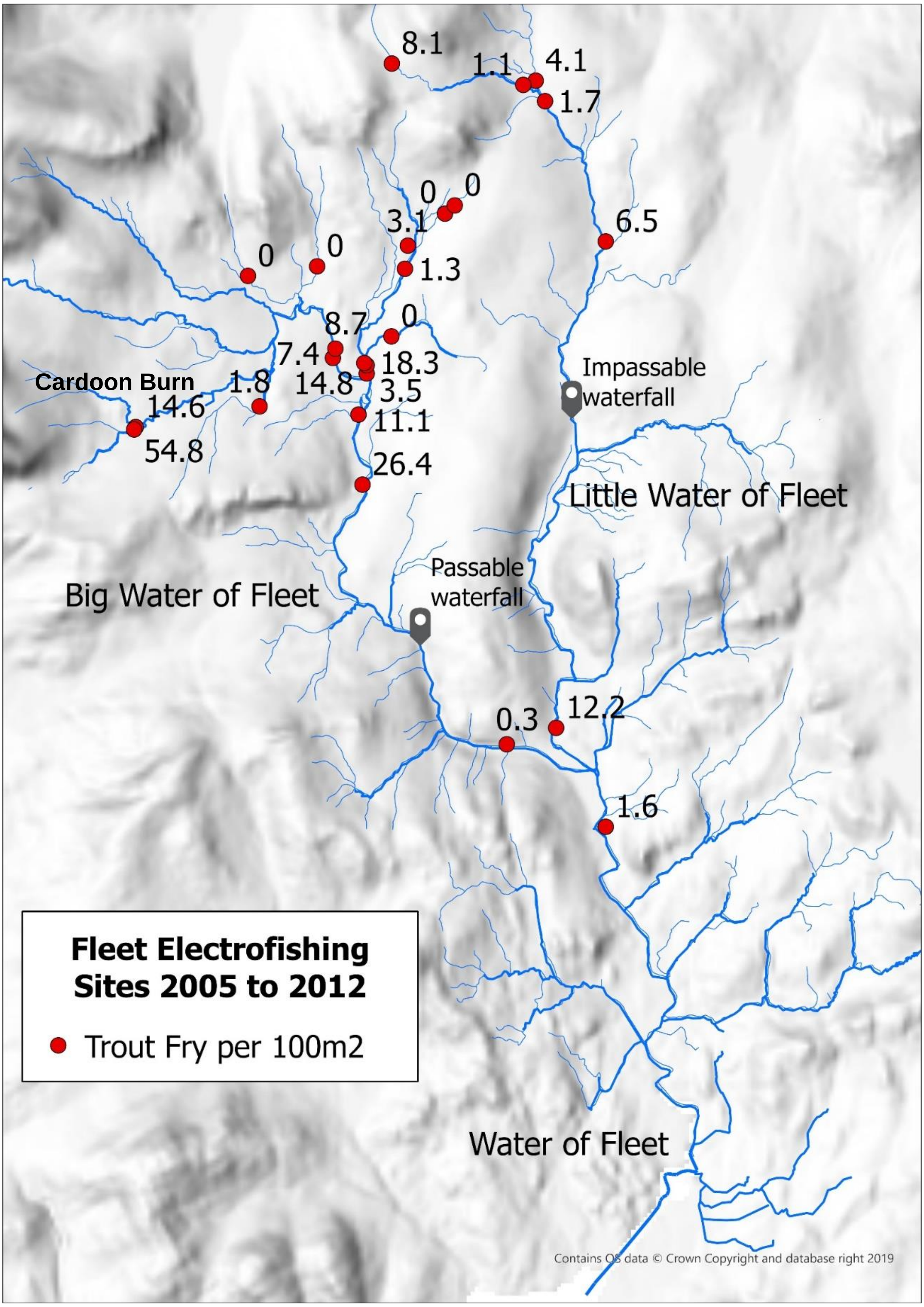
Whilst no salmon fry should be expected within any of the medium to small sized Fleet burns (generally under 2-3 m average width), or above the impassable falls on the Little Water of Fleet, we would expect to see salmon fry on the main stem of the Big Water of Fleet well above the (passable) waterfall in areas where channel width averages over 2-3 m. Historic records from other Galloway rivers indicate salmon fry should be present within these areas, but are likely to have been lost (Puhr, 1997). The salmon fry records from the electrofishing surveys fall short of both this mark, indicating that acidification is still impacting salmon populations in upland areas. There were some signs of salmon expanding their range upstream during the 2005 to 2012 time period, but salmon distribution appears to have reverted back to previous levels within the 2013 to 2019 period. However, it should be noted that the results come from only a small number of main stem sample sites and it is likely that there will be variation from year to year in egg survival based on the timing of acid water flushes and the amount of rainfall.

Trout fry records show a clearer picture with a number of areas which recorded no trout fry during the 1997 to 2004 recording period now holding trout populations, indicating at least the beginning of a recovery of trout populations in many areas. However, it should be noted that some burns still hold no trout fry despite suitable substrate and habitat indicating that acidification to a level that prevents the survival of any eggs laid still persists. Maps 14, 15 and 16 show the trout fry densities for each site during each time period.

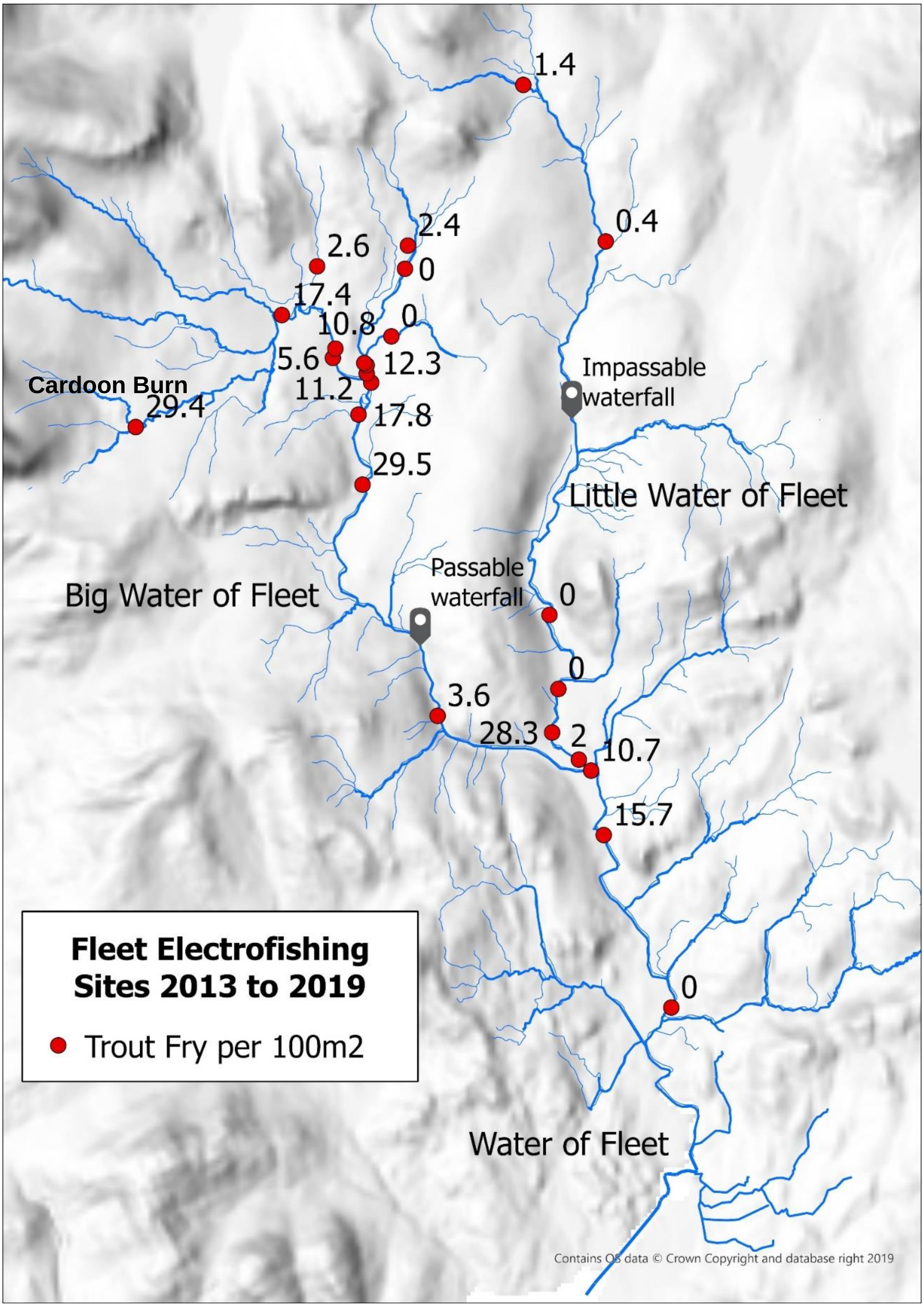
Map 20 – Trout fry density (fry/100 m^2) for electrofishing sites in the Fleet headwaters sampled between 1997 and 2004



Map 21 – Trout fry density (fry/100m²) for electrofishing sites in the Fleet headwaters sampled between 2005 and 2012



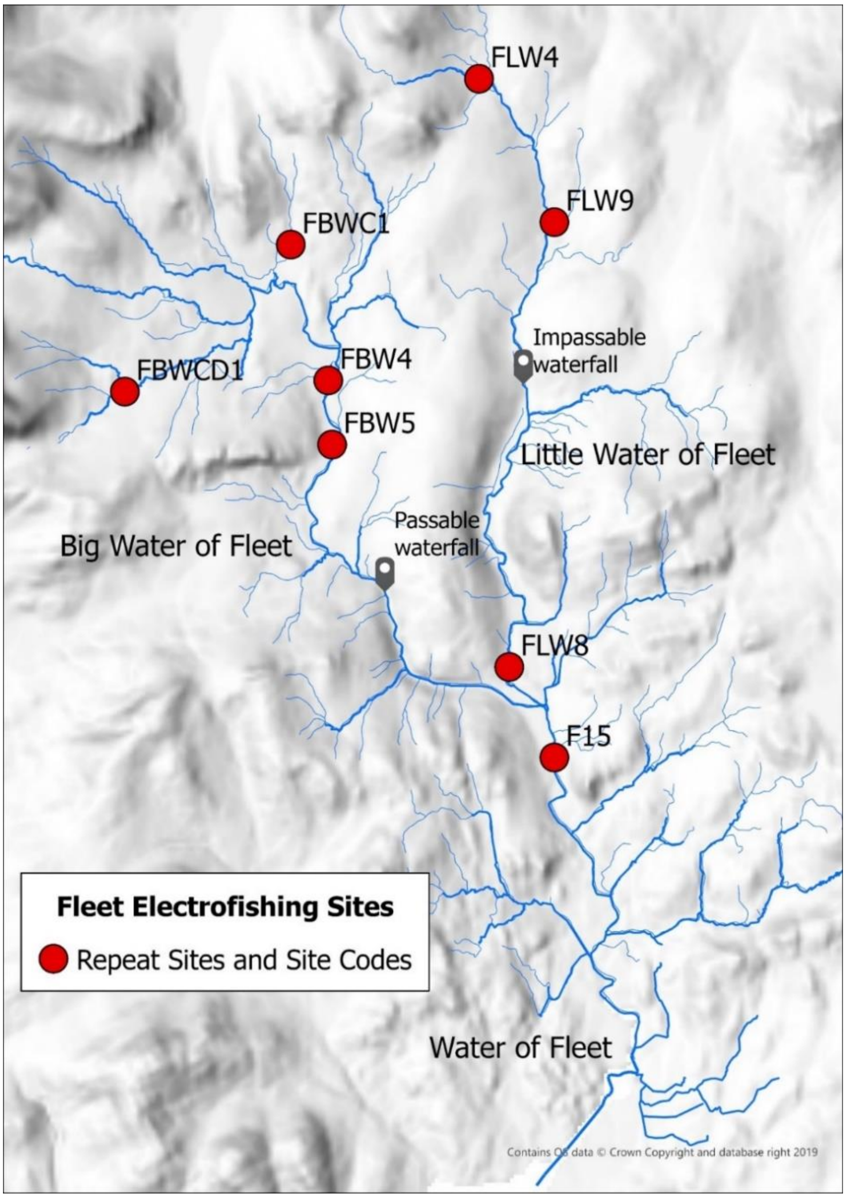
Map 22 – Trout fry density (fry/100m^2) for electrofishing sites in the Fleet headwaters sampled between 2013 and 2019



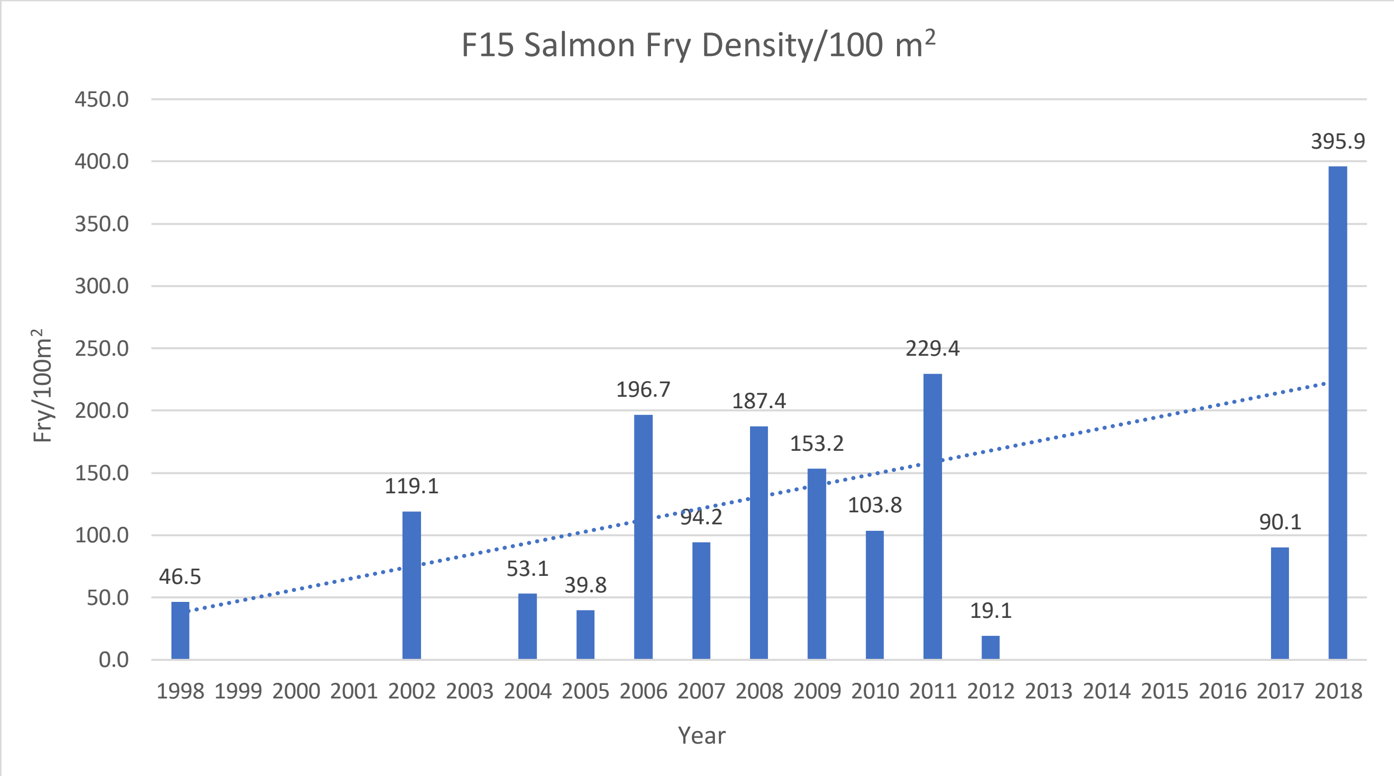
The individual trout fry densities give an indication of the health of the trout population at each site and how they vary over time. Salmon fry have been left as a large proportion of the Fleet headwaters consists of watercourses that are of a size that should be dominated by trout, and from which salmon should naturally be absent. As such, whilst salmon are also impacted, it is easier to see any trends within the trout results. Again, it should be noted that naturally low trout numbers should be expected in the larger further downstream channels which would typically be dominated by juvenile salmon. No pre-acidification baseline electrofishing results exist for the Fleet catchment, meaning that there is nothing available to give an indication of what should be considered "good" or "poor" electrofishing results. However, the burns in Fleet headwaters run of granite bedrock and are generally nutrient poor, so lower fry numbers than further down the system should be expected. Given electrofishing results from elsewhere around Galloway the density of 54.8 trout fry/100 m^2 from the Cardoon Burn in the 2005-2012 time period probably represents a good result that is potentially un-impacted by low pH levels. Densities in single figures, or low double figures, will almost certainly represent a poor result heavily impacted by low pH. It is difficult to make out too much detail in the map but what is clear is that the trout population in the Little Water of Fleet is still severely impacted by acidification and well below the level at which it should be. As with the presence/absence maps there is clearly an improvement in trout fry numbers at some sites between the 1997-2004 and 2005-2012 time periods. It is harder to tell if that improvement continues into the 2013-2019 time period. Although more electrofishing data is needed to have more confidence in the results (due to the small number of sample sites/visits) the trout fry densities from the Cardoon Burn (marked on the maps) were consistently amongst the highest of any burn during each of the time periods.

For sites that have been visited on multiple occasions is possible to look at trends in fish numbers over time. Map 23 shows the locations and site codes for sites that have been visited on five or more occasions between 1997 and 2019 and Graphs 5 to 13 give the electrofishing results. Salmon fry results are given for sites F15 and FLW8, which are located on wide, main stem sites (and should naturally be dominated by salmon fry). Trout fry results are given for FLW4 and FLW9, which are above the impassable falls on the Little Water of Fleet, and for FBWCD1 and FBWC1, which are on burns. Sites FBW4 and FBW5 are in areas that historically should have salmon present. Low numbers of salmon fry were recorded for FBW5 whilst salmon were absent from all site visits for FBW4. As such salmon and trout results are given for FBW5 but only trout results are given for FBW4.

Map 23 - Locations and site codes for sites that have been visited on five or more occasions between 1997 and 2019

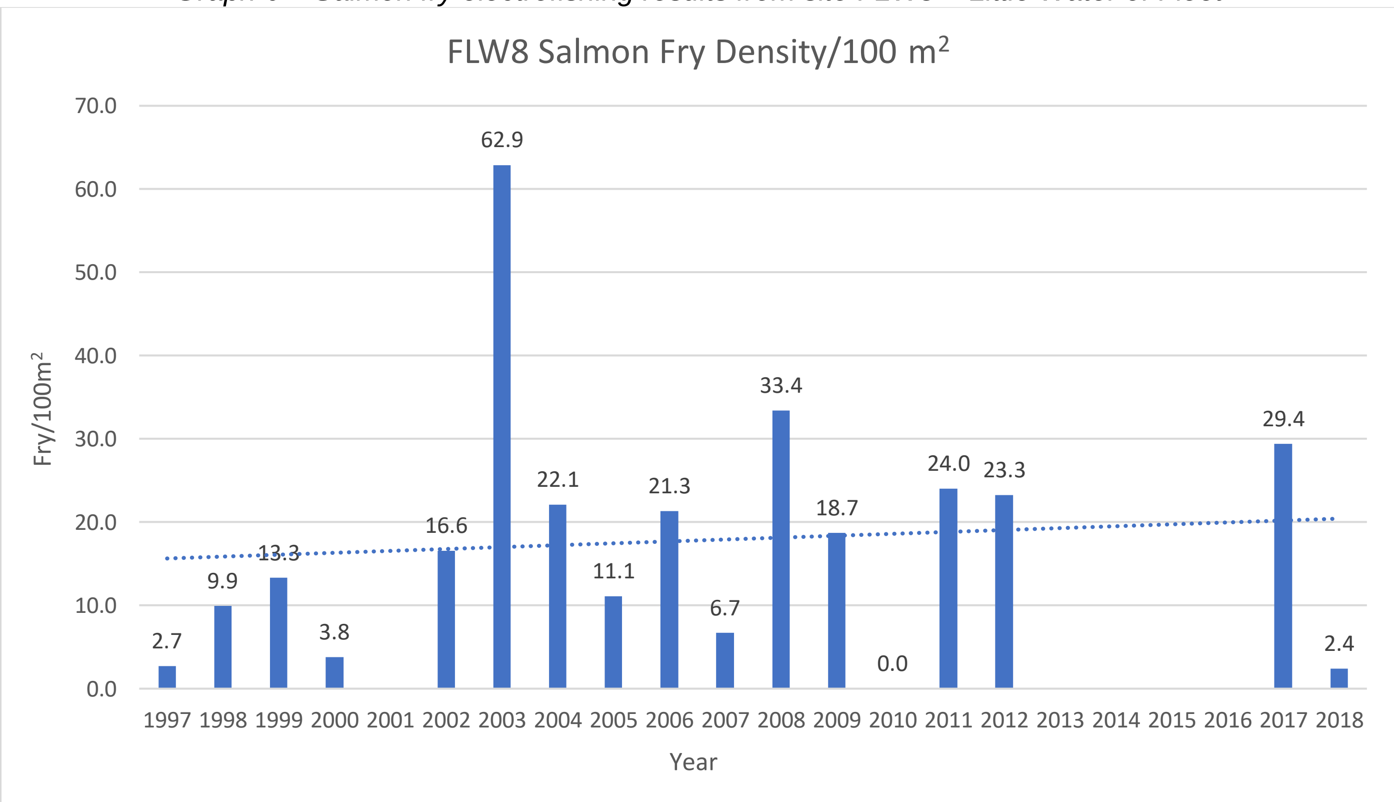


Graph 5 – Salmon fry electrofishing results from site F15 – Water of Fleet



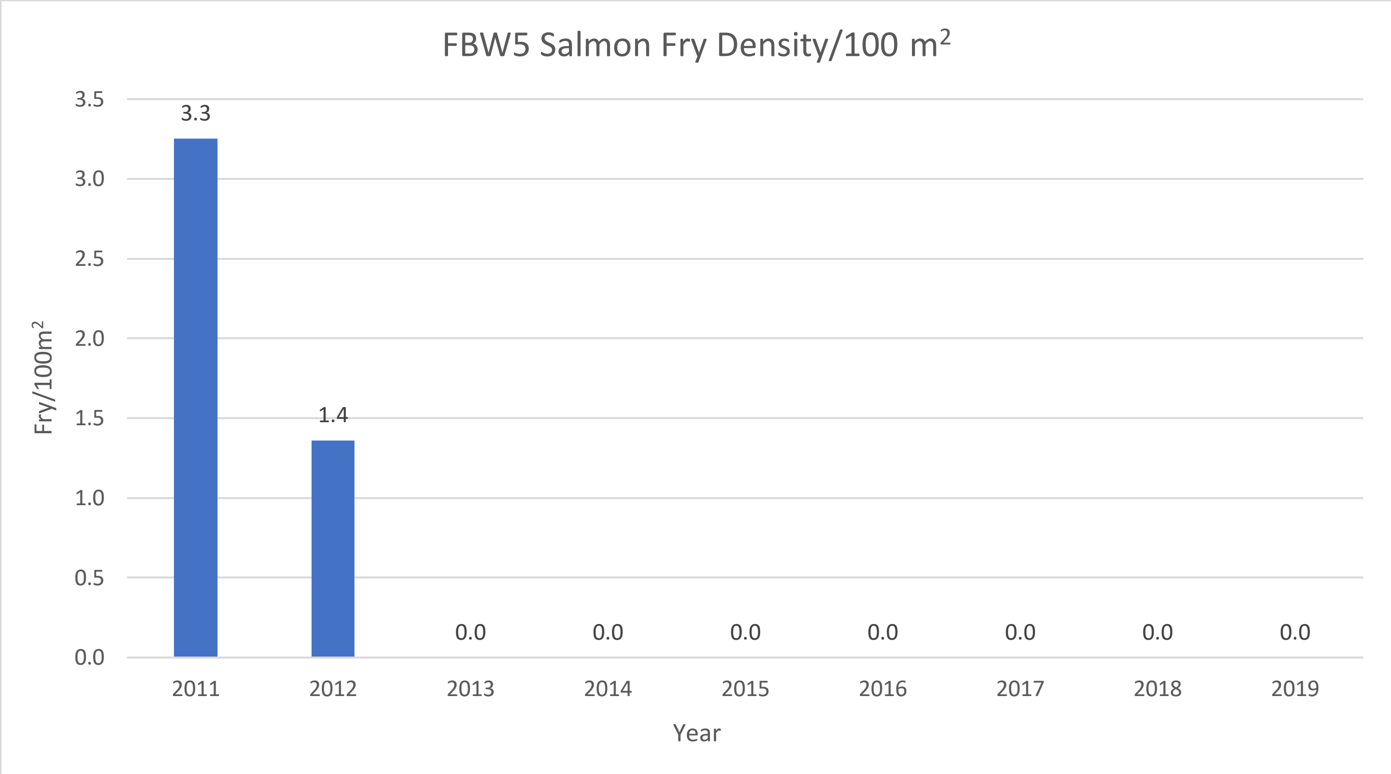
Although highly variable between years the overall trend does appear to be one of improving salmon fry numbers, although the particularly good result in 2018 is having a disproportionate influence on the trend line.

Graph 6 – Salmon fry electrofishing results from site FLW8 – Little Water of Fleet



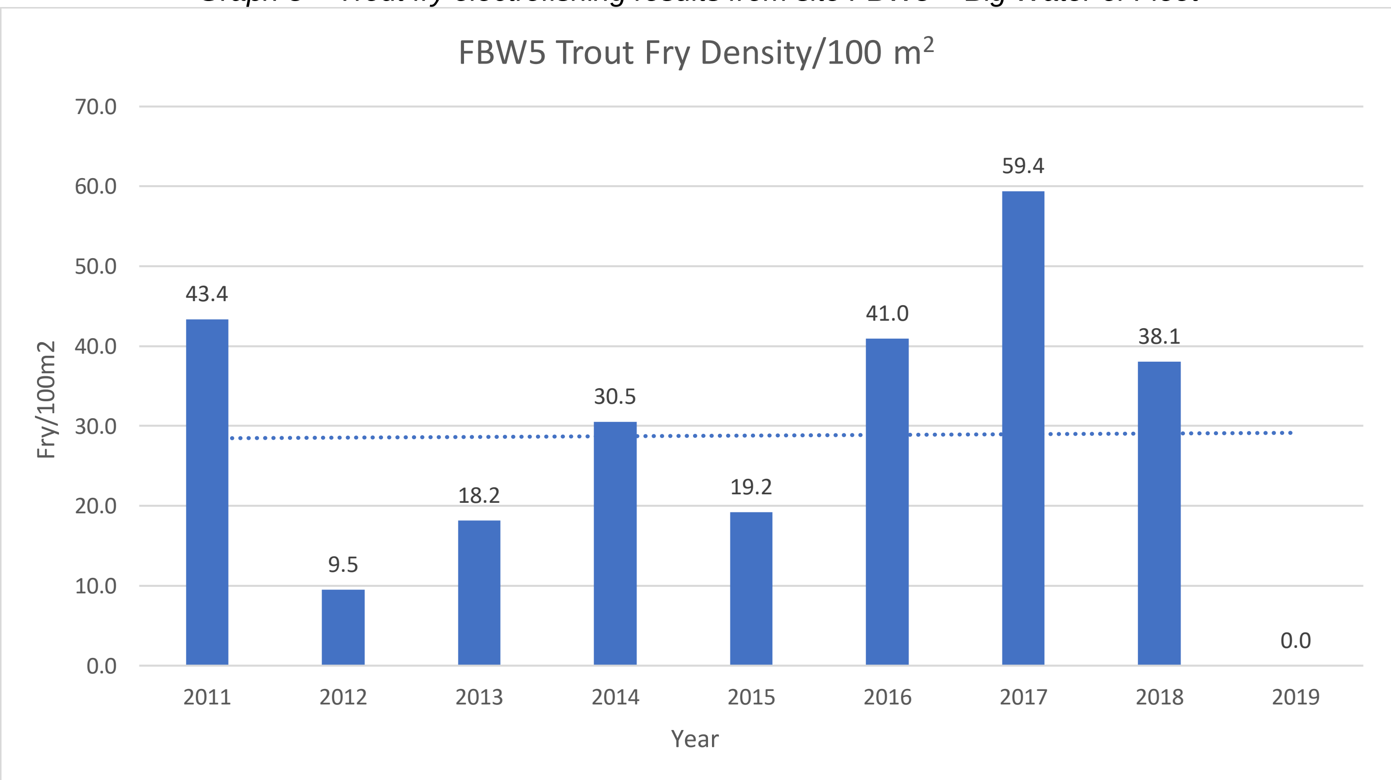
Again we see highly variable salmon fry results from one year to the next, but with a slight upwards trend overall. There were no years where no trout fry or salmon fry were recorded at this site indicating that pH was above levels that would cause complete failure in egg survival during the winter preceding all of the site visits.

Graph 7 – Salmon fry electrofishing results from site FBW5 – Big Water of Fleet



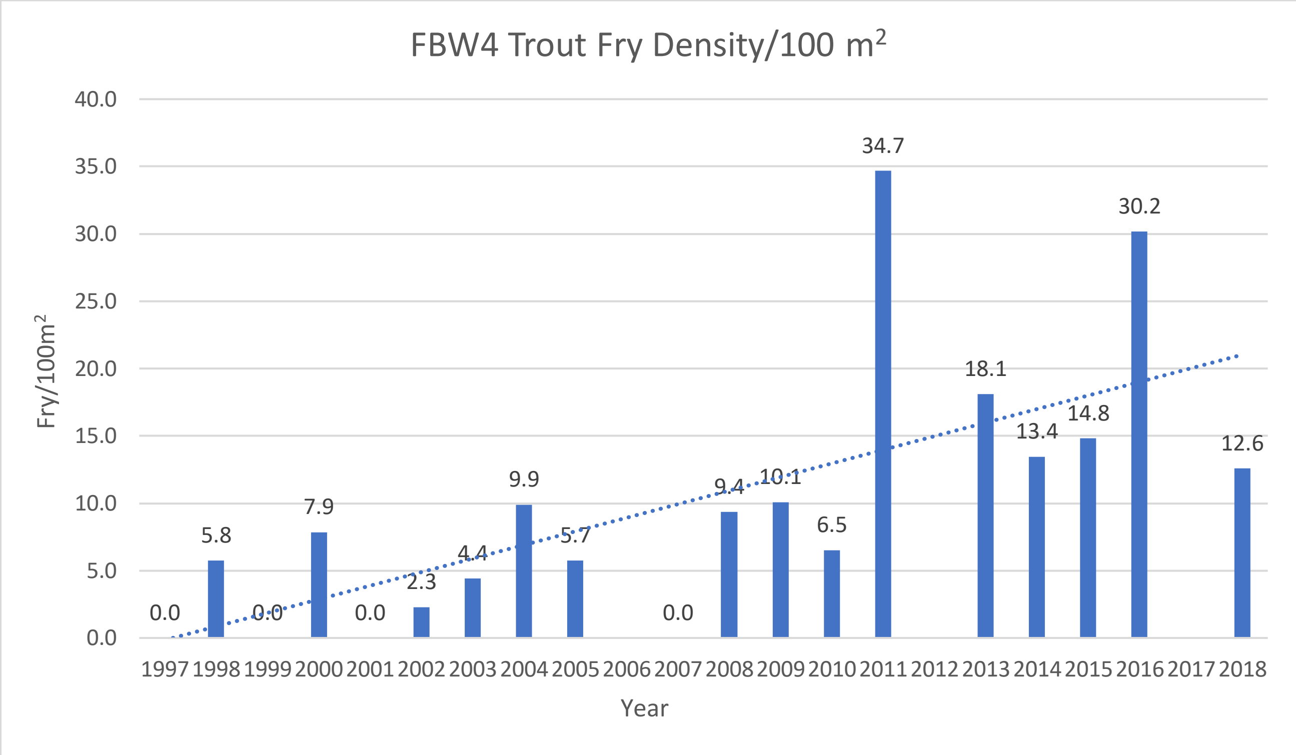
The general absence of salmon fry from this site is likely due to the impact of acidification, as historically this section of river would likely have been spawned in by adult salmon. Whilst salmon fry were recorded in both 2011 and 2012, giving an indication at the time that water quality may be recovering, numbers recorded were very low and these two years do not appear representative of the results as a whole.

Graph 8 – Trout fry electrofishing results from site FBW5 – Big Water of Fleet



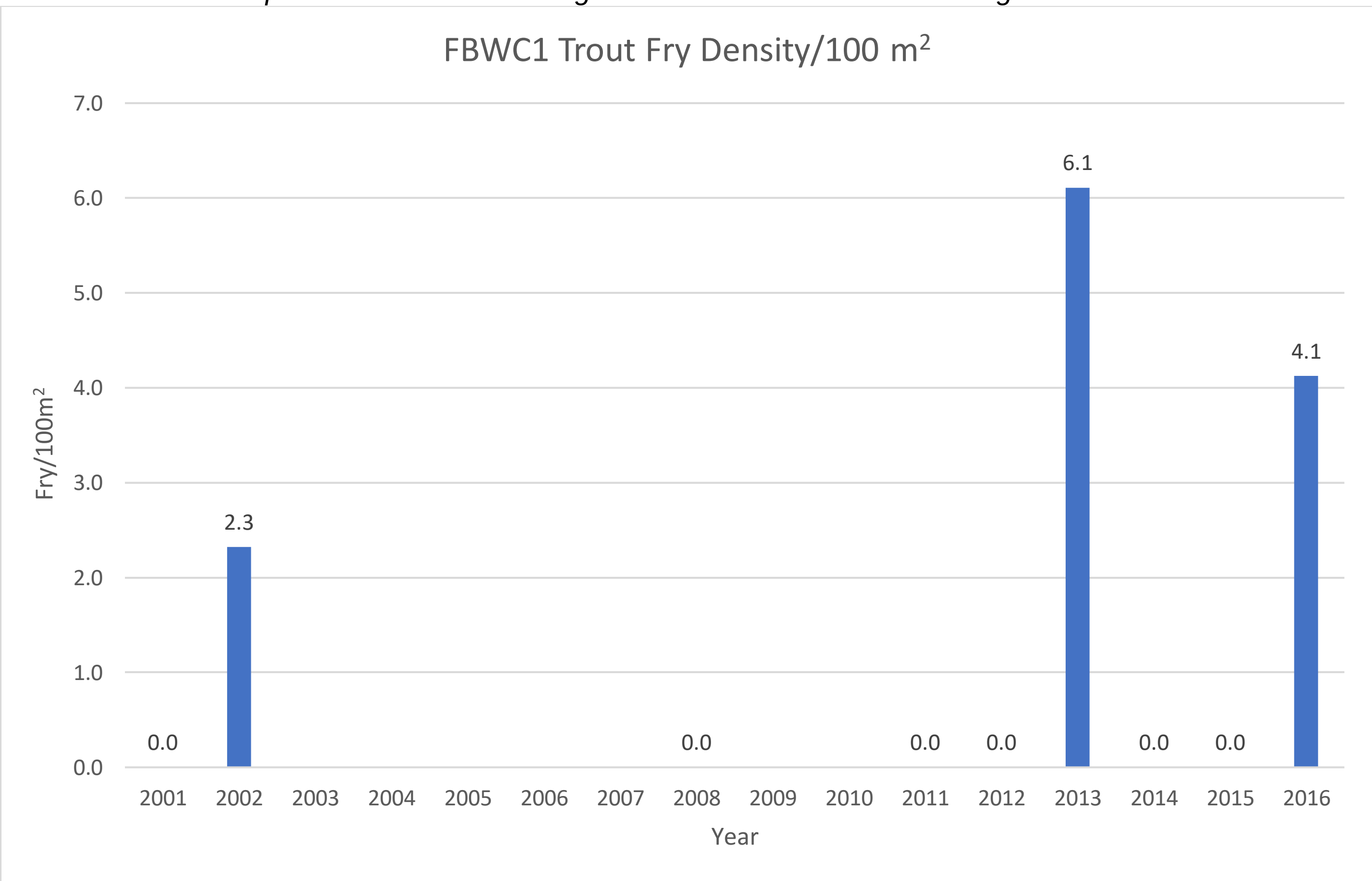
The trout fry results show no overall trend, although the absence of trout in 2019 may be a cause for concern. It should be noted that this is a site that historically would likely have been dominated by salmon fry and trout fry may only be present in reasonable numbers (during some years) because of their absence.

Graph 9 - The electrofishing results from site FBW4 – Big Water of Fleet



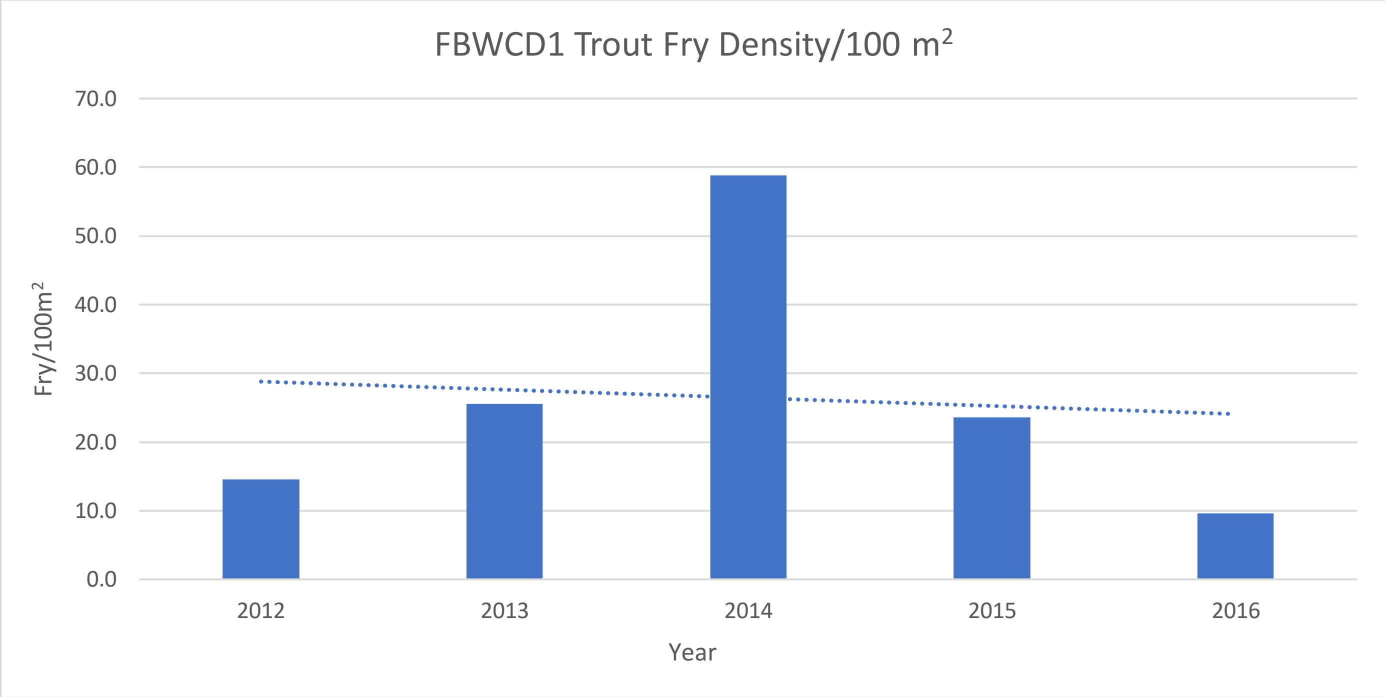
Although not shown salmon fry were absent from this site (bar one single fry in 2010), most likely due to the impact of acidification, as historically this section of river would have been spawned in by adult salmon. Although the water quality may not yet be at a level that allows salmon populations to build up the trout fry results show signs of improvement and follow a general upwards trend.

Graph 10 - The electrofishing results from site FBWC1 – Craiglowrie Burn



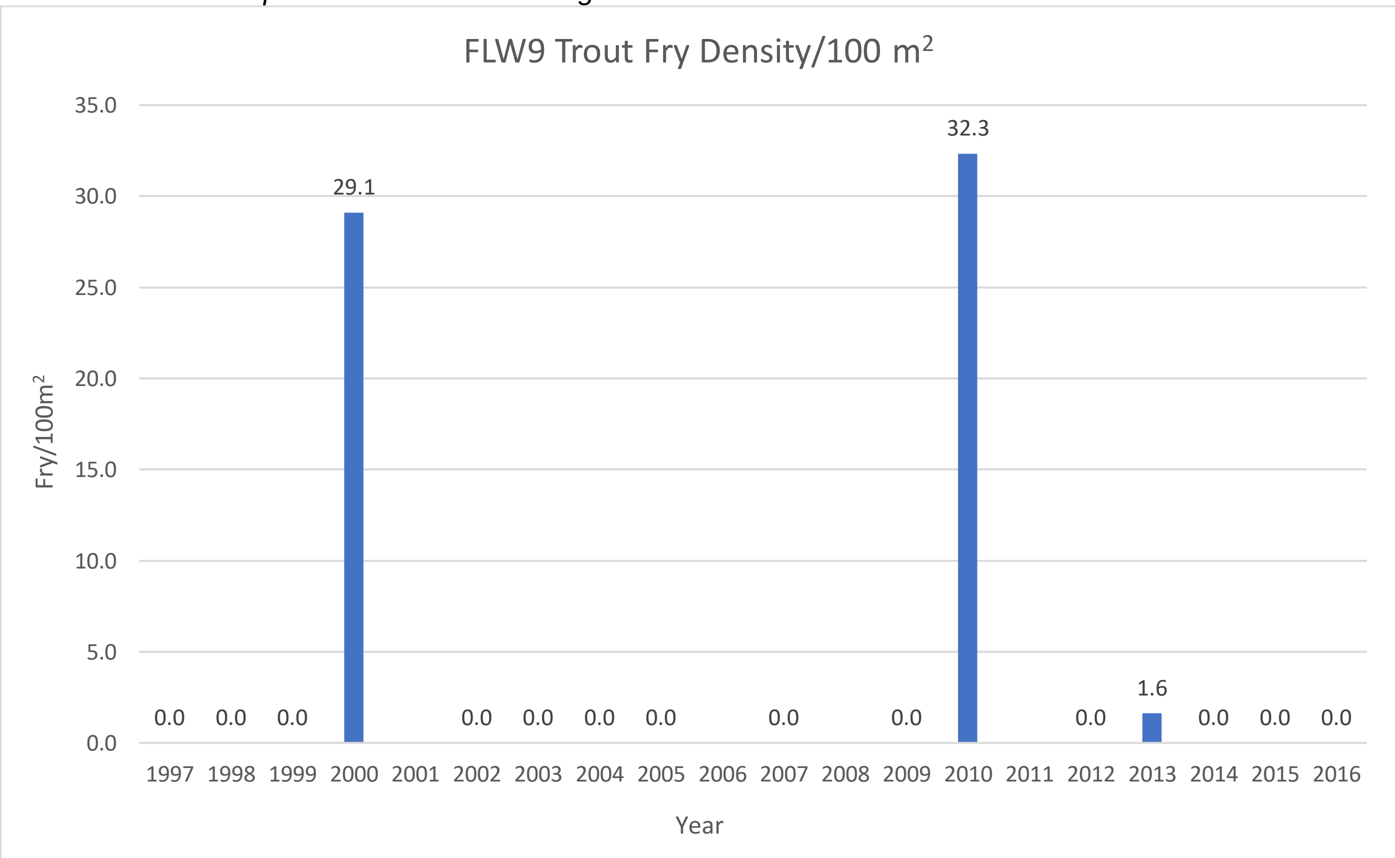
The low and often absent fry density from this Craiglowrie Burn site indicate that this burn is still suffering from the impacts of acidification/low pH, although the habitat within this site is possibly more suitable for parr than fry.

Graph 11 - The electrofishing results from site FBWCD1 – Cardoon Burn



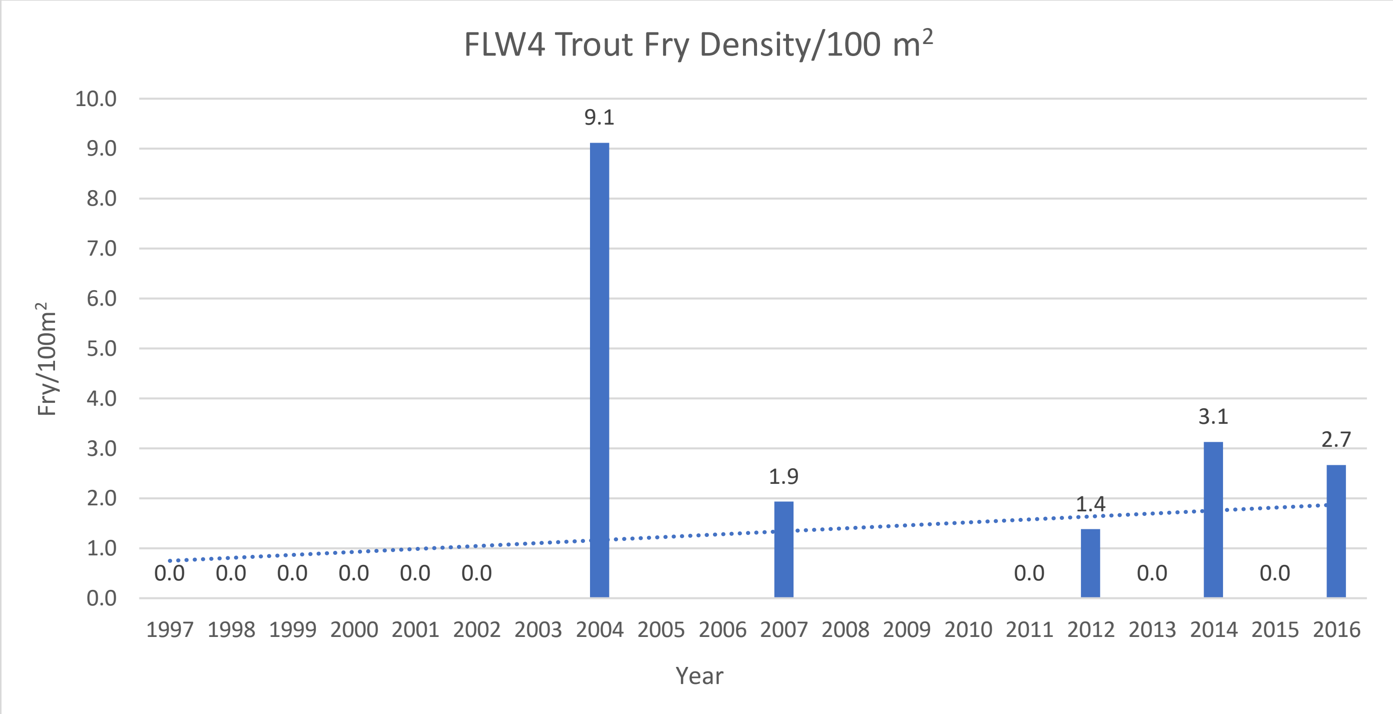
With only five years of data from this site on the Cardoon Burn it is difficult to conclude too much from the data. The trout fry density from 2014 of just under 60 fry/100m^2 is likely close to what should be expected in this burn, although numbers are still generally higher than those recorded in other burns.

Graph 12 - The electrofishing results from site FLW9 – Little Water of Fleet



Whilst recorded in some year's trout fry are generally absent from this electrofishing site on the Little Water of Fleet. This may indicate significant egg mortality over most winters, with just the occasional winter where low pH does not coincide with sensitive stages in egg development.

Graph 13 - The electrofishing results from site FLW4 – Little Water of Fleet



As with FLW9 trout fry are generally absent from FLW4. In this instance, on the occasions when fry are present, their numbers are very low. However, low numbers do appear to be coming more consistent in later years. As both FLW9 and FLW4 are above the impassable falls their results indicate that the trout population within the Little Water of Fleet above the impassable falls is significantly impacted by acidification resulting in greatly reduced trout numbers.

As with the results which were split into broad time periods, the results for some of the sites which have been visited on multiple occasions show signs of improving fish numbers, although the impacts of acidification are still evident in most. Of note is the upwards trend in salmon fry numbers at sites F15 and FLW8. This is of note as the general trend in adult salmon numbers across Scotland is one of decline (Fisheries Management Scotland Annual Report, 2022) and as such the results may indicate improving conditions within these sites.

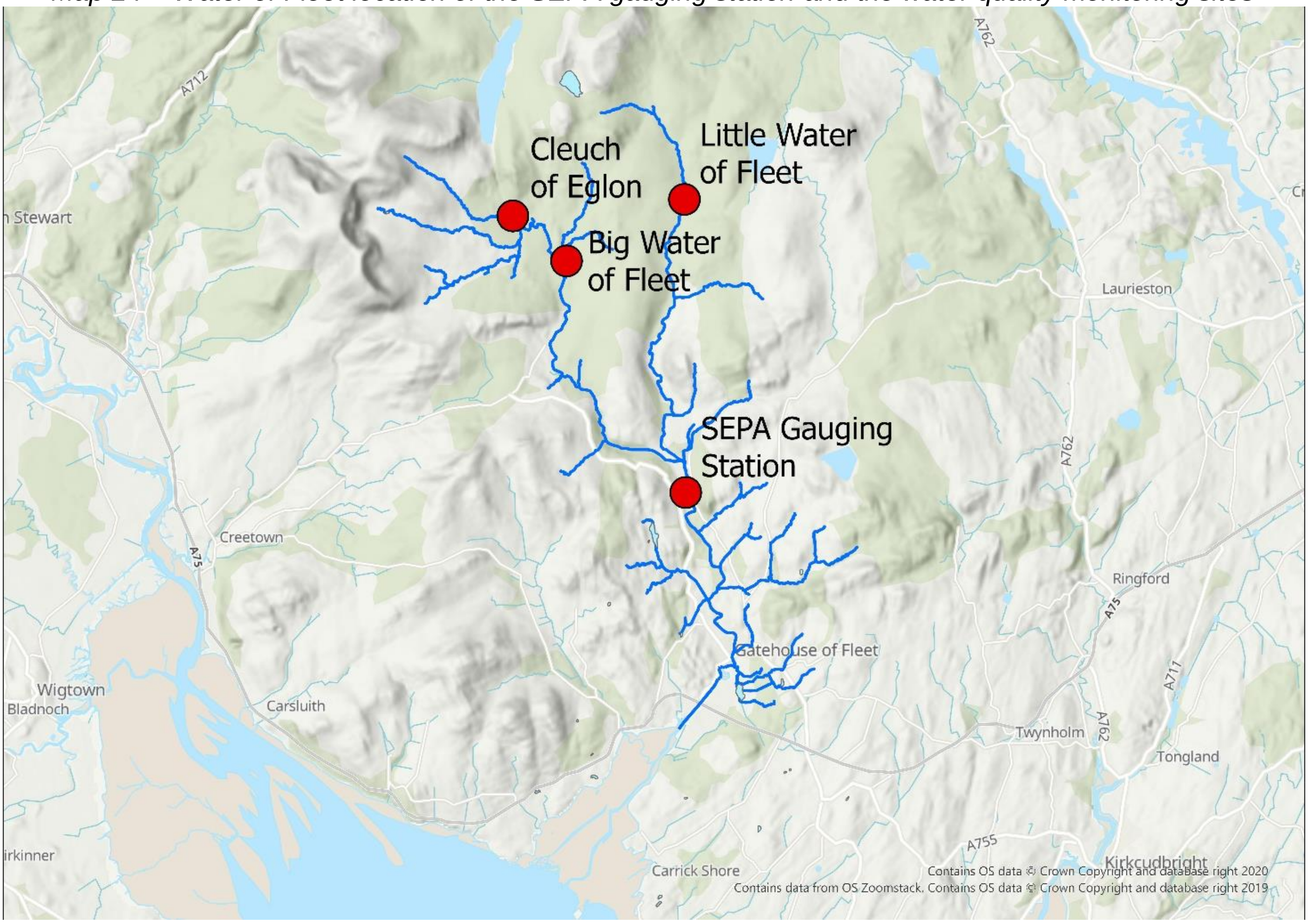
3.2.2 EXO1 Sonde Results - Big and Little Waters of Fleet, Cleuch of Eglon Burn

The EXO1 Sondes in the Big and Little Waters of Fleet started recording at 16.00 hours on 21.01.2022 and finished recording at 09.45 hours on 29.03.2022. There was a short period between 13.30 hours on 02.03.2022 and 15.00 hours on 03.03.2022 when the Sondes were retrieved for calibration then redeployed. Upon redeployment an additional Sonde which had become available was deployed within the Cleuch of Eglon Burn. It was also set to begin recording at 15.00 hours. All three Sondes stopped recording at at 09.45 on 29.03.2022. The variation in pH from each site and comparisons between each site can be seen on Graph 14.

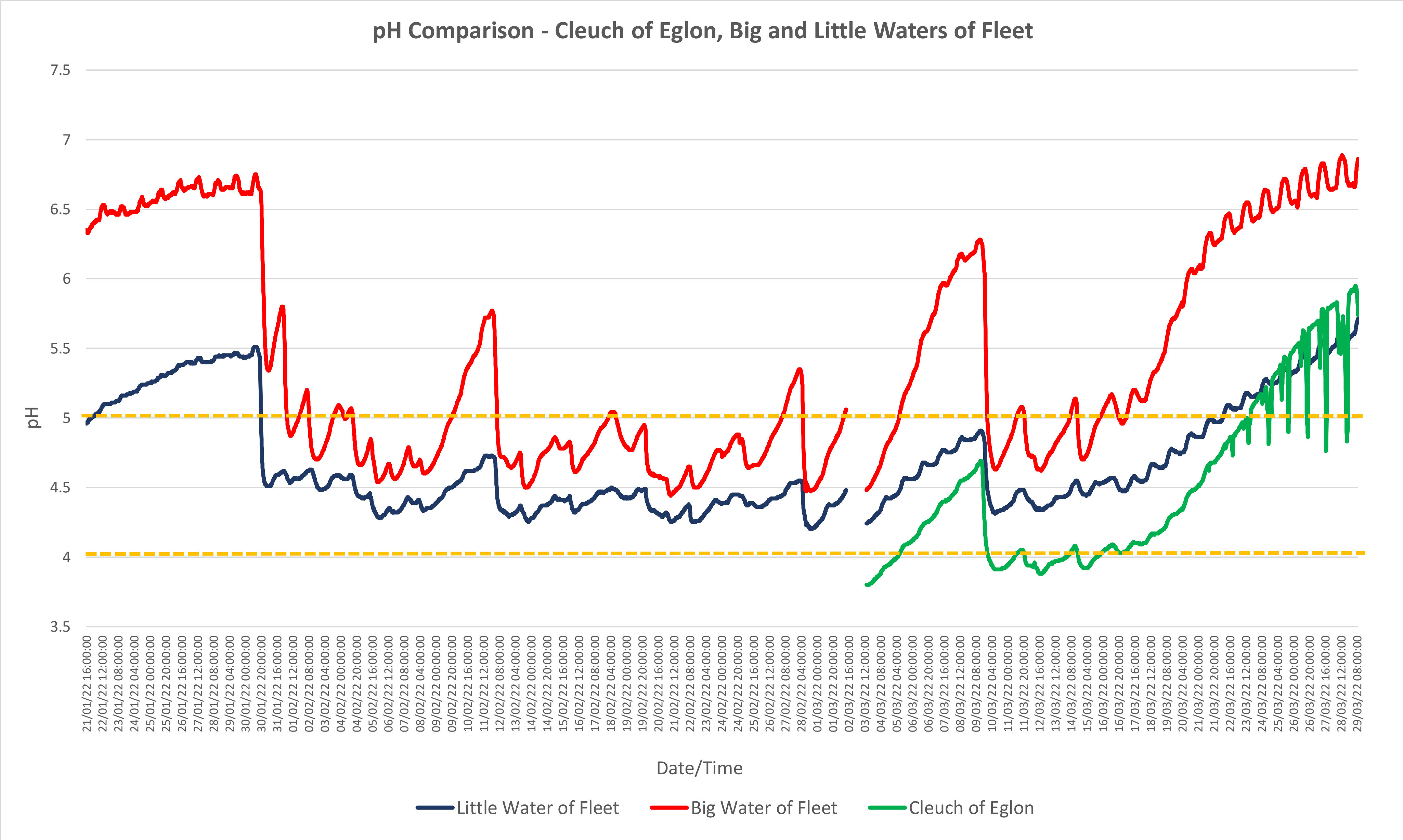
Whilst all three show similar variation in rises and falls in pH levels over the course of the recording period there are some clear differences between the three watercourses. The Cleuch of Eglon Burn clearly has the lowest pH of the three and the Big Water of Fleet the highest, but all three show dips to levels of acidity that are a cause for concern for salmon and trout survival (below pH 5). Whilst the Big Water of Fleet regularly fell below pH 5 during the recording period it rarely fell below 4.5 and it is possible that fish populations may be able to survive largely un-impacted at this pH, dependant on other factors such as labile Aluminium levels. In contrast the Little Water of Fleet regularly fell below 4.5 and at times got close to 4, whilst the Cleuch of Eglon Burn was regularly below 4.5 and at times fell below 4. It should be noted that the variation in daily pH levels within the Cleuch of Eglon Burn towards the end of the recording period would indicate that there may be an issue with the pH sensor. The Sonde was fully calibrated without any issues before deployment and it is likely the results are accurate up until the large variation in pH is seen after 23.03.2022.

Graphs 15 shows pH against flow for the Big and Little Waters of Fleet. The Flow levels readings are taken from the SEPA gauging station at Nether Rusko on the main stem of the Water of Fleet a short distance below the confluence between the Big and Little Waters. The gauging station is located approximately 6 km below both the Big Water of Fleet and Little Water of Fleet water quality monitoring sites. As the Fleet is a relatively small catchment, and as no accurate flow readings are available from anywhere else within the Fleet catchment, it is thought that the flow readings gave a relatively accurate indication of relative flows at each recording site (although there may be a minor time lag as a result of the gauging station being further downstream). Map 24 gives the location of the gauging station in relation to the water quality monitoring sites.

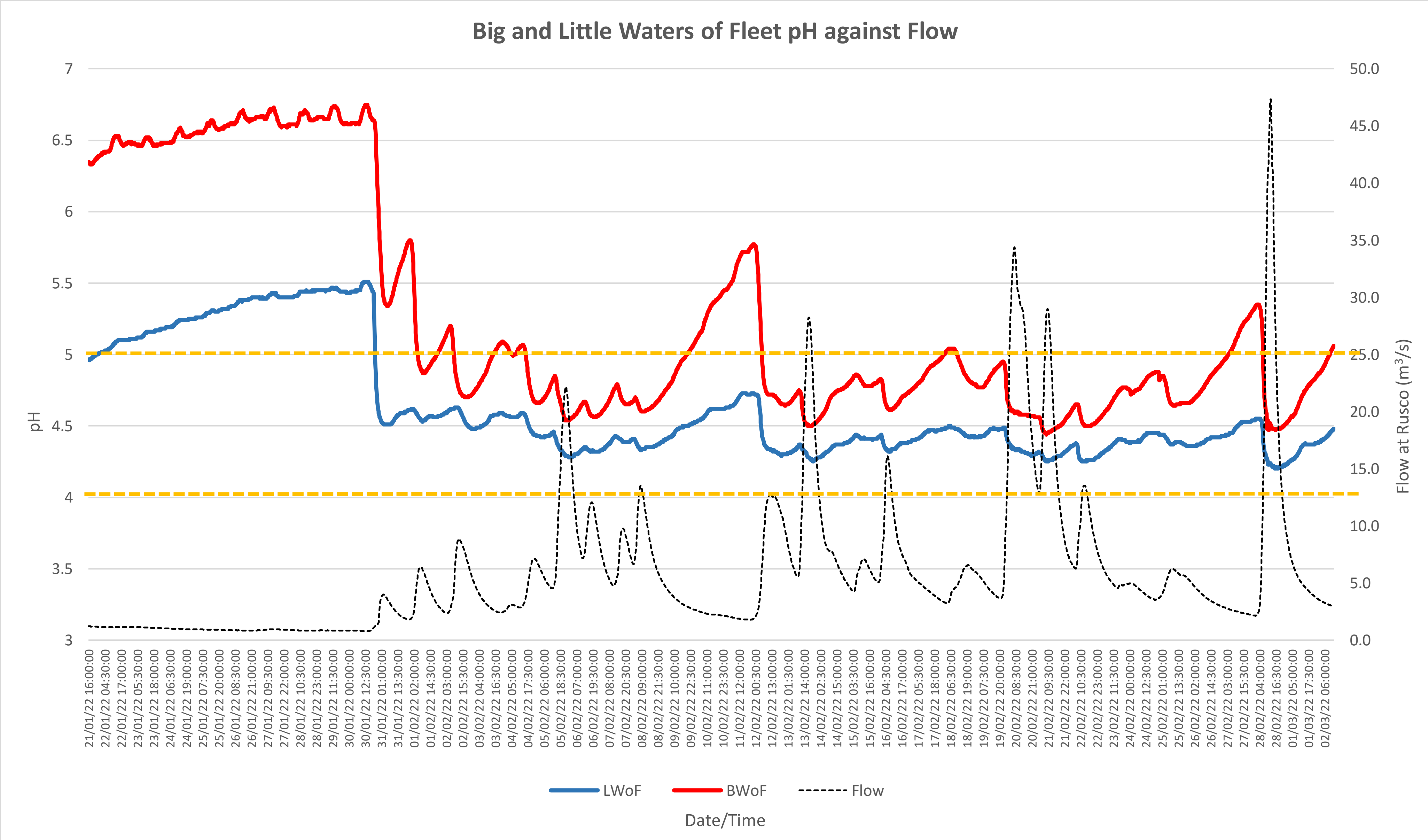
Map 24 – Water of Fleet location of the SEPA gauging station and the water quality monitoring sites



Graph 14 – Variation in pH and comparisons between the Big Water of Fleet, Little Water of Fleet and Cleuch of Eglon Burn between 21.01.2022 and 29.03.2022 with pH 5 and pH 4 highlighted (below 5 is likely harmful to Salmonids with below 4 likely being lethal)



Graph 15 – Comparison between pH and flows on the Big and Little Waters of Fleet between 21.01.2022 and 29.03.2022 with pH 5 and pH 4 highlighted (below 5 is likely harmful to Salmonids with below 4 likely being lethal)

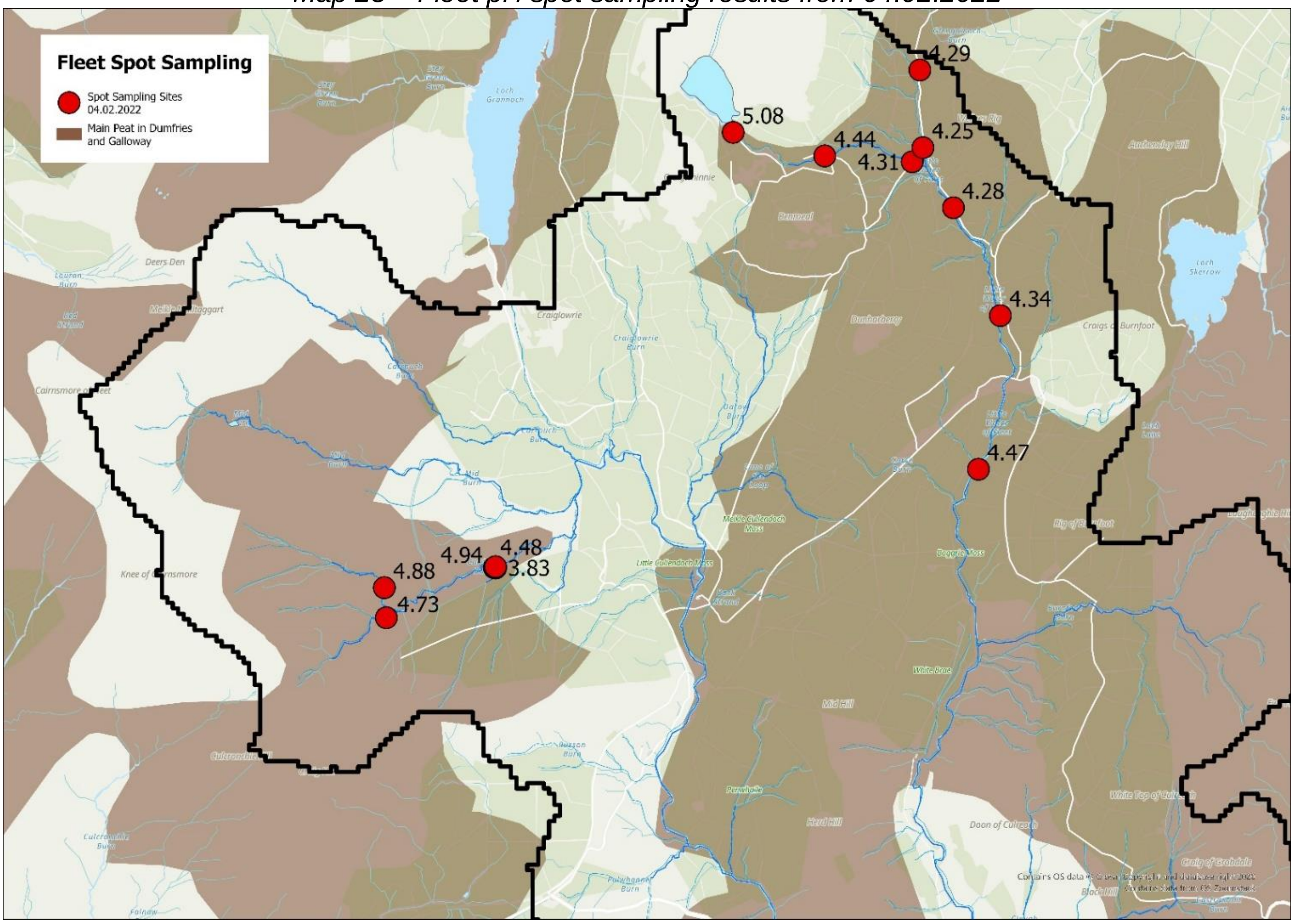


As would be expected both graphs show a clear relationship between pH and flow levels (and therefore rainfall). After an initial period of dry weather, where pH levels on both the Big and Little Waters of Fleet were above levels that are of concern, the remainder of the recording period consists of frequent rises and falls in flow levels – representing a period of persistent rainfall. This clearly has the effect of lowering pH to levels that are of concern and holding them there for prolonged periods. In addition to the rises in flows holding the pH at more acidic levels there also appears to be a knock on effect in lowering pH further, with small rises in flows during the wet period resulting in lower pH than similar rises in flows recorded after the end of the dry period at the beginning of recording. Of note is the variation in the speed of recovery between the three watercourses (most clearly seen in Graph 14). The speed of recovery from dips in pH is much greater in the Big Water of Fleet than in the other two watercourses. This is significant in regards to fish survival as exposure time to lowered pH can be as much as an issue as the pH level itself. It is likely that the speed of recovery on the Big Water of Fleet is related to the better overall water quality and lower levels of acidification.

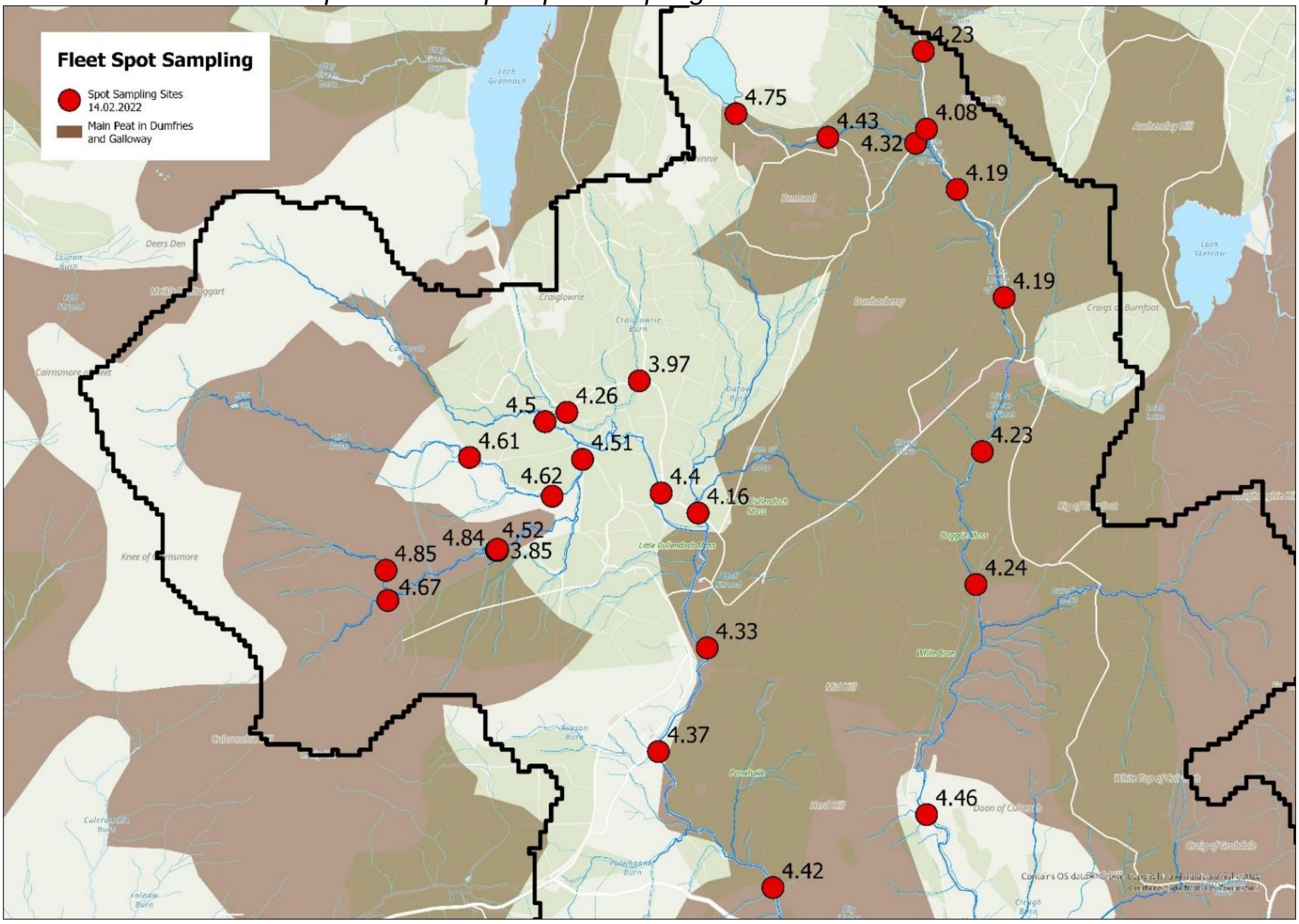
3.2.3 Spot Sampling Water of Fleet

Maps 25 to 28 show the spot sampling results from the Big and Little Waters of Fleet. In addition to the spot sampling sites a number of samples from forestry drainage ditches next to watercourses were also taken opportunistically during sampling. Although taken on different sampling days they have been combined and are shown in Map 28. Graph 16 highlights when each spot sampling occurred within the Fleet flow map. Prior notice was required to access the headwater forestry which meant that periods of high flow had to be predicted from weather forecasts. With peaks in flow often occurring overnight, and prior work arrangements occasionally coinciding with high flows, this meant that sampling immediately after peak flows, and therefore when water was at its most acidic, sometimes was not possible. The Sonde pH record from the Big Water of Fleet have therefore been left on Graph 16 to give a rough indication of how close each spot sample record would have been to the lowest pH achieved during the flood that preceded it.

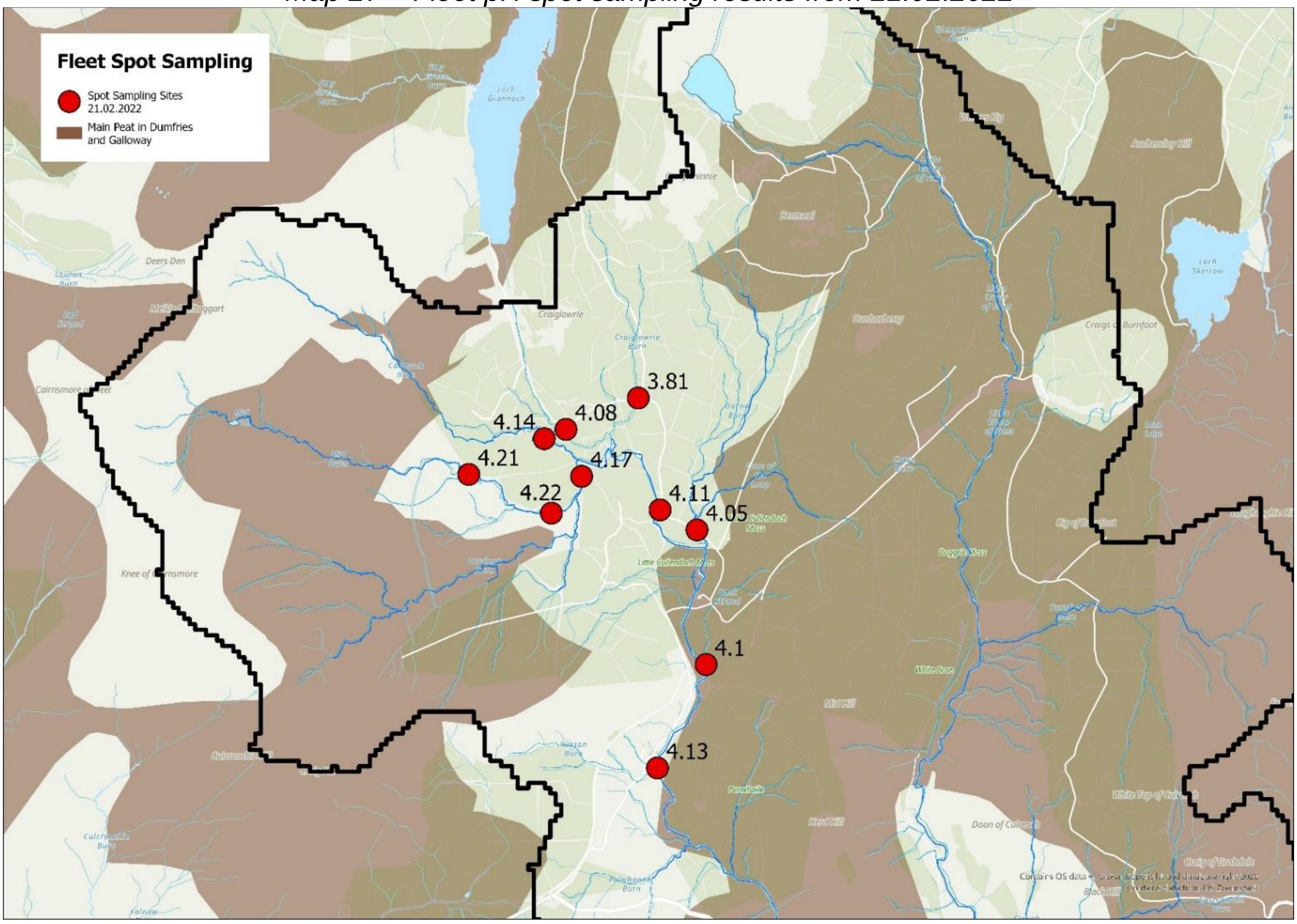
Map 25 – Fleet pH spot sampling results from 04.02.2022



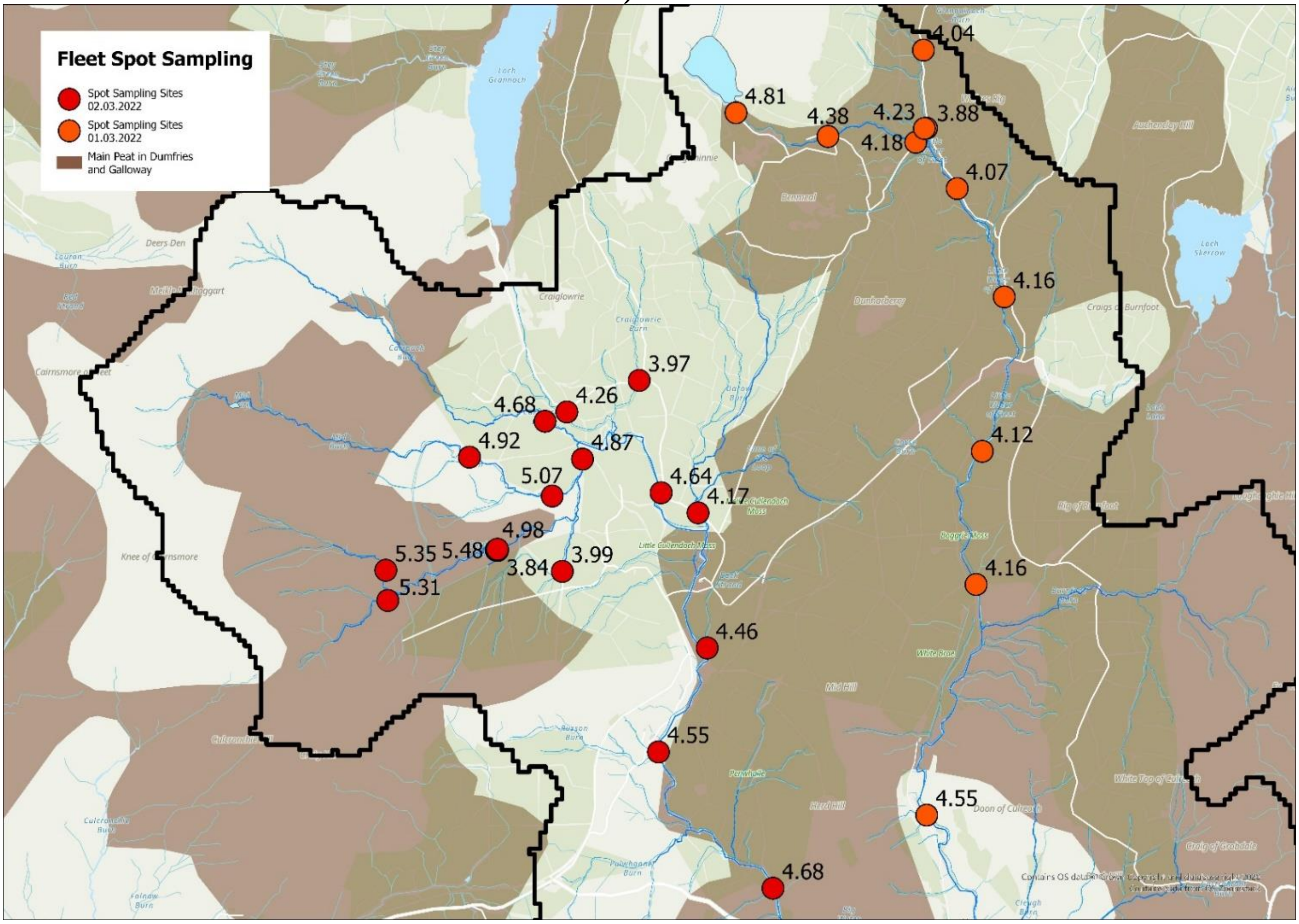
Map 26 – Fleet pH spot sampling results from 14.02.2022



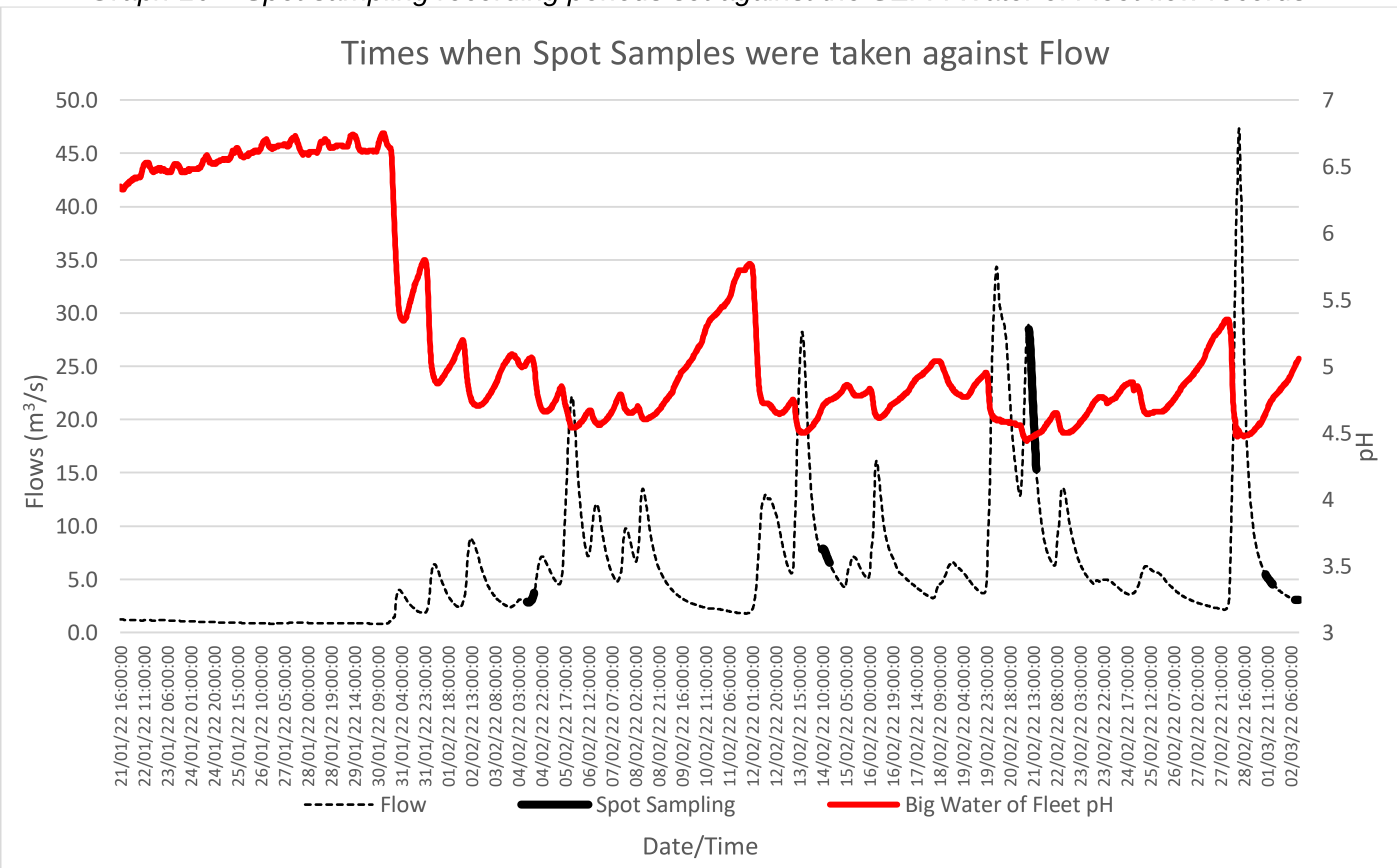
Map 27 – Fleet pH spot sampling results from 21.02.2022



Map 28 – Fleet pH spot sampling results from 01.03.2022 (Little Water of Fleet) and 02.03.2022 (Big Water of Fleet) combined

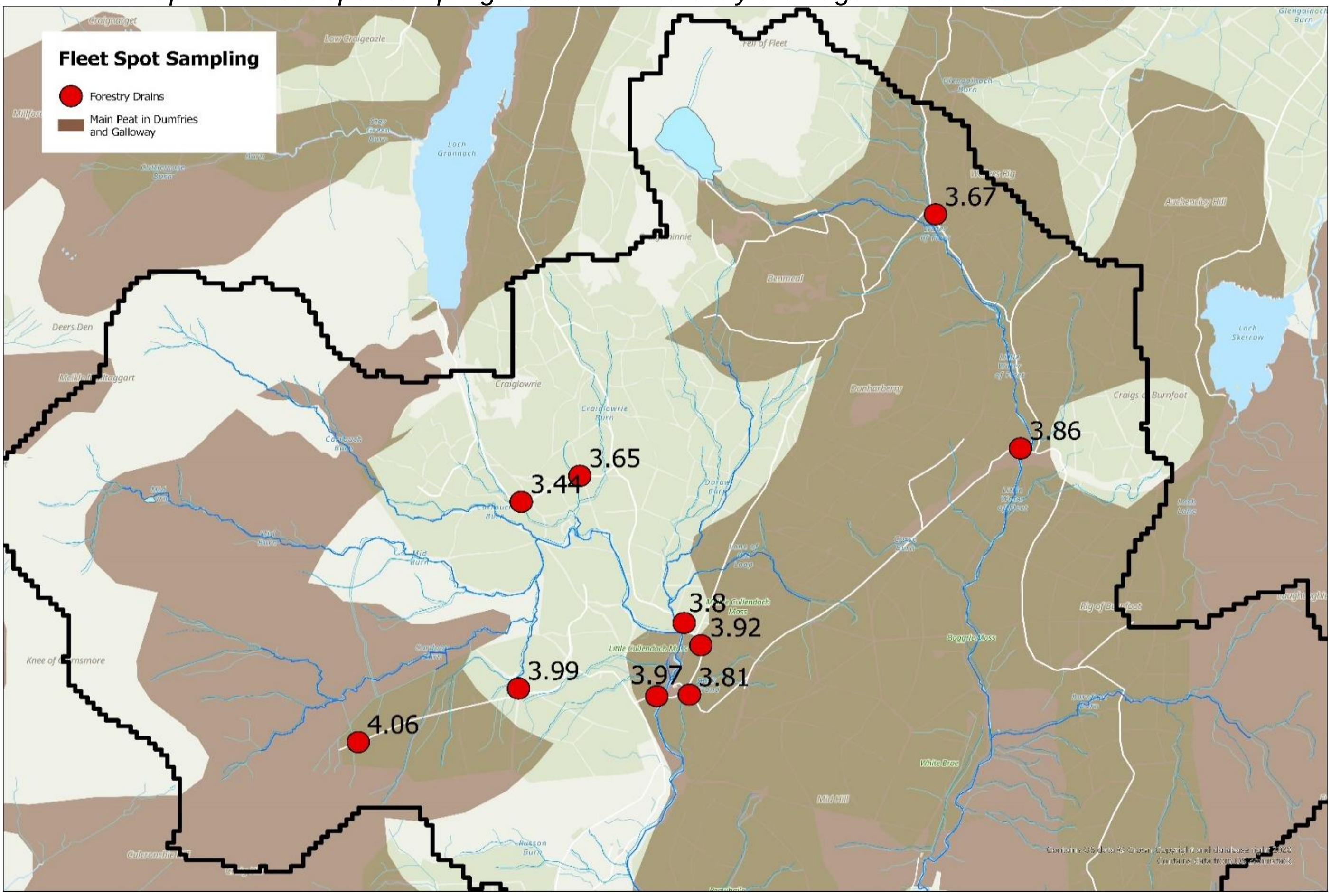


Graph 16 – Spot sampling recording periods set against the SEPA Water of Fleet flow records



As can be seen from Graph 16 pH levels were falling during sampling on 04.02.2022 but were rising and becoming less acidic during the other recording periods. The significance of this is that, on a given sampling day some results may be closer, or further away, from the lowest pH reached depending upon the time of day they were sampled. Even though the pH levels recorded during each spot sampling will be, to varying degrees, less acidic than at the lowest pH achieved, the results still show low pH levels that are indicative of varying degrees of acidification. Many of the pH readings recorded are at levels which are of concern to fish populations. A few significant patterns are also evident within the results. Firstly, the Little Water of Fleet again appears more acidic than the Big Water of Fleet, backing up the results from the Sondes and showing the acidification goes far beyond the three Sonde sample sites. Secondly, within both the Big and Little Waters of Fleet water becomes more acidic as it flows downstream from the upper reaches of each watercourse before beginning to slowly recover towards the lower (furthest downstream) sample sites. Thirdly, at the lowest sample site on both the Big and Little Waters of Fleet pH has still not recovered to the levels recorded at the furthest upstream site. Finally, from the small amount of data collected and taking into account the limitations of the data collected, the pH levels from the Cardoon Burn (excluding the gully that drains the forestry on the South slope) appear to be consistently less acidic than at all other sites (with the exception of the outflow from Loch Fleet which is at the bottom of an area that has been subject to past liming to increase pH levels (Howells and Dalziel, 1992). During the flows in which it was sampled the pH levels from the gully that drains the forestry on the South slope are (repeatedly) roughly ten times more acidic that the pH in the Cardoon Burn.

Map 29 – Fleet spot sampling results from forestry drainage ditches near watercourses

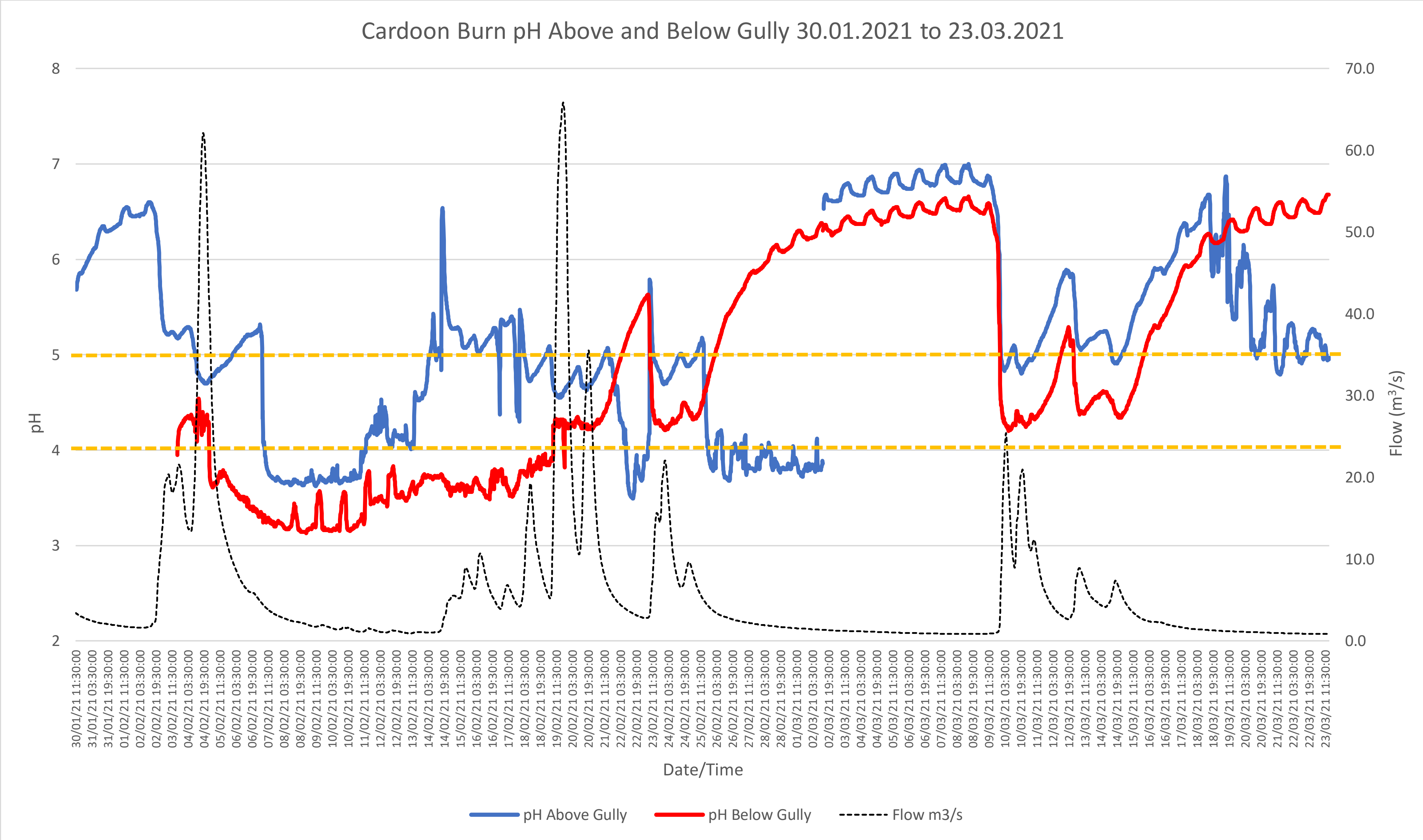


As can be seen by comparing the drainage ditch results with the spot sampling results the water in the sampled drainage ditches is significantly more acidic than the water in the burns/rivers and is at a level that is potentially very harmful to fish populations.

3.2.4 Cardoon Burn Water Quality Monitoring – Winter 2020/2021

Graph 17 shows the pH records for above and below the gully that drains the forestry on the South side of the Cardoon Burn valley, for the winter 2020/2021 recording period. The flow data from the SEPA gauging site at Rusko has been added to show the influence of flow on pH levels. The Sondes at both sites were taken out for calibration on 02.03.2021 and redeployed within two hours of being removed.

Graph 17 – pH and flow comparisons between the above and below gully sample sites on the Cardoon Burn with pH 5 and pH 4 highlighted (below 5 is likely harmful to Salmonids with below 4 likely being lethal)

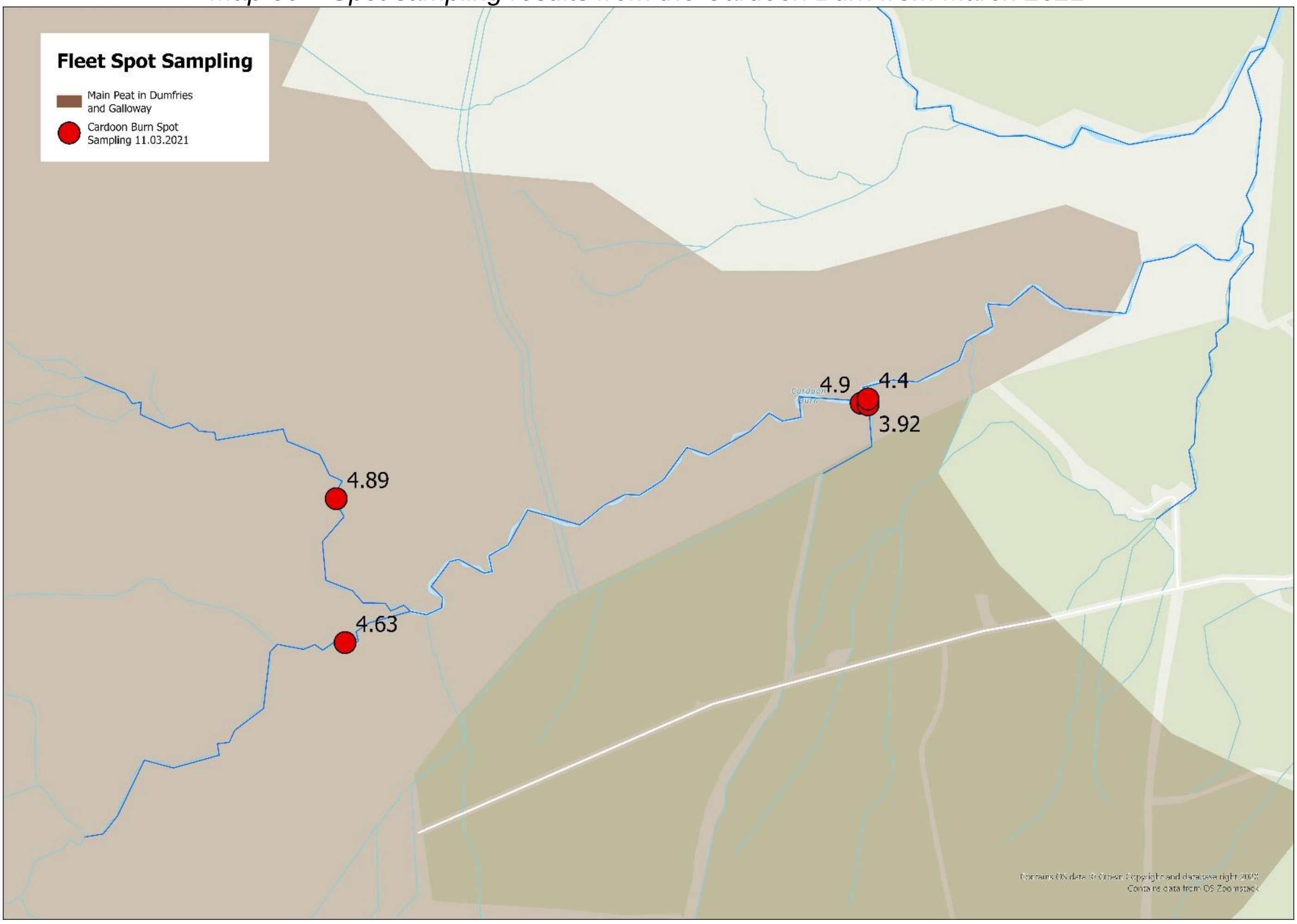


It was noted in the field sheet that the Sonde located above the Gully was exposed to the air when it was taken out for calibration on 02.03.2021. The frame that the Sonde sits in had been moved slightly at some point by high flows. Looking at the data it appears to be the high flow period on the 19th February that has moved the frame. As flow levels start to get low on the 21.02.2021, and again on the 26.02.2021, the pH records from the upstream Sonde greatly diverge from those of the downstream site, having followed a similar pattern up until that point. The support frame was repositioned when the Sonde was redeployed after calibration on 02.03.2021. The pH records from above the gully appear to have developed another issue on 18.03.2021. This time it appears unrelated to flow and is most likely as a result of an issue developing within the pH sensor.

From Graph 17 it is clear that the water coming in from the Gully is having an impact on the pH levels downstream, with the pH in the Cardoon Burn below the gully being more acidic than the pH above. In regards to fish health this results in the Cardoon Burn below the Gully spending longer periods of time below pH 5, and more significantly longer below pH 4. This is highlighted by the period between 04.02.2021 and 19.02.2021 when the pH below the gully was below 4 for the entire period (approximately 15 days) whilst the pH above the gully was only below pH 4 for four days. This also indicated that whilst pH recovery in the Cardoon Burn above the gully responds relatively quickly after periods of rainfall, the pH in the gully persists at low levels for much longer, prolonging low pH impacts on the Cardoon Burn downstream.

Spot sampling was also carried out for five sites on the Cardoon Burn in March 2021.

Map 30 – Spot sampling results from the Cardoon Burn from March 2021



As with the spot sampling from the Cardoon Burn in 2022 the results show the impact the water coming out of the gully has on the Cardoon Burn pH after periods of high flow, with the Gully pH being almost 10 times more acidic than the Cardoon Burn upstream. This results in the Cardoon Burn downstream of the gully being 0.5 of a pH unit more acidic.

4 DISCUSSION

4.1 Tannylaggie Flow Peatland Restoration Water Quality Monitoring

With monitoring having now been carried out during three winter monitoring periods a good series of data has been collected from the Dargoal Burn prior to Peatland restoration work being carried out at Tannylaggie. As discussed in previous GFT Water Quality Monitoring reports the pH levels in the Dargoal Burn are low and are impacting fish populations within the burn. Such are the low pH levels, and the consistency at which they can stay at that level, that they will likely be having a knock-on effect on the watercourses into which the burn flows. The Dargoal Burn flows into the Polbae Burn, which in turn flows into the River Bladnoch a short distance downstream. Both form part of the River Bladnoch Special Area of Conservation of which Atlantic salmon are the qualifying feature. The Tannylaggie restoration work has the potential to significantly improve water quality, and improve conditions for fish populations and it is important that all of the potential benefits of the work are covered in the recording. Whilst this report has concentrated on pH, as it is the biggest concern to fish health at this location, other variables recorded by the Sondes such as temperature, DOM and conductivity are also available for pre and post restoration comparison. DOM may prove important in future comparisons as part of the restoration works will likely include ditch blocking, or infilling, potentially reducing the quantity of eroding peat entering the watercourse. It is also important to consider variables not currently covered within the monitoring. 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 temperature. The GFT is involved in a national recording scheme run by Marine Science Scotland which looks at high summer temperatures across Scottish rivers to identify locations where temperatures are beginning to impact trout and salmon populations. As part of this project the GFT has data from a number of temperature loggers spread around the Bladnoch catchment. The results from this data indicate that there is a significant chance that temperatures in the Dargoal Burn my reach levels that cause stress for salmonid fish. Whilst there is little research available on the impacts of peatland restoration on burn/river temperatures there is the potential for a cooling effect resulting from the increased storage, and slower release, of water within the restored peatland. Summer water temperatures should therefore be recorded within the Dargoal Burn going forward. Another parameter for consideration is DO levels. As shown in the results DO saturation levels are well below 100% during winter recording. Whilst slightly reduced oxygen levels should be expected as the Dargoal Burn is slow and deep within the monitored section, it is possible that erosion from the old forestry drainage network is resulting in accelerated levels of eroding peat entering the watercourse. This may reduce oxygen levels further due to the action of bacteria digesting the peat. As oxygen levels and bacterial activity in water are directly impacted by water temperature then consideration should be given to using a Sonde to record levels over the summer when DO levels should be at their lowest. The results also clearly show that the upstream monitoring site on the Dargoal Burn (TL01) is unreliable and that it should be moved to a more reliable location, if there is still time before restoration work commences. One final point of note for the Dargoal Burn is the close association between low pH and increased levels of labile Aluminium (which is toxic to fish). Aluminium levels may be one of the key factors in regards to whether fish populations recover. Although recording it would likely have to be outsourced and may prove expensive consideration should be given to monitoring Aluminium levels.

<u>Tannylaggie Flow Peatland Restoration Water Quality Monitoring Recommendations</u>

1. Monitor water quality and temperature within the Dargoal Burn during peak summer months
2. Relocate the furthest upstream EXO1 Sonde sampling site
3. Explore the possibility of monitoring labile Al levels within the Dargoal Burn at Sonde sample sites

4.2 Water of Fleet Electrofishing Review and Water Quality Monitoring

4.2.1 Water of Fleet Electrofishing Review

The electrofishing results from the Water of Fleet show signs of recovery from the low and often absent fish numbers recorded during the earliest recording period. There are signs of both increases in range and numbers for both salmon and trout. Whilst there are indications of recovery from a more acidified state when recording began, juvenile salmon are still missing, or are present at supressed levels, in many parts of the Water of Fleet System where healthy numbers should be expected. This is also the case with juvenile trout with most of headwater spawning burns having low numbers, or on occasion a complete absence, of trout fry. Of particular note is the Little Water of Fleet above the impassable falls where fry numbers are particularly low, suggesting a population that is “just hanging on” and no more. As this is an isolated population it is particularly susceptible to the impacts of acidification as it cannot be recolonised by fish straying from other parts of the system out with the impacts of acidification.

As such, whilst improvements in air quality, habitat restoration and some localised changes in land use/management have all helped improve water quality and fish numbers, acidification still remains a major problem impacting fish populations in the Water of Fleet and more needs to be done to bring fish populations back to near pre-acidification levels.

One point of note is that more data is required to see 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. Going forward it may not be possible to collect large amounts of additional electrofishing data but all of the sites which have had multiple visits should be regularly revisited in the future, and if possible some of the sites which have only been visited occasionally should be visited more regularly. It may also be worth considering timed electrofishing on the Big Water of Fleet on an annual basis to look at the variations in salmon fry range and relative abundance from one year to the next. It should be possible to do this based on only one additional day sampling per year.

4.2.2 Water of Fleet Water Quality Monitoring

The results from the Water of Fleet for both the Sonde continual monitoring and for the spot sampling also show that acidification is still a major problem within the headwaters of the catchment at a level that will be impacting both trout and salmon. Despite improvements in air quality resulting in less acid deposition than when levels were at their peak (Ferrier et al., 2001) salmonids remain at very low levels within, or are absent from, some headwater watercourses. In addition to the localised impacts within the headwaters, the impacts of the reduced pH appear to extend a considerable distance downstream. Although the pH starts to improve roughly half way through the headwater conifer plantations in both the Little and Big Waters of Fleet, the pH recorded at the lowest spot sampling sites on both watercourses had not yet recovered to the level recorded at the furthest upstream sites above the forestry (Cardoon Burn sites on the Big Water of Fleet and site immediately below Loch Fleet on the Little Water of Fleet). The relationship between pH and flows should also be noted. As rainfall varies from winter to winter, and the impacts of low pH are influenced by exposure and timing (in relation to key hatching stages in egg development), fish/egg mortalities may vary from one year to the next based on the frequency of rainfall and the exact egg hatching timing. This has not been looked in any detail this report and in future the collection of data that would allow hatching timing to be calculated and compared to flows should be considered. Of the two main tributaries of the Water of Fleet, the Little Water of Fleet is more acidified than the Big Water of Fleet (although some burns flowing into the Big Water of Fleet show localised issues with lower pH, for example the Cleuch of Eglon Burn). Of particular note is the rapid fall in pH between Loch Fleet and the next spot sampling site downstream. As can be seen from the land use and peat layers added to the spot sampling maps the Little Water of Fleet catchment has greater land coverage of both peat and conifer plantations. It is clear from the Big Water of Fleet that there can be significant acidification issues resulting from the planting of trees alone, and the lower percentage of conifers on the Big Water of Fleet has to be taken into account, however, the lower pH on the Little Water Fleet is still most likely a result of the combination of a greater percentage of the catchment being planted combined with a greater percentage of drained peat. Whilst the Little Water of Fleet is more acidified, there are still significant issues on the Big Water of Fleet. The peat map would indicate that there is a much lower percentage of peat in the Big Water of Fleet catchment. As a result there would appear to be less opportunities for peatland restoration, with much of the peat that is present already being unplanted or under restoration (Cardoon Burn/Mid Burn). Whilst the benefits of restoration on the Little Water of Fleet would potentially provide greater improvements to fish populations on a local level, and to a more fragile population, any additional restoration on the Big Water of Fleet would be of greater benefit to the Fleet fishery as the population on the Little Water of Fleet above the waterfall is isolated and confined to the area above the falls, whilst there is free migration between the majority of the Big Water of Fleet catchment and the lower river/sea. The results from the Fleet headwaters indicate that the low pH recorded within both the Big and Little Waters of Fleet are the result of changes in land use on a catchment level, as opposed to any single localized issue, and although some areas are worse than others, restoration at a larger scale than has currently been undertaken would be required to restore fish populations to levels that are close to pre-acidification levels. The restoration of areas of deep peat would still appear to offer the best opportunity for any expansion of restoration work due to the importance of peatland in regards to both carbon storage and nature.

The results from the Cardoon Burn are of particular interest. The water quality data shows that despite the peatland restoration, and only a low percentage of conifer planting within the catchment, pH still dips to levels that are potentially damaging to fish. This is not unexpected. Water Quality Monitoring on the nearby Round Loch of Glenhead, an unplanted, acidified, upland loch, showed limited recovery from peak acidification levels in the early 1990's (Battarbee et al., 2011). Whilst reductions in the burning of coal has resulted in significant reductions in Sulphate deposition, equivalent reductions in Nitrate deposition have not occurred limiting recovery from acidification. Increased deposition from Sea salt from stormier conditions linked to the North Atlantic Oscillation has also been listed a significant factor limiting recovery. The recovery from historic levels of acidification appears much less studied in rivers than in still waters but studies from Galloway lochs would indicate that some level of acidification would still be expected, even where there are no land use issues. Despite this the results from the Cardoon Burn show the least impact from acidification. In addition the Cardoon electrofishing results consistently show some of the highest fish numbers, suggesting that the dips in pH are not at a level that is having a significant impact on fish, or that dips in pH to levels that damage fish populations are much less likely and/or persistent. As such the lack of trees and restoration of peatland does appear to be benefiting fish populations. More electrofishing and environmental data would be needed to say conclusively if this were the case. The resources for such a project would likely be significant but it should be considered for future monitoring. Alternatively, if resources can be found, a Masters or PHD study could provide the level of detail required and give valuable insights into the impacts on both fish populations and the greater environmental benefits in general.

The impact of the gully that flows into the Cardoon Burn at the monitoring site is significant. The pH after high flows is 10 times more acidic than the water it flows in to and drags the water in the Cardoon Burn down by half a pH unit. From the electrofishing data that is available it is difficult to say if there is a greater impact on egg survival in the burn below the gully, but it is a possibility particularly as associated labile Al levels are also likely to be substantially higher. As with the Dargoal Burn, monitoring of Al levels for the Fleet catchment should be considered for future studies. The map of the forestry drains from which spot samples were taken shows that the low pH levels within the gully which flows the Cardoon Burn is not an isolated occurrence. The pH levels from the sampled drains were significantly more acidic than the watercourses they flow into and show that the resulting reduction in pH recorded on the Cardoon Burn is likely to be happening in other locations throughout the upper Fleet catchment. Given the adverse impacts on watercourses more focus in finding these features should be given in future sampling in the hope that the results can be added to the data already collected and used in combination with peat maps and forestry plans to identify locations where peatland restoration is a realistic possibility.

Water of Fleet Catchment Management Recommendations

- The results from the water quality monitoring show the importance of finding opportunities to improve water quality through peatland restoration (in addition to all of the other peatland associated ecological and climate benefits). Whilst there is variation from location to location the pH levels and fish numbers within the afforested areas sampled indicate that there are acidification issues anywhere within the upper Fleet catchment where mature conifer plantations are located on base-poor Geology. As such this report contains data on water quality and fish populations that will help support, and provide weight to, a change in land management and the restoration of peatland in the majority of Fleet catchment headwater locations where deep peat can be found.

- This report therefore also supports carrying out additional work to establish peat depths within afforested sections of the upper Fleet catchment to supplement any information currently available.

- Given the ongoing work by NatureScot to restore Peatlands in the area around the Cardoon Burn, and the apparent improvements in water quality and fish populations, the impact of the gully which flows into the Cardoon Burn from the adjacent conifer plantation appears to be of particular concern. It is a recommendation of this report that this issue should be addressed if at all possible. As the gully drains deep peat that has been extensively drained and planted the removal of conifers and the restoration of peatland would be the ideal fix. However, it is noted that there has been recent re-planting within this area and restoration of the peatland may be difficult under the current management plan. If this is the case it is vital that lessons are learned from situations like this so that they do not occur in the future or so that they can be identified and highlighted for restoration/protection in future management plans. Correction, 22.12.2022 – this area has been left by the forestry following the last harvesting of trees with the potential for restructuring/restoration, however there has been extensive conifer regeneration to the point where it looks as if replanting has taken place and all of the problems remain at the time of this update.

- It is important that this report and the information it contains is shared with all bodies involved in the management of areas that contain Peatland, and to any other parties that may be interested or may find it of use.

- Although not discussed in detail climate change is considered a major threat to water quality around the globe (Whitehead et al., 2008). In particular, given the findings of this report, forecasts of wetter and more stormy winters could lead to conditions where low pH events are more common and pH levels are held at lower values, subsequently increasing the chances of low pH coinciding with vulnerable stages in trout and salmon life cycles. As peatland restoration provides a multitude of benefits on many different levels and across multiple parties it is a much more realistic restoration aim, and is much more likely to find funding, than water quality improvements based solely on fish benefits alone and may provide protection against the warming climate potentially amplifying the impacts of acidification.

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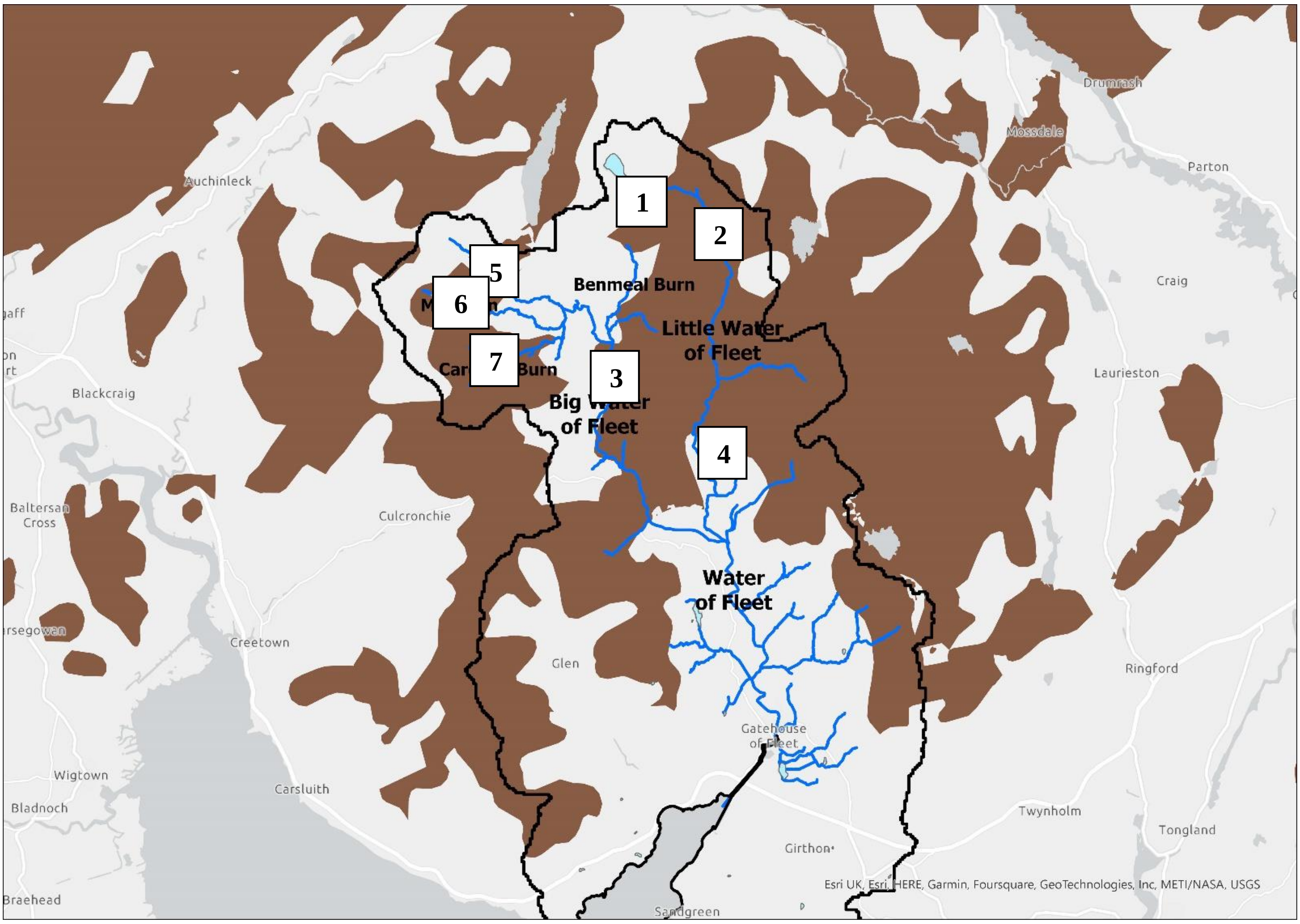
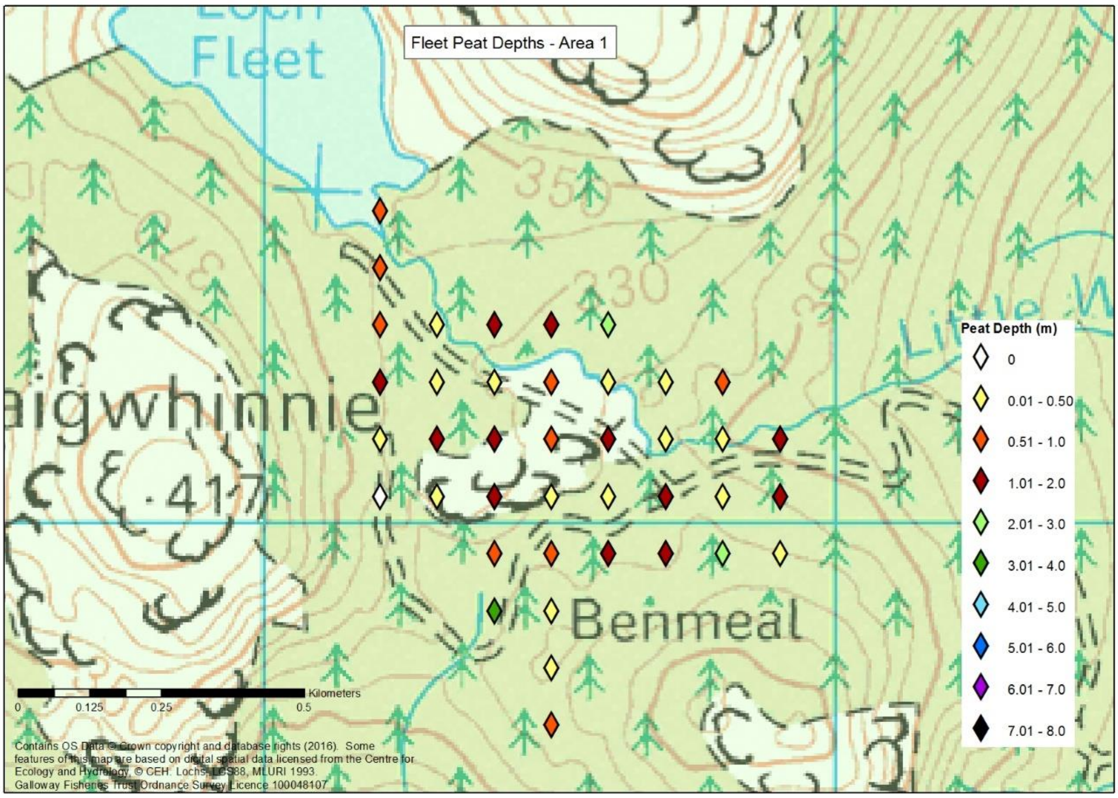
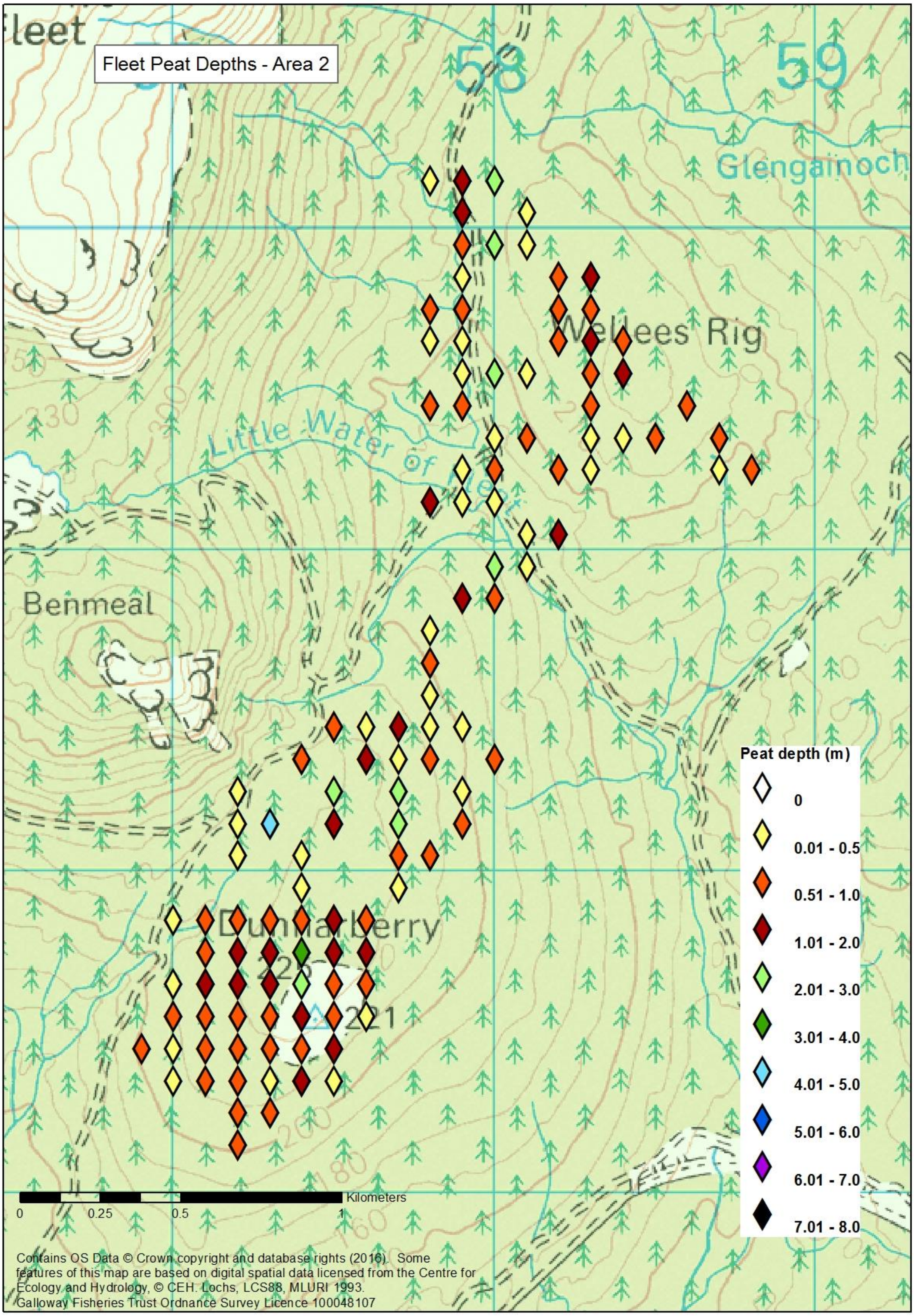
APPENDIX 1 – WATER OF FLEET PEAT DEPTH DATA

Water of Fleet peat map (peat in brown) showing locations where peat depth measurements (numbered) have been taken






Fleet Peat Depths - Area 2
Fleet
58
59
Glengainoch
Wellees Rig
Little Water of Fleet
Benmeal
Dunharberry
225
221
Peat depth (m)
0
0.01 - 0.5
0.51 - 1.0
1.01 - 2.0
2.01 - 3.0
3.01 - 4.0
4.01 - 5.0
5.01 - 6.0
6.01 - 7.0
7.01 - 8.0
0
0.25
0.5
1
Kilometers
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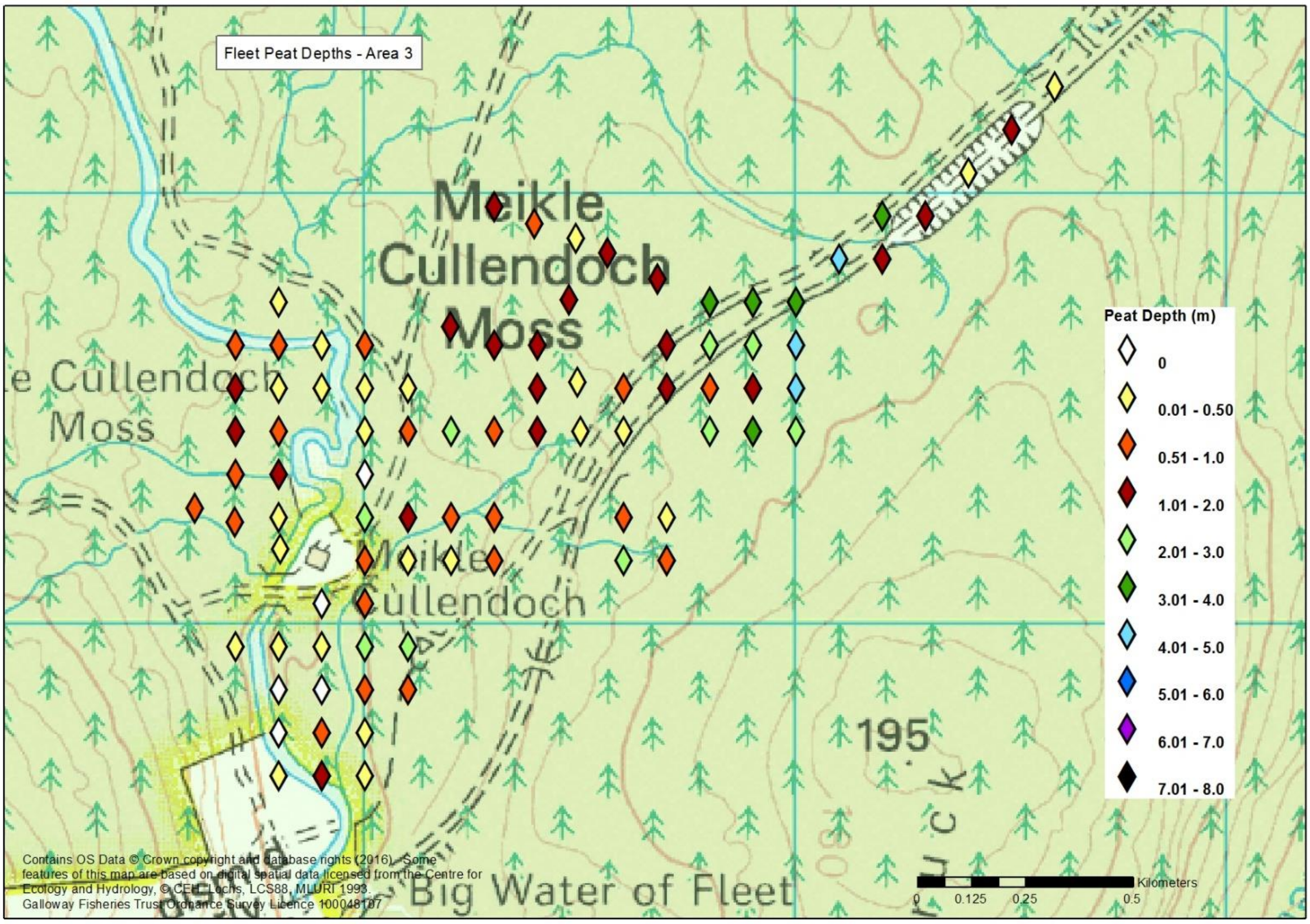
Fleet Peat Depths - Area 3
Meikle Cullendoch Moss
Cullendoch Moss
Meikle Cullendoch
195
Big Water of Fleet
Peat Depth (m)
0
0.01 - 0.50
0.51 - 1.0
1.01 - 2.0
2.01 - 3.0
3.01 - 4.0
4.01 - 5.0
5.01 - 6.0
6.01 - 7.0
7.01 - 8.0
0 0.125 0.25 0.5 Kilometers
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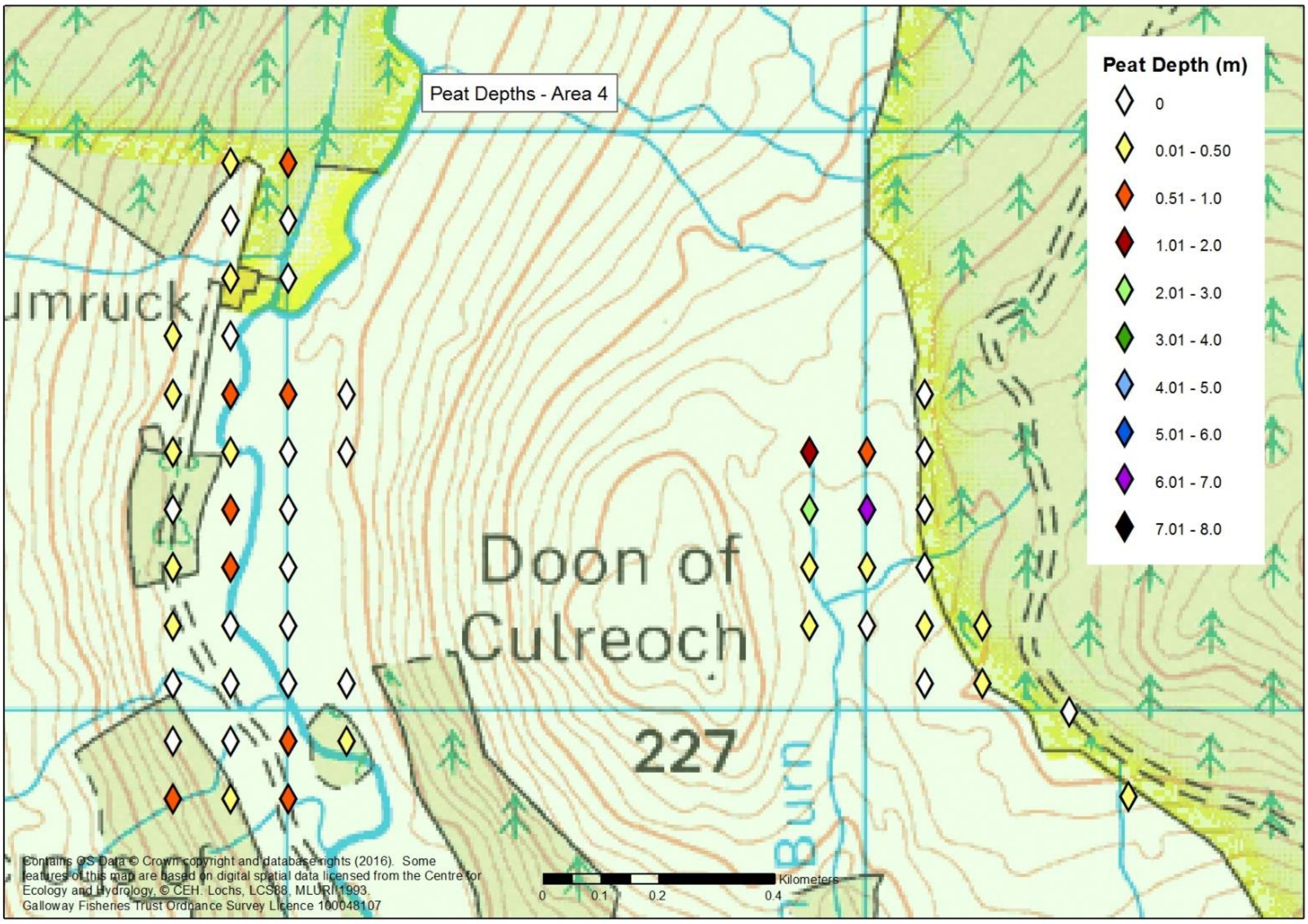
Peat Depths - Area 4
umruck
Doon of Culreoch
227
Burn
Peat Depth (m)
0
0.01 - 0.50
0.51 - 1.0
1.01 - 2.0
2.01 - 3.0
3.01 - 4.0
4.01 - 5.0
5.01 - 6.0
6.01 - 7.0
7.01 - 8.0
0 0.1 0.2 0.4 Kilometers
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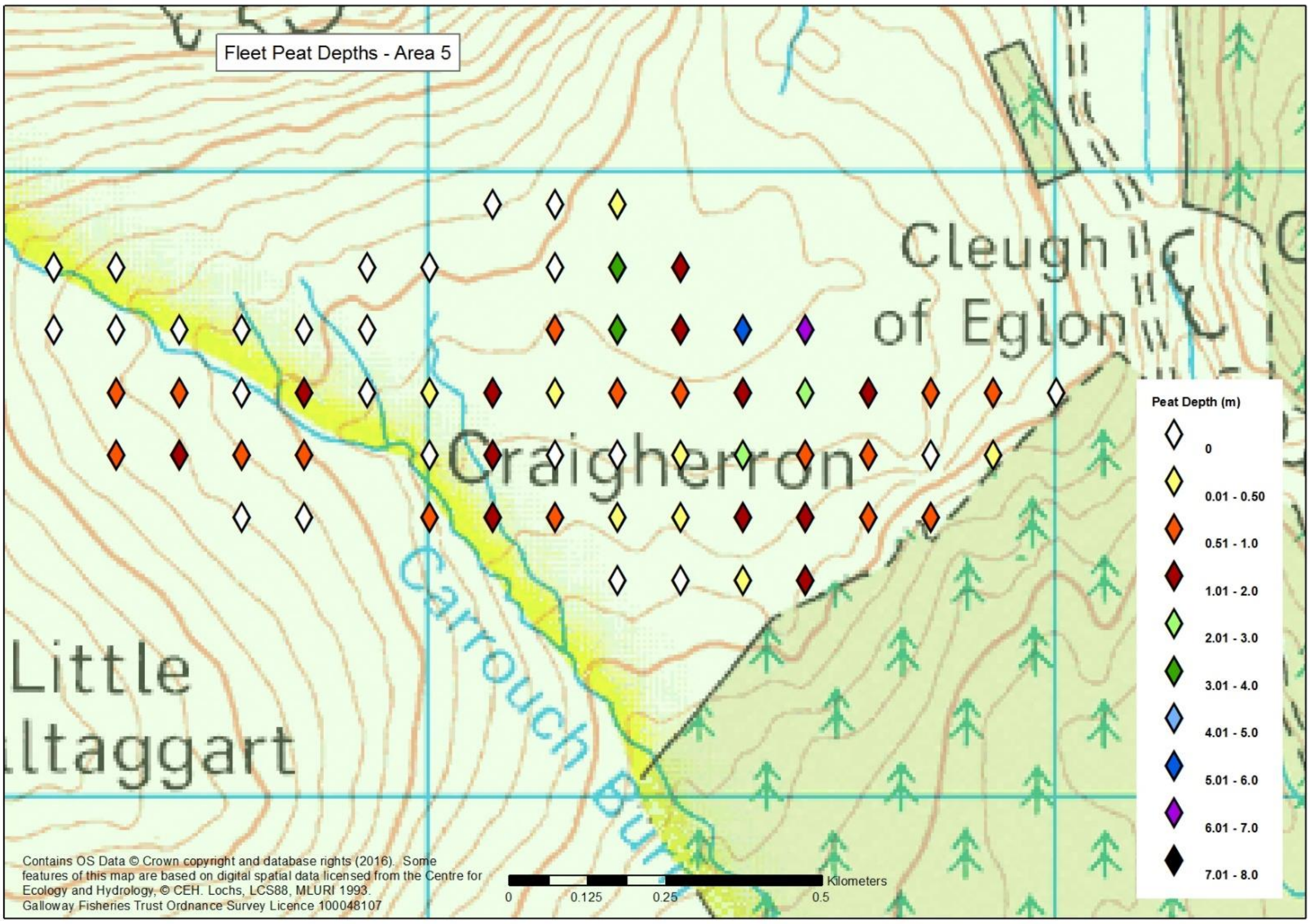
Fleet Peat Depths - Area 5
Cleugh of Eglon
Craigherron
Little Mulltaggart
Carrouch Burn
Peat Depth (m)
0
0.01 - 0.50
0.51 - 1.0
1.01 - 2.0
2.01 - 3.0
3.01 - 4.0
4.01 - 5.0
5.01 - 6.0
6.01 - 7.0
7.01 - 8.0
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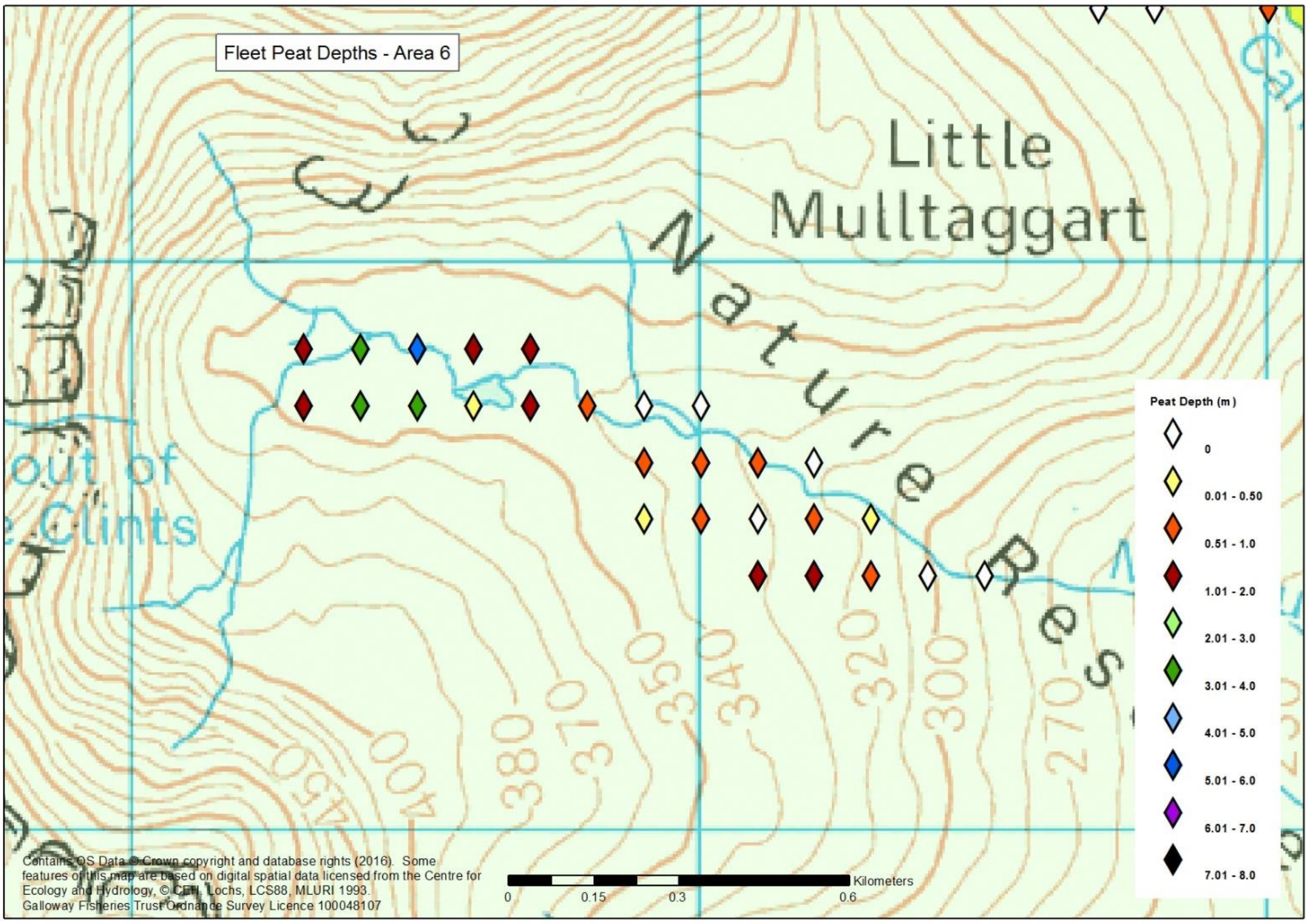
0 0.125 0.25 0.5 Kilometers


Fleet Peat Depths - Area 6
Little Mulltaggart
Nature Res
out of Clints
Peat Depth (m)
0
0.01 - 0.50
0.51 - 1.0
1.01 - 2.0
2.01 - 3.0
3.01 - 4.0
4.01 - 5.0
5.01 - 6.0
6.01 - 7.0
7.01 - 8.0
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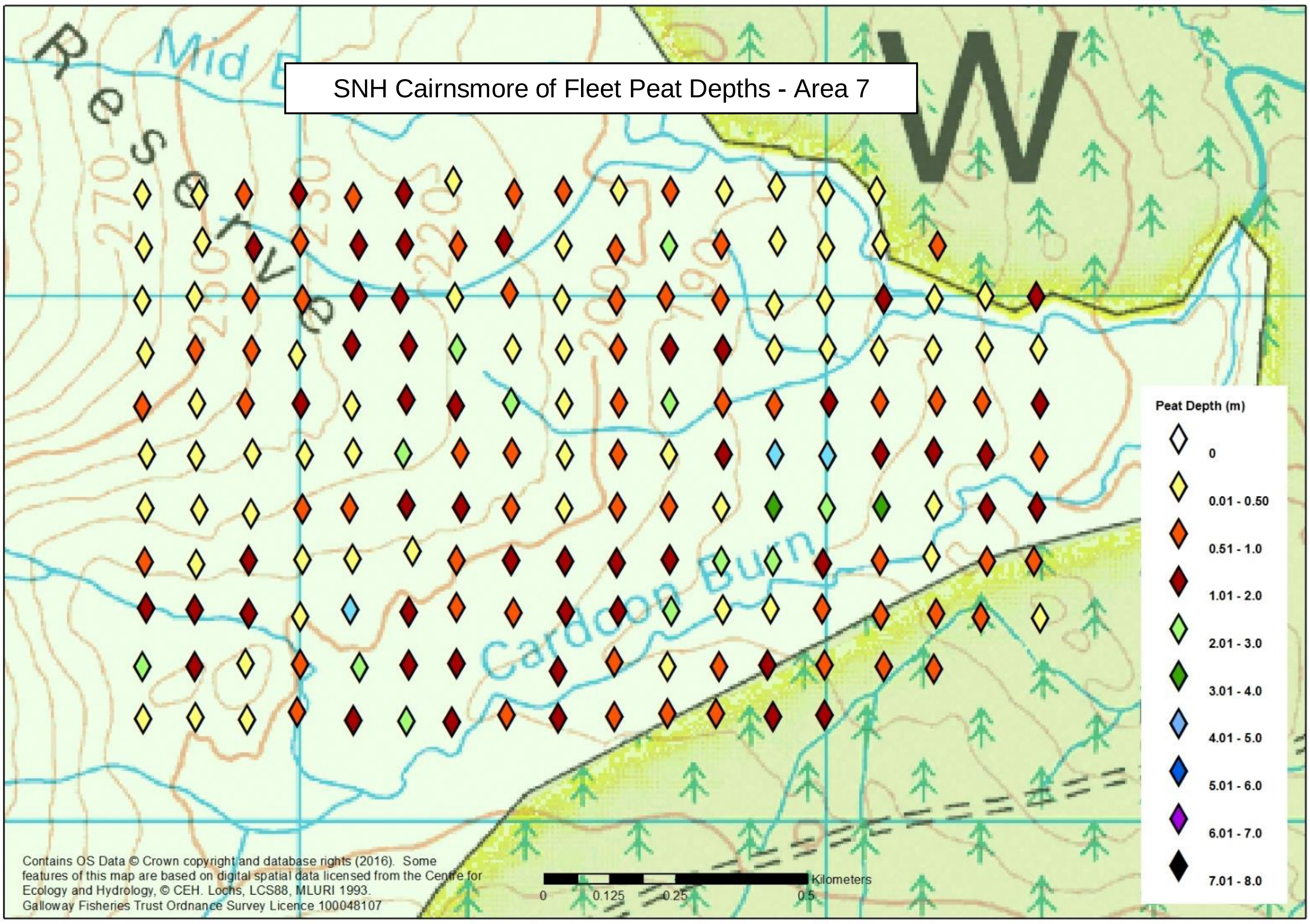
0 0.15 0.3 0.6 Kilometers


SNH Cairnsmore of Fleet Peat Depths - Area 7
Mid B
Reserve
Cardoon Burn
Peat Depth (m)
0
0.01 - 0.50
0.51 - 1.0
1.01 - 2.0
2.01 - 3.0
3.01 - 4.0
4.01 - 5.0
5.01 - 6.0
6.01 - 7.0
7.01 - 8.0
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0 0.125 0.25 0.5
Kilometers