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Bladnoch Restoration Feasibility Study

For

Kirkcowan Angling Club

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Summary

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Keywords

Bladnoch; Acidification; Atlantic salmon; water quality.

Background

Acidification of freshwater is the main limiting factor for juvenile Atlantic salmon recruitment in the upper River Bladnoch catchment. Acidification occurs as a result of atmospheric deposition of pollutants, scavenged from the air by conifer plantations. This has been exacerbated by the degradation of peatland in the upper River Bladnoch catchment. Therefore, this report aims to investigate the distribution of juvenile Atlantic salmon in relation to water acidity and other limiting factors such as habitat availability and quality and barriers to migration. Recommendations for restoration projects are then made with the aim of improving water quality and/or Atlantic salmon abundance.

Main findings

- Juvenile Atlantic salmon are found in moderate to low densities in the lower reaches and are absent from the upper reaches of the upper River Bladnoch catchment.
- Water quality monitoring of pH demonstrated both spatial and temporal variation, with the upper reaches of the River Bladnoch and Tarf Water recording a pH less than 5, which is most likely detrimental to juvenile Atlantic salmon.
- Anthropogenic factors such as peatland degradation and afforestation are likely to have driven acidification of the upper catchment and this should be addressed through forestry restructuring and peatland restoration. Liming could be used as a temporary solution to improve water quality until forestry restructuring and peatland restoration have been completed.
- Habitat availability could also be a factor limiting juvenile Atlantic salmon abundance. Improvements could be made with deciduous tree planting, removal of Sitka spruce regeneration, woody debris addition, gravel addition and boulder placement. Habitat availability could also be improved by opening up small watercourses which have previously been diverted or altered by forestry plantations, which would also improve water quality as alterations are made.

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1 INTRODUCTION

In recent decades, Atlantic salmon (*Salmo salar*) numbers have declined across the UK (Marine Scotland 2018). Similarly, reported catches of Atlantic salmon in Solway rivers have shown a significant decline during the last ten years (Figure 1) (Marine Scotland 2018). Due to the economic importance of Atlantic salmon understanding their decline is crucial but a highly complex problem. Anthropogenic impacts ranging from the freshwater to the marine environment, such as impassable barriers, past overexploitation, marine fish farms, reduced habitat availability and reduced water quality, have all contributed to the decline of Atlantic salmon (Thorstad *et al.,* 2008). For example, barriers impassable to migration, such as weirs, dams and river turbines, disrupt the spawning migration of Atlantic salmon, resulting in the decline or extinction of migratory populations above these barriers (Thorstad *et al.,* 2011). Another anthropogenic impact, which affects fish species, such as Atlantic salmon, Arctic charr (*Salvenius alpinus*) and Brown trout (*Salmo trutta*) is acidification (Milner & Varallo 1990). Acidification is one of the most detrimental anthropogenic impacts for freshwater fish in Galloway (Environment Agency 2015).

Acidification, defined as an increase in soil and surface water acidity, is driven by the deposition of pollutants (Cresser & Edwards 1988). There are three deposition processes, which are: wet (atmospheric pollutants react with water molecules lowering the pH of precipitation); dry (airborne pollutants in the form of dust are deposited onto surfaces); and occult (pollutants react with water molecules in clouds and mist and are deposited as condensation on surfaces) (Cresser & Edwards 1988). During the industrial revolution there was a rapid increase in sulphur and nitrogen emissions released into the atmosphere (Evans *et al.,* 2001). Due to a growing evidence base demonstrating atmospheric deposition results in acidification of surface waters, European legislation was formed with the aim of significantly reducing emissions of pollutants (Evans *et al.,* 2001).

As a result of surface water acidification, substantial losses of freshwater fish populations were first noted in the 1970s in the UK (Schofield 1976). Salmonids, were particularly sensitive to acidification with declines of Atlantic salmon, Brown trout and Arctic charr populations (Ikuta *et al.,* 2003). Salmonids exist in freshwater between pH 5 and 9 with successful recruitment of young between pH 6 and 9 (Hendry & Cragg-Hine 2000). However, tolerance to acidified surface waters is species dependent. For example, due to the polytypic nature of Brown trout, naturally adapted populations occur in low abundance in acidified water bodies, such as Loch Grannoch (Maitland 1992). In comparison, Atlantic salmon are particularly sensitive to acidification and their presence or absence can indicate the health of a river. Therefore, Atlantic salmon are the focal species of this report.

Atlantic salmon are anadromous whereby they spawn in freshwater and feed in the marine environment (Klemesten *et al.,* 2003). Adult Atlantic salmon migrate in late autumn/early winter to spawn in their natal rivers (Hendry *et al.,* 2003). Females lay their externally fertilised eggs in redds (Klemesten *et al.,* 2003). The eggs are then covered with gravel where they incubate for several months (Hendry *et al.,* 2003). Alevin hatch from the eggs in spring and once they consume their yolk sac the alevin emerge from the gravel as free-swimming fry. They continue to feed and grow until their second year, when they are known as parr (Klemetsen *et al.,* 2003). After a year or two, Atlantic salmon undergo a radical change in behavior, physiology and morphology and smolt. Smolts migrate downstream to the sea where they feed and grow until they sexually mature as adult Atlantic salmon (Klemetsen *et al.,* 2003).

Each life stage is differently affected by acidification and have different sensitivities (Figure 2) (Peterson *et al.,* 1980). Eggs, alevin and fry are adversely affected by acidification due to their small size during the winter (Peterson *et al.,* 1980). During winter and early spring, high levels of precipitation, as rain and snow melt, result in a decrease in pH as an increased volume of pollutants are deposited into surface waters (Laudon & Bishop 2002). It has been shown, increased mortalities of Atlantic salmon eggs, alevin and fry occur when pH falls to 4.5 - 5 (Peterson *et al.,* 1980). Atlantic salmon eggs, have higher mortalities at a low pH due to chorionase, the enzyme required to dissolve the eggs membrane, failing to work correctly (Peterson *et al.,* 1980). Chorionase works optimally at pH 6.6 - 6.8 and alevin are delayed or fail to hatch when a pH falls below 5 (Peterson *et al.,* 1980). A low pH can also adversely affect alevin and result in high mortalities (Sayer *et al.,* 1993). Alevin consume their yolk sac, develop tissues and calcify their skeleton while they remain in the gravel (Sayer *et al.,* 1993). However, when exposed to a low pH, these processes are disrupted and yolk absorption, tissue development and skeleton calcification are impaired (Sayer *et al.,* 1993). Considered to be a more sensitive life history stage transition is when alevin emerge as free swimming fry (Lacroix *et al.,* 1985). A Low pH (below pH 5) at this stage can result in cessation of feeding, modified behaviour, emaciation, impaired growth and increased mortalities of Atlantic salmon fry (Lacroix *et al.,* 1985). Acidified water bodies often have lower concentrations of calcium (Ca^{++}) and higher concentrations of Dissolved Organic Carbon (DOC) and total dissolved aluminum which are leached into waterbodies during periods of high precipitation (Neal *et al.,* 1990). Smolts are susceptible to acidification, during the energy demanding parr-smolt transformation, as toxic inorganic aluminum ions add addition stress (Grassie *et al.,* 2013). High inorganic aluminum concentrations are also toxic to Atlantic salmon adults and parr. Acidification results in respiratory failure of Atlantic salmon by altering gill tissue structure and function (Kroglund *et al.,* 2007). Therefore, all Atlantic salmon life history stages are at risk of being adversely affected by acidification.

Due to the underlying geology of Galloway, peatland degradation and conifer afforestation of much of the uplands, surface waters in Galloway are acidified (Environment Agency 2015). In Scotland, 17 river catchments are affected by acidification, four of which are in Galloway (Rivers Cree, Bladnoch, Kirkcudbrightshire Dee and Water of Fleet) (Environment Agency 2015). 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 Bladnoch supports a range of Atlantic salmon populations including distinct spring run (multi-sea winter) Atlantic salmon (SNH 2007). However, 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 and appear to be improving slightly (Figure 3). However, rod catches from the upper River Bladnoch catchment have declined over the last decade, which is likely to be the result from acidification (Figure 4).

The relationship between acidification and successful hatching of Atlantic salmon eggs/ alevin survival was investigated by Galloway Fisheries Trust (GFT) through several egg box experiments in the upper River Bladnoch catchment (GFT 2008; GFT 2013). In 2008, three egg boxes were buried in gravel at 15 sampling locations, with each egg box containing 100 eyed Atlantic salmon eggs. The results from this experiment demonstrated at six sampling locations more than 60% of Atlantic salmon eggs produced viable alevin. However, at two sampling locations, Polbae Burn and Dargoal Burn, less than 5% of the Atlantic salmon eggs hatched (Figure 5).

This egg box experiment was repeated between 2010 and 2013 at five sites (Upper and Lower Polbae Burn, Dargoal Burn, Loch Maberry outflow and Waterside) in the upper River Bladnoch catchment (GFT 2013). At each site three egg boxes containing 100 eyed Atlantic salmon eggs were buried in the river bed. Surviving alevin were then counted. The average survival rate fluctuated between years but showed a similar trend to the data collected in 2008. Dargoal Burn and lower Polbae Burn had extremely low survival rates which could indicate poor water quality as a result of acidification. In comparison, survival rates of alevin in egg boxes in the upper Polbae Burn had much better survival rates (83 - 99%). However, egg boxes at sites lower in the catchment, such as at Waterside, demonstrated temporal variation in Atlantic salmon survival as a result of acidification (GFT 2013). However, the time these eyed eggs are in the egg boxes is limited and may potentially miss acidic flushes in some years. Despite this, these experiments provide an indication of the impact acidification has on juvenile Atlantic salmon. These experiments also demonstrate surface water acidity fluctuates both temporally and spatially (i.e. between years and between sampling locations). Therefore, acidification is a likely driver of declining abundance of Atlantic salmon in the upper River Bladnoch catchment.

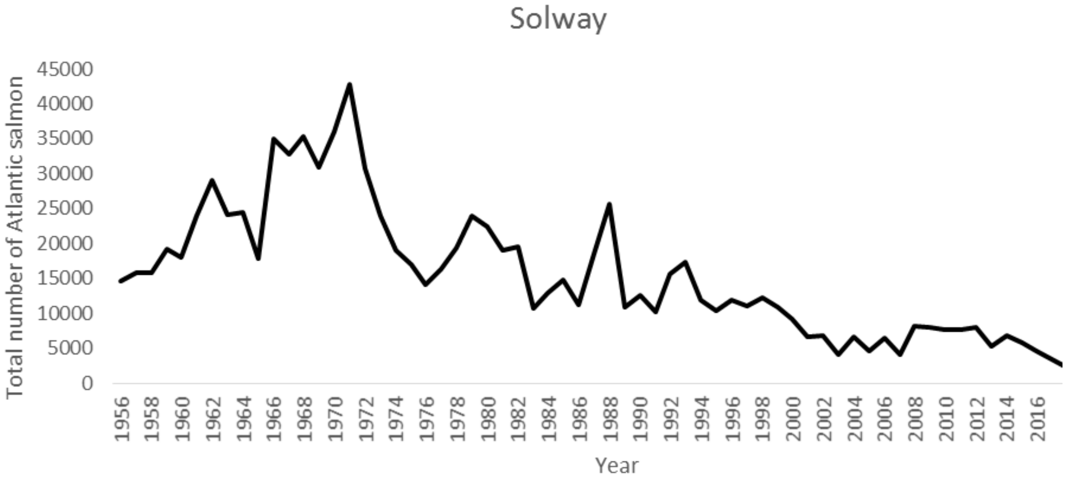

Figure 1: Solway catches of Atlantic salmon between 1956 and 2017 from net, cobble, fixed engine and rod and line fisheries

Figure 2: Sensitivity of Atlantic salmon life history stages to acidification, from most sensitive to least sensitive

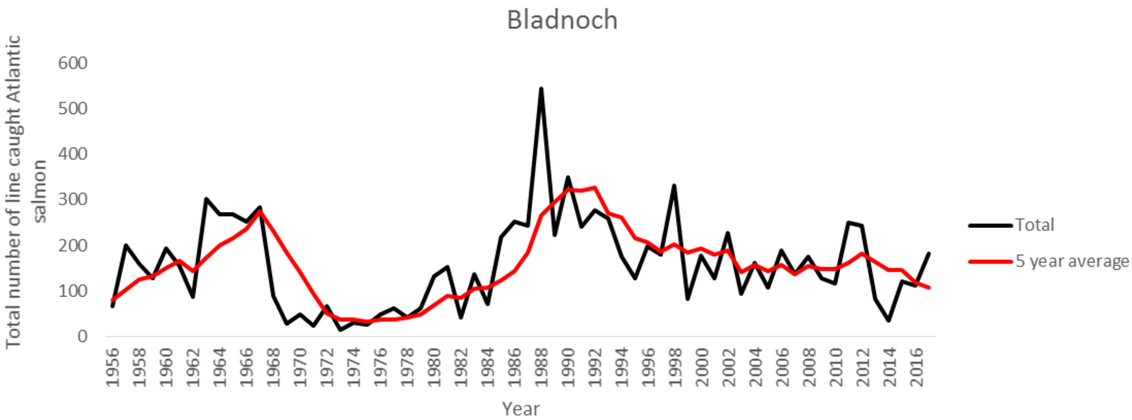

Figure 3: River Bladnoch rod catches of Atlantic salmon between 1956 and 2017. Despite rod catches (5 year average) increasing for several years, they decline again after 1990

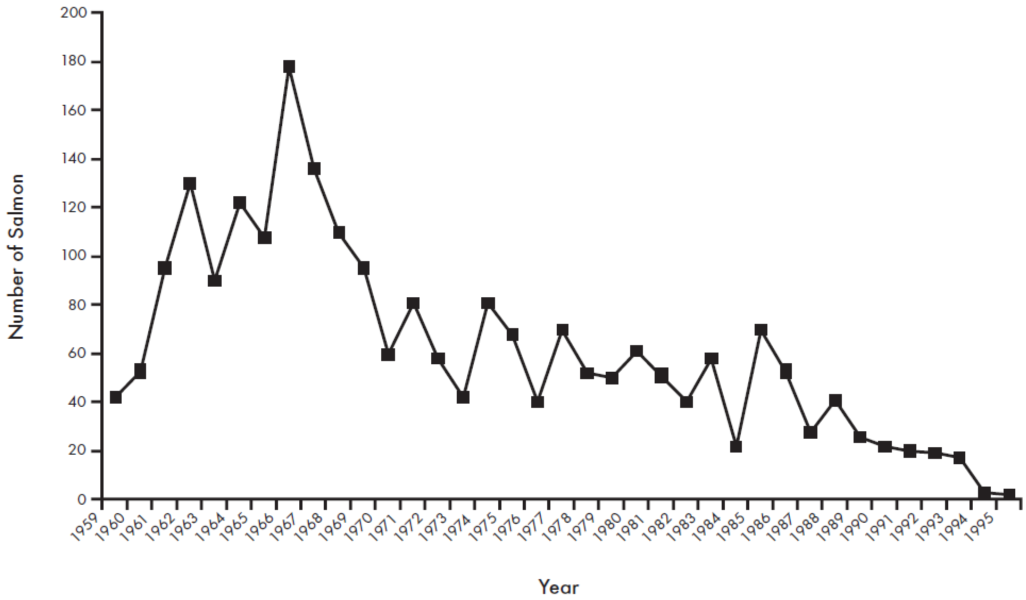

Figure 4: Rod catches from the upper River Bladnoch catchment (Shennanton beat) highlighting the decline of Atlantic salmon in the upper reaches of the River Bladnoch catchment (SNH 2007)

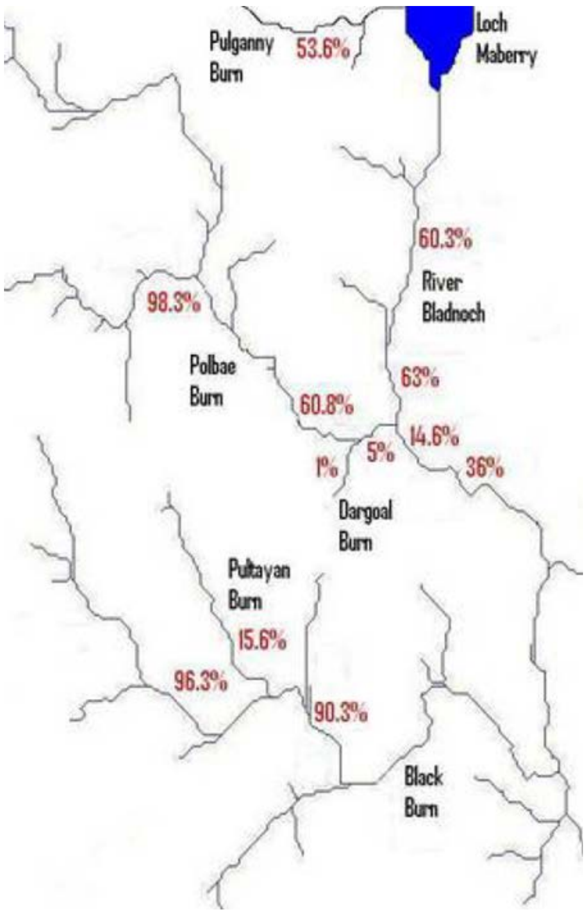

Figure 5: Survival of Atlantic salmon alevin from egg box experiments, with survival rates ranging from 1 - 98.3%. Thus, highlighting areas where Atlantic salmon survival is poor and most likely the result of acidification (GFT, 2008)

2 AIMS

The aim of this report was to:

- Review available data, to determine the distribution of juvenile Atlantic salmon and water quality of the River Bladnoch catchment.
- Review restoration techniques which could be employed to improve water quality and/or Atlantic salmon abundance.
- Provide recommendations for future restoration projects on the upper River Bladnoch catchment.

3 ASSESSING THE CURRENT STATUS OF JUVENILE ATLANTIC SALMON ABUNDANCE AND WATER QUALITY OF THE UPPER RIVER BLADNOCH CATCHMENT

3.1 Distribution of juvenile Atlantic salmon populations in the upper River Bladnoch catchment

3.1.1 Method

The distribution of juvenile Atlantic salmon in the upper River Bladnoch catchment was assessed in 2017 using electrofishing surveys at 16 sampling locations. Electrofishing surveys are an effective method to determine the health of salmonid fish populations. Single run electrofishing surveys were carried out to the Scottish Fisheries Co-ordination Centre's (SFCC) high standards following their set methodology. Thus, enabling the distribution of Atlantic salmon to be established (SFCC, 2018). Surveyed sites were selected based on habitat quality suitable to support juvenile Atlantic salmon and were evenly distributed across the upper catchment.

From electrofishing surveys the age of each Atlantic salmon and the density of Atlantic salmon at each sampling location can be determined. Age determination is often made by examination of the distribution of fork lengths (mm) for each species at each surveyed site. The distribution of fork lengths will often present a break which marks the fork length below which all fish are fry (0+ year class) and fish with a greater fork length are parr (1+ or 1++ year class) (Table 1). If this break is not present due to low salmonid densities best judgement is often used, whereby an experienced biologist can examine the distribution and determine if the salmonid is likely to be a fry or parr. However, it is very difficult to use this technique to determine the age of older fish. Scale samples can be collected, if determining the age of older fish provides vital information.

Once the age of each salmonid had been determined, densities can be calculated. They can then be classified into several density categories. A classification scheme for salmonid densities was previously generated by the SFCC using data collected from 1,638 Scottish electrofishing survey sites between 1997 and 2002 (SFCC, 2006). From this, more accurate local 'density ranges' were calculated from created regional figures. The categories referred to in this report are based on quintile ranges for one-run electrofishing events in the Solway region (Table 2).

However, there are limitations of this scheme. It is based solely on data from surveyed sites containing fish in 1997 to 2002 and refers to regional conditions at that time. It must only be used as a guide and should not be used to draw conclusions. Therefore, the classification of densities should only be used as a relative indication of salmonid population densities.

Table 1: Salmonid age classifications

Atlantic salmon Fry (0+):	Juvenile fish less than one year old as a result of spawning at the end of 2016
Brown trout Fry (0+):	Juvenile fish less than one year old as a result of spawning at the end of 2016
Atlantic salmon Parr: (1+ and older (1++))	Juvenile fish greater than one year as a result of spawning in 2015 or before
Brown trout Parr: (1+ and older (1++))	Juvenile fish greater than one year as a result of spawning in 2015 or before. Brown trout up to three or four years old are also included in this category

Table 2: Quintile ranges for juvenile salmonid densities (per 100 m²) based on one-run electrofishing events, calculated on densities >0 over 291 sites in the Solway Statistical Region

	Salmon 0+	Salmon 1++	Trout 0+	Trout 1++
Minimum (Very Low)	0.22	0.38	0.38	0.35
20th Percentile (Low)	5.21	2.86	4.14	2.27
40th Percentile (Moderate)	12.68	5.87	12.09	4.71
60th Percentile (High)	25.28	9.12	26.63	8.25
80th Percentile (Very High)	46.53	15.03	56.49	16.28

3.1.2 Results

The 16 sampling locations were surveyed in October 2017. Using the fork length of individual Atlantic salmon and the electrofished area of the survey site (m²), the density of Atlantic salmon per 100 m² was calculated (Table 3). The distribution of Atlantic salmon was the focus of this study as acidification has a detrimental impact on juvenile Atlantic salmon. For detailed electrofishing results for Atlantic salmon and Brown trout see Appendix 1.

Atlantic salmon fry are a particularly sensitive life stage to acidification. Understanding their distribution can provide key insights into the reproductive success of Atlantic salmon in an area. During this study, Atlantic salmon fry (Figure 6) were found at moderate to high densities between site 1 (19.48 Atlantic salmon per 100 m²) and site 5 (29.94 Atlantic salmon per 100 m²) on the River Bladnoch (Figure 6; Table 3). Atlantic salmon fry were also found at lower densities between site 11 (54.11 Atlantic salmon per 100 m²) and site 14 (8.86 Atlantic salmon per 100 m²) on the Tarf Water (Figure 6; Table 3). However, Atlantic salmon fry were absent from all other electrofishing survey sites in the upper River Bladnoch catchment indicating no recruitment of Atlantic salmon in these areas in 2017. There were two sampling locations, site 13 on the Tarf Water and site 10 in the Black Burn, which had excellent densities of Atlantic salmon fry (90.5 and 54.11 per 100 m² respectively). However, site 13 on the Tarf Water was stocked in spring 2017 with 30 000 unfed Atlantic salmon fry. Therefore, this site would need to be monitored over a five year period to determine if stocking had successfully resulted in natural recruitment of juvenile Atlantic salmon. If successful, it would be expected to find both Atlantic salmon fry and parr present at this sampling location within five years. Stocking at sampling site 13 most likely influenced Atlantic salmon densities at sampling sites 12 and 14 as Atlantic salmon fry dispersed upstream and downstream after stocking.

Understanding the distribution of Atlantic salmon parr can also be used to determine if recruitment of juvenile Atlantic salmon has successfully resulted in a healthy population. Parr are less sensitive than fry to acidification but are adversely affected by acid flushes which are associated with increased levels of toxic aluminium (Evans *et al.,* 2001). During this study, Atlantic salmon parr where found at very low densities (0.68 - 6.95 Atlantic salmon per 100 m²) at all sampling locations on the River Bladnoch, with the exception of sites 5 and 8 (Figure 7; Table 3). Atlantic salmon parr were also found at site 11 (10.31 Atlantic salmon per 100 m²), site 13 (2.59 Atlantic salmon per 100 m²) and site 15 (1.14 Atlantic salmon per 100 m²) at low densities on the Tarf Water (Figure 7; Table 3).

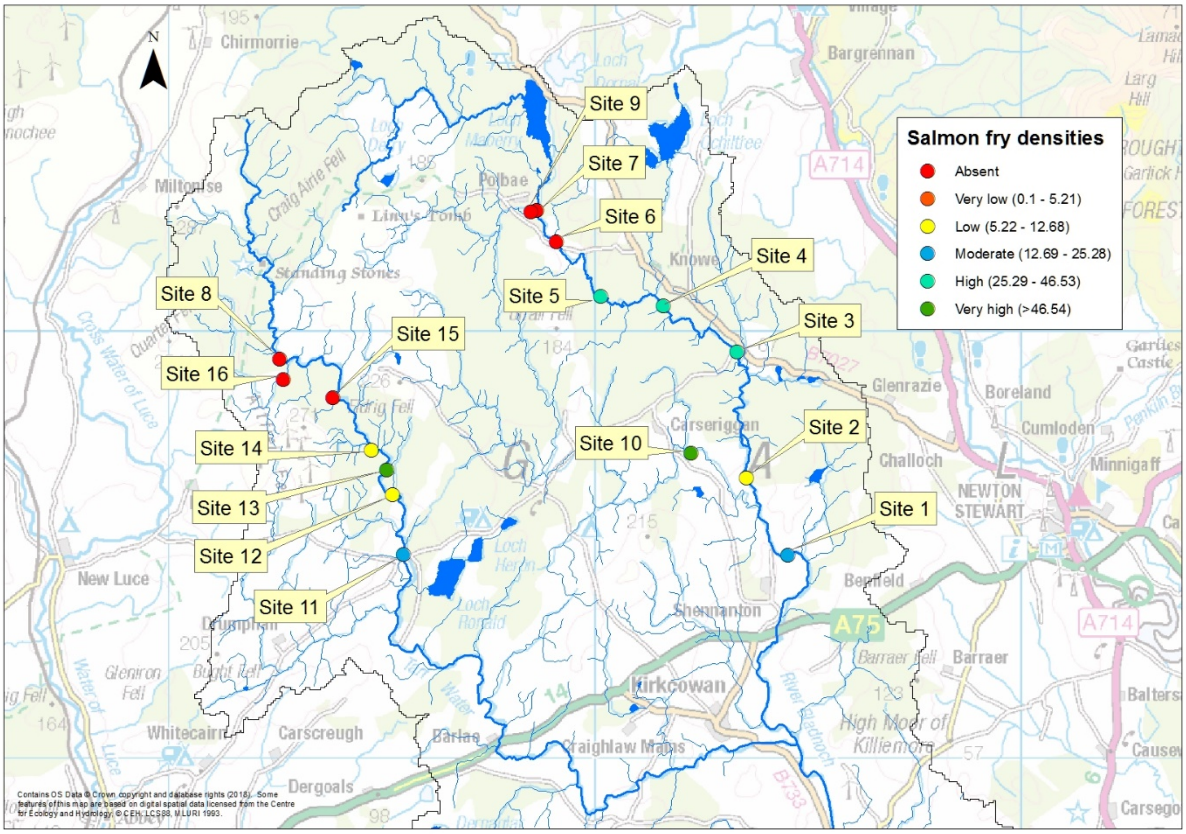

Figure 6: The distribution and density of Atlantic salmon fry at 16 sampling locations in the upper River Bladnoch catchment 2017. See Table 3 for site information

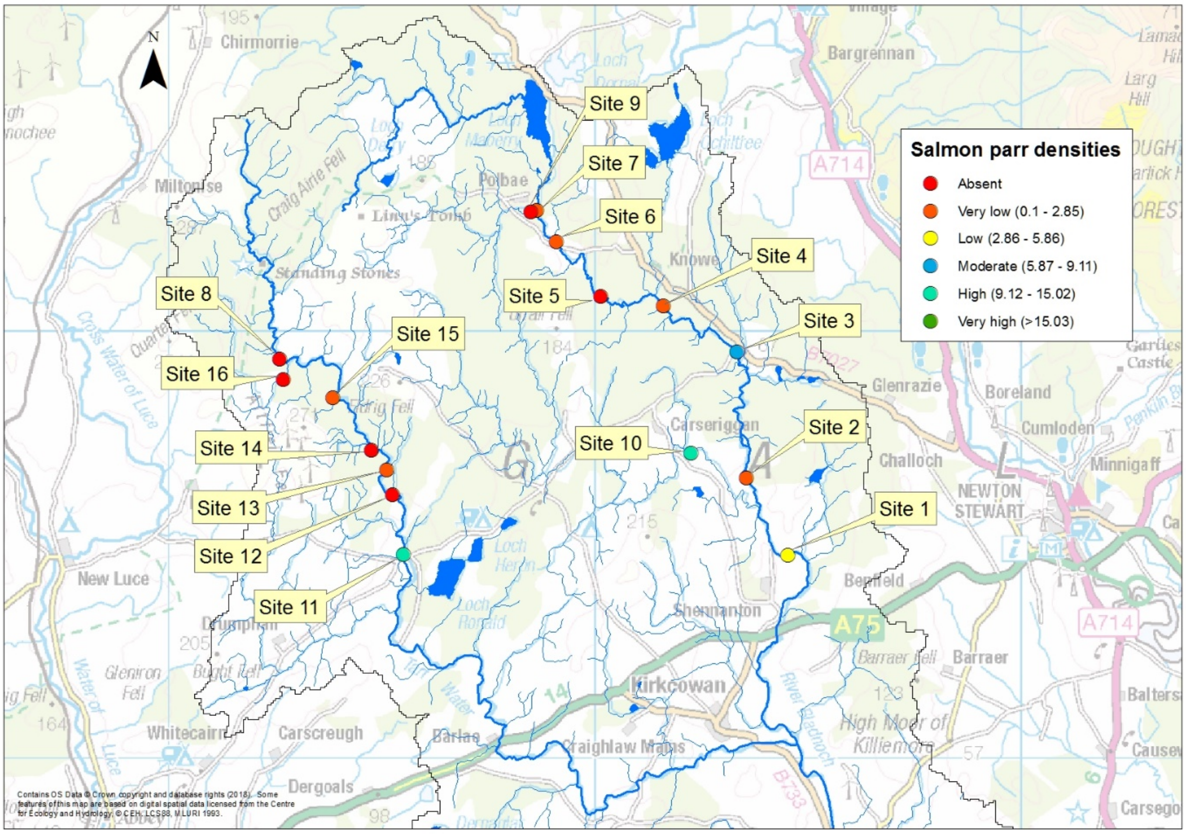

Figure 7: The distribution and density of Atlantic salmon parr at 16 sampling locations in the upper River Bladnoch catchment surveyed in 2017. See Table 3 for site information

Table 3: Density per 100 m^2 of Atlantic salmon fry and parr at 16 sampling sites on the upper River Bladnoch catchment surveyed in 2017. Atlantic salmon and Brown trout were classified as fry and parr based on their fork length (mm). Fry were classed as 0$^+$, which fish are less than a year old (spawning occurred 2016) and parr were classed as 1$^+$ and 1^{++}, which were fish more than a year old (spawning occurred 2015 or before)

				Density per 100 m²			
Site	**Watercourse**	**Grid Ref**	**Survey Date**	**Atlantic salmon Fry (0+)**	**Atlantic salmon Parr (1+ and older)**	**Brown trout Fry (0+)**	**Brown trout Parr (1+ and older)**
1	River Bladnoch	234523 564748	30/10	19.48	5.20	0	0
2	River Bladnoch	233549 566559	30/10	10.92	2.18	3.28	1.09
3	River Bladnoch	233333 569522	18/10	30.59	6.95	0	0
4	River Bladnoch	231600 570600	18/10	31.16	0.68	0.68	0
5	River Bladnoch	230129 570819	18/10	29.94	0	1.58	1.58
6	River Bladnoch	229100 572100	09/10	0	1.59	11.11	3.17
7	River Bladnoch	228625 572831	18/10	0	1.78	16.04	1.78
8	River Bladnoch	222600 569350	09/10	0	0	1.14	6.82
9	River Bladnoch, Polbae Burn	228500 572800	09/10	0	0	2.16	2.16
10	River Bladnoch, Black Burn	232255 567146	30/10	54.11	11.60	0	0
11	River Bladnoch, Tarf Water	225497 564771	18/10	12.89	10.31	12.89	0
12	River Bladnoch, Tarf Water	225246 566167	30/10	10.24	0	7.51	4.78
13	River Bladnoch, Tarf Water	225107 566751	19/10	90.50	2.59	2.59	0
14	River Bladnoch, Tarf Water	224744 567206	19/10	8.86	0	0	0
15	River Bladnoch, Tarf Water	223851 568448	19/10	0	1.14	2.29	0
16	River Bladnoch, Tarf Water, Purgatory Burn	222685 568873	19/10	0	0	0	0

3.1.3 Discussion

This study found Atlantic salmon fry were present at 10 out of 16 sampling locations. Sampling locations surveyed with no juvenile Atlantic salmon were located primarily in the upper reaches of the River Bladnoch and Tarf Water. Understanding if the results presented here are 'typical' for the upper River Bladnoch catchment is vital for conclusions to be drawn. Therefore, data collected by GFT during previous electrofishing surveys from 2013 - 2017 at 46 sampling locations was compared with the results from the 16 sampling locations examined in this study (Figures 8 & 9; Table 4). The results from previous electrofishing surveys showed similar results to the electrofishing surveys conducted for this study. Healthy populations of Atlantic salmon fry were located in the lower reaches of the upper River Bladnoch catchment. Whereas, Atlantic salmon fry were absent from the upper reaches of the upper River Bladnoch catchment (Figure 8). A similar picture can be seen when comparing Atlantic salmon parr densities from previous electrofishing surveys and electrofishing surveys conducted for this report (Figure 9). Sampling locations in the lower reaches of the upper River Bladnoch catchment typically have moderate to high densities of Atlantic salmon parr. However, again in the upper reaches Atlantic salmon parr are absent or at very low densities. Thus, the distribution of Atlantic salmon fry and parr suggests recruitment of Atlantic salmon may be unsuccessful in the headwaters of the catchment. This could be linked to acidification of the upper River Bladnoch catchment, as it has been previously shown the primary effect of acidification is recruitment failure. This will ultimately result in extinction of Atlantic salmon populations from areas affected by acidification. Therefore, further investigations would be needed to investigate whether acidification and other anthropogenic impacts are affecting Atlantic salmon survival in the upper River Bladnoch catchment.

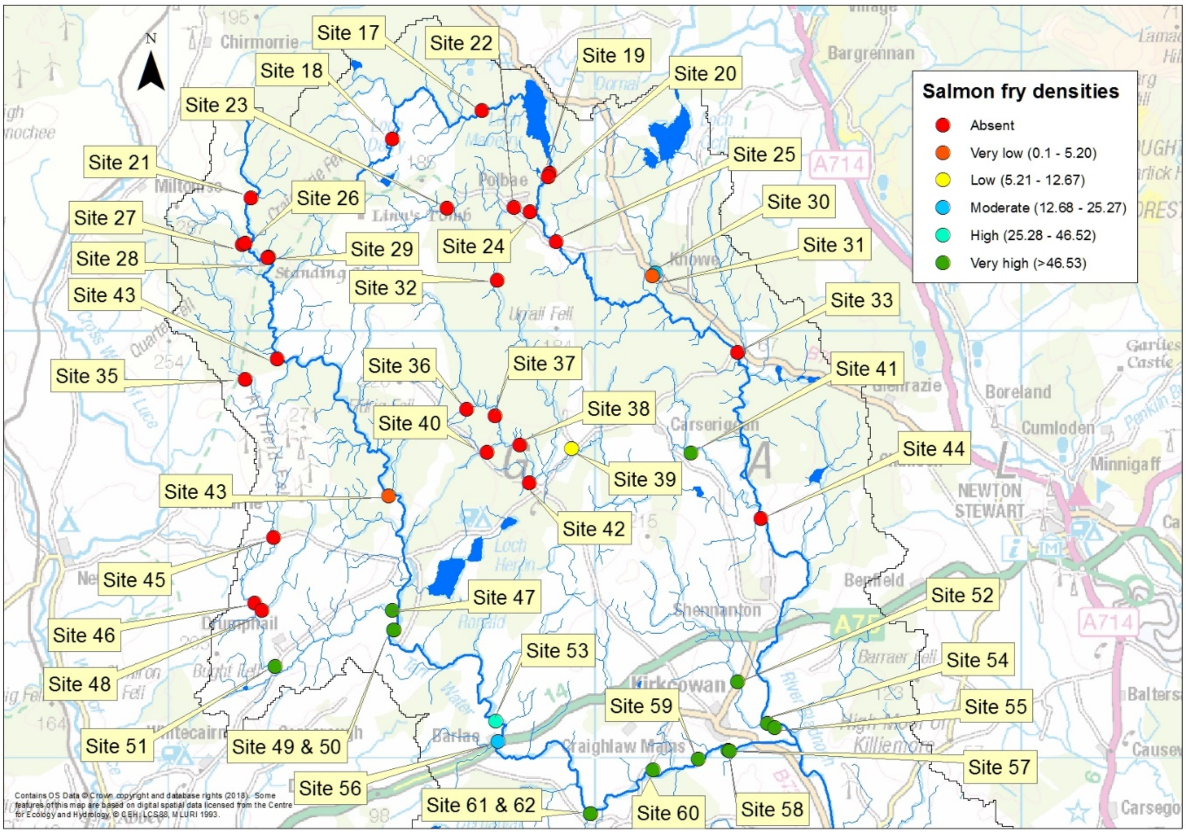

Figure 8: Distribution of Atlantic salmon fry in the upper River Bladnoch catchment, based on previous electrofishing surveys at 46 sampling locations conducted by GFT between 2013 and 2017. See Table 4 for site information

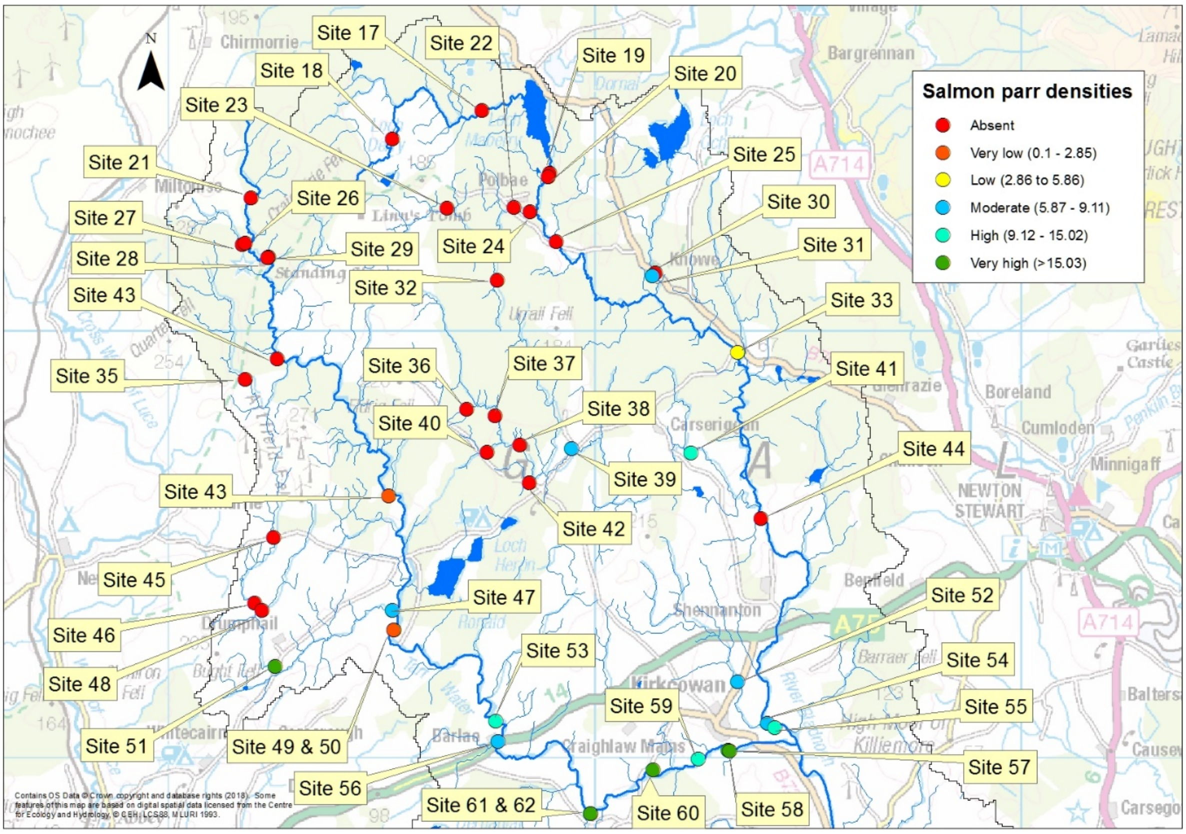

Figure 9: Distribution of Atlantic salmon fry in the upper River Bladnoch catchment, based on previous electrofishing surveys conducted at 46 sampling locations by GFT between 2013 and 2017. See Table 4 for site information

Table 4: Density per 100 m² of Atlantic salmon fry and parr at 46 sampling sites on the upper River Bladnoch catchment. Previous electrofishing surveyed were conducted by GFT between 2013 and 2017

Site	Watercourse	Grid Ref	Survey Date	Density per 100 m²			
				Atlantic salmon Fry (0+)	**Atlantic salmon Parr (1+ and older)**	**Brown trout Fry (0+)**	**Brown trout Parr (1+ and older)**
17	River Bladnoch Pulganny Burn	227350 575180	15/09/2017	0	0	22.9	4.29
18	River Bladnoch, Libberland Burn	225245 574513	15/09/2017	0	0	105.15	10.99
19	River Bladnoch	228931 573700	19/07/2013	0	0	12.32	1.54
20	River Bladnoch	228900 573620	09/10/2017	0	0	1.14	6.82
21	Tarf Water	221940 573130	30/08/2017	0	0	34.53	4.93
22	River Bladnoch, Polbae Burn	228100 572900	31/07/2014	0	0	0	2.95
23	River Bladnoch, Polbae Burn	226532 572793	09/07/2015	0	0	15.62	10.41
24	River Bladnoch Polbae Burn	228474 572793	09/07/2015	0	0	0	3.71
25	River Bladnoch	229100 572100	31/07/2014	0	0	2.72	1.09
26	Tarf Water	221800 572070	16/09/2016	0	0	32.18	7.15
27	River Bladnoch, Ring Burn	221718 572037	30/08/2017	0	0	63.54	14.66
28	Tarf Water	222340 571732	16/09/2016	0	0	0	1.41
29	Tarf Water	222330 571720	30/08/2017	0	0	0.84	2.53
30	River Bladnoch, Beoch Burn	231419 571360	09/07/2015	16.57	0	24.22	2.55
31	River Bladnoch, Beoch Burn	231350 571300	07/07/2014	1.15	8.05	11.51	0
32	River Bladnoch, Dargoal Burn	227700 571200	19/07/2013	0	0	0	0
33	River Bladnoch	233352 569504	24/07/2015	0	5.07	254	0
34	Tarf Water	222550 569340	15/09/2017	0	0	0	1.5
35	Tarf Water, Purgatory Burn	221790 568870	04/09/2017	0	0	0	0
36	River Bladnoch, Black Burn, Un-named tributary	226990 568167	12/08/2015	0	0	0	0

37	River Bladnoch, Black Burn	227665 568010	18/08/2017	0	0	68.15	13.63
38	River Bladnoch, Black Burn	228236 567334	18/08/2017	0	0	22.88	20.47
39	River Bladnoch, Black Burn	229450 567250	19/07/2013	6.58	6.58	11.84	1.32
40	River Bladnoch, Black Burn, un-named tributary	227474 567168	18/08/2017	0	0	88.02	22.47
41	River Bladnoch, Black Burn	232255 567146	30/10/2016	54.12	11.6	0	0
42	River Bladnoch, Black Burn, unnamed tributary	228464 566435	18/08/2017	0	0	11.76	2.94
43	Tarf Water	225161 566130	10/07/2014	2.37	2.37	54.48	2.37
44	River Bladnoch	233900 565600	20/08/2013	0	0	0	0
45	Tarf Water, Drumpail Burn	222461 565160	24/08/2017	0	0	16.28	12.21
46	Tarf Water, Drumpail Burn	222022 563622	22/08/2017	0	0	0	0
47	Tarf Water, Drumpail Burn	225255 563451	22/08/2017	243.09	6.69	0	0
48	Tarf Water, Drumpail Burn, un-named tributary	222194 563450	22/08/2017	0	0	0	2.95
49	Tarf Water	225274 562982	24/08/2017	176.01	21.05	1.91	0
50	Tarf Water	225274 562982	23/07/2015	131.34	1.99	1.99	0
51	Tarf Water, Drumpail Burn	222503 562139	22/08/2017	98.21	38.69	14.88	0
52	River Bladnoch, Barhoise Burn	233347 561773	09/07/2015	60.63	7.82	89.97	29.34
53	Tarf Water	227666 560800	24/07/2015	37.34	11.59	0	0
54	River Bladnoch	234050 560856	21/08/2013	218.45	6.62	15.45	
55	River Bladnoch	234213 560692	07/10/2016	115.66	9.64	1.61	0
56	Tarf Water	227718 560379	07/10/2016	17.58	7.33	0	0
57	Tarf Water	233122 560170	09/08/2013	68.95	31.45	3.63	4.84
58	Tarf Water	233165 560152	09/08/2013	147	37.27	12.42	0
59	Tarf Water	232433 559972	07/10/2016	64.18	9.79	4.35	1.09
60	Tarf Water	231358 559715	08/08/2013	213.67	40.98	0	0
61	Tarf Water	229900 558686	07/10/2016	65.27	15.15	0	1.17
62	Tarf Water	229898 558681	24/07/2015	104.4	15.91	0	0

3.2 Water quality of the upper River Bladnoch catchment

3.2.1 Method

There are many methods which can be used to access water quality. However, the two methods used to assess whether watercourses are acidified in this study were: constant water quality monitoring and spot sampling. Understanding the rate at which the upper River Bladnoch catchment is recovering from past acidification is critical for improving juvenile Atlantic salmon abundance. Water quality monitoring was completed between December 2017 and March 2018. Winter/early spring is a particularly sensitive time of year for Atlantic salmon, as vulnerable life stages (eggs and alevin) occupy rivers when they are most acidic.

Constant water quality monitoring is a technique used to monitor changes in environmental variables over a period of time. An Exo1 sonde was deployed on the River Bladnoch at waterside (Grid reference: 228993, 572210) to record pH every 15 minutes and remained in situ between 16 December 2017 and 4 April 2018 (Figure 10). The pH probe was calibrated once a month to ensure accurate readings and the sonde was calibrated once every three months to ensure all other probes were working correctly.

The second technique used was spot sampling which was used to understand spatial changes in water quality on the upper River Bladnoch catchment. Spot sampling can also be used to highlight areas where pH is a concern for juvenile Atlantic salmon. Twenty sampling locations were chosen from across the upper River Bladnoch catchment to cover all major tributaries and both main stem rivers (River Bladnoch and Tarf Water) (Table 5). The 20 sampling sites were to be sampled each month from December - March when water levels in the upper River Bladnoch catchment were high (i.e. during flood events) and ideally after a period of dry weather. This criterion was to ensure sampling took place when surface waters are the most acidic. Water quality (or pH) was recorded at each sampling location using an Exo1 sonde which was lowered into the water and remained in position until a stable reading pH reading could be recorded.

Figure 10: Constant water quality monitoring at Waterside (Grid reference: 228993 572210). Exo1 sonde is housed in a pipe and secured to the river bank to remain in situ for several months

3.2.2 Results

Constant water quality monitoring was used to highlight key periods when pH fell below pH 5, the critical pH below which is detrimental for juvenile Atlantic salmon survival. It has been demonstrated that a high number of mortalities of juvenile Atlantic salmon are expected when pH falls below pH 5 (Peterson *et al.,* 1980). During December, the average pH was 5.12 with a minimum pH of 4.70 (recorded 15/12/17) and a maximum pH of 5.77 (recorded 11/12/2017) (Figure 11). Over the month of December, pH was recorded at or below the critical pH for juvenile Atlantic salmon (pH 5) 31.5% of the time. During January, the average pH was 5.00 with a minimum pH of 4.63 (recorded 03/01/2018) and a maximum pH of 5.37 (recorded 10/01/2018) (Figure 12). Over the month of January, pH was recorded at or below the critical pH for juvenile Atlantic salmon 56.5% of the time. During February, the average pH was 5.18 with a minimum pH of 4.69 (recorded 11/02/2018) and a maximum pH of 5.71 (recorded 28/02/2018) (Figure 13). Over the month of February, pH was recorded at or below the critical pH for juvenile Atlantic salmon 23.6% of the time. Finally during March, the average pH was 5.57 with a minimum pH of 4.81 (recorded 23/03/2018) and a maximum pH of 6.09 (recorded 06/03/2018) (Figure 14). Over the month of March, pH was recorded at or below the critical pH for juvenile Atlantic salmon 2.0% of the time.

The second technique used during this study to monitor water quality was spot sampling. Spot sampling was used to investigate spatial variation in pH and highlight areas of concern for juvenile Atlantic salmon survival. Initially, the aim of this study was to use spot sampling to record pH every month from December - March when water levels were high during floods. However, this was not always possible due to the timing these floods. Therefore, spot sampling was completed in December and March as water levels were decreasing. Although pH recorded would not be the lowest possible pH, spatial variation of pH could be investigated.

During December, pH ranged from 4.09 - 7.3, with sampling locations at the headwaters of the catchment having a lower pH than sampling locations further down the catchment (Figure 15; Table 5). The majority of sampling locations had a pH greater than 5.5 which is above the critical threshold for Atlantic salmon. However, eight sampling locations had a pH less than 5.5, with four sampling locations (Polbae Burn, Polbae Burn outflow, Dargoal Burn and Mulniegarroch of Pulgatory Burn) having a pH less than 5. As has previously been discussed, pH between 4.5 and 5 are detrimental for juvenile Atlantic salmon and often results in mortalities (Peterson *et al.,* 1980). December, is a critical month for Atlantic salmon as eggs incubate in gravel redds.

During March, pH ranged from 4.74 - 6.53, again with sampling locations at the headwaters of the catchment having a lower pH than sampling locations further down the catchment (Figure 16; Table 5). The vast majority of sampling locations had a pH above pH of 5.5. However, six sampling locations had a pH below 5.5, with one sampling location (tributary of the Polbae Burn) recording a pH below 5.

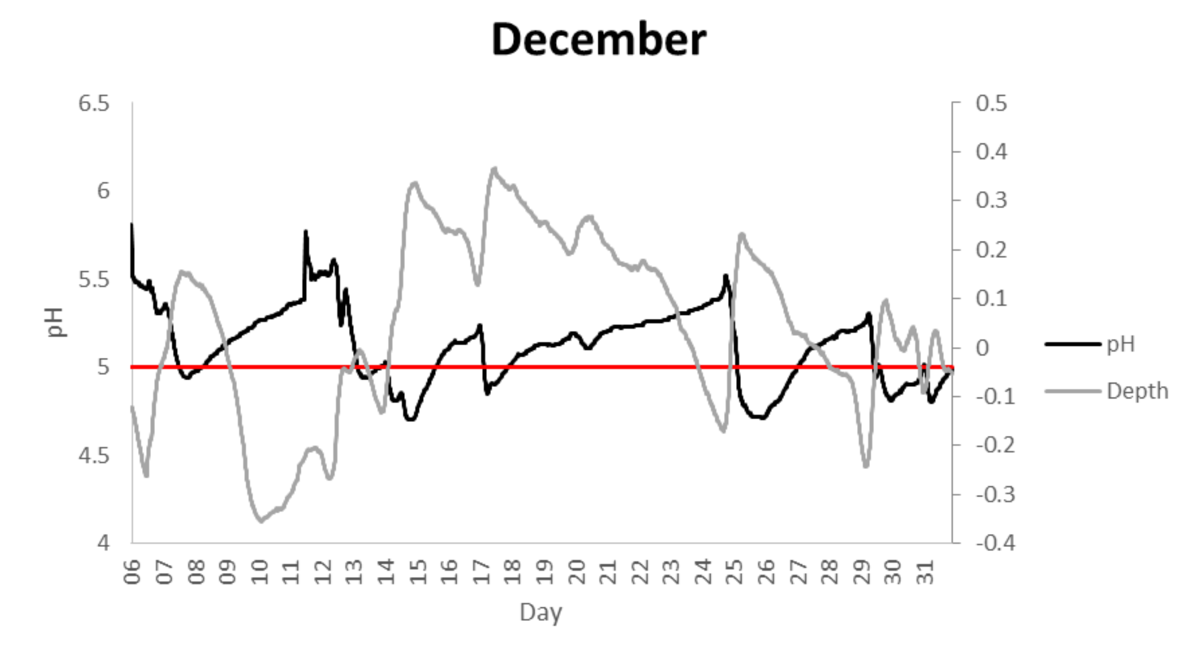

Figure 11: Time series graph from constant monitoring of pH (black line) and depth (grey line) during December 2017. Red line is the critical pH below which is detrimental for juvenile Atlantic salmon. As can be seen from the graph, pH and depth are correlated. As depth increases as a result of increased precipitation, as rain and snow melt, a greater volume of pollutants are deposited into surface waters and pH decreases (in other words becomes more acidic)

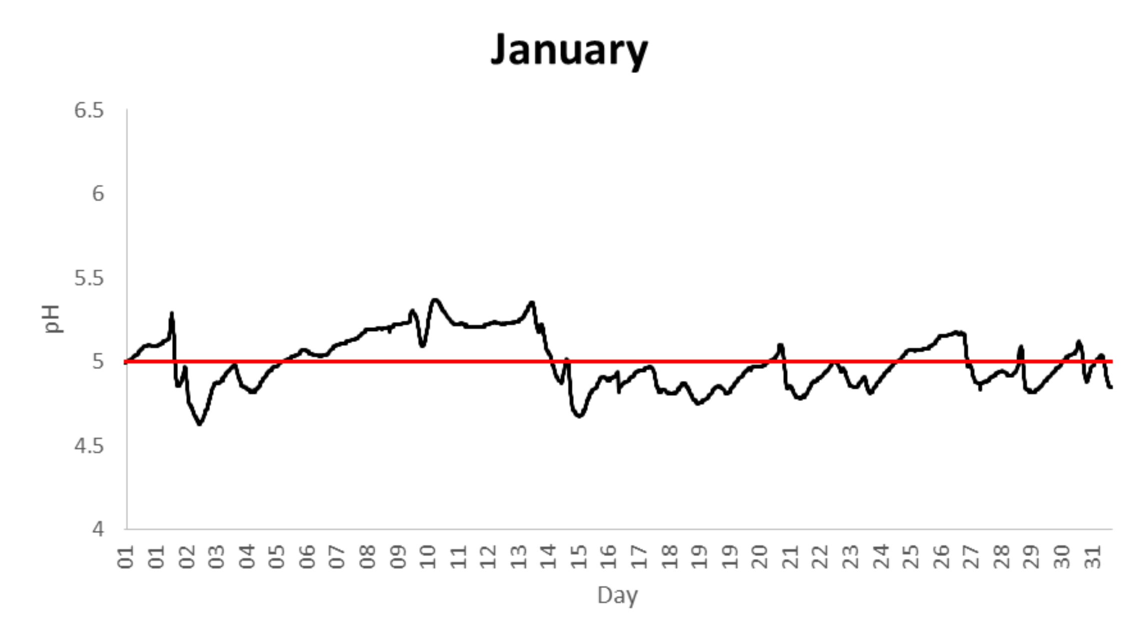

Figure 12: Time series graph from constant monitoring of pH during January 2018. Red line is the critical pH below which is detrimental for juvenile Atlantic salmon

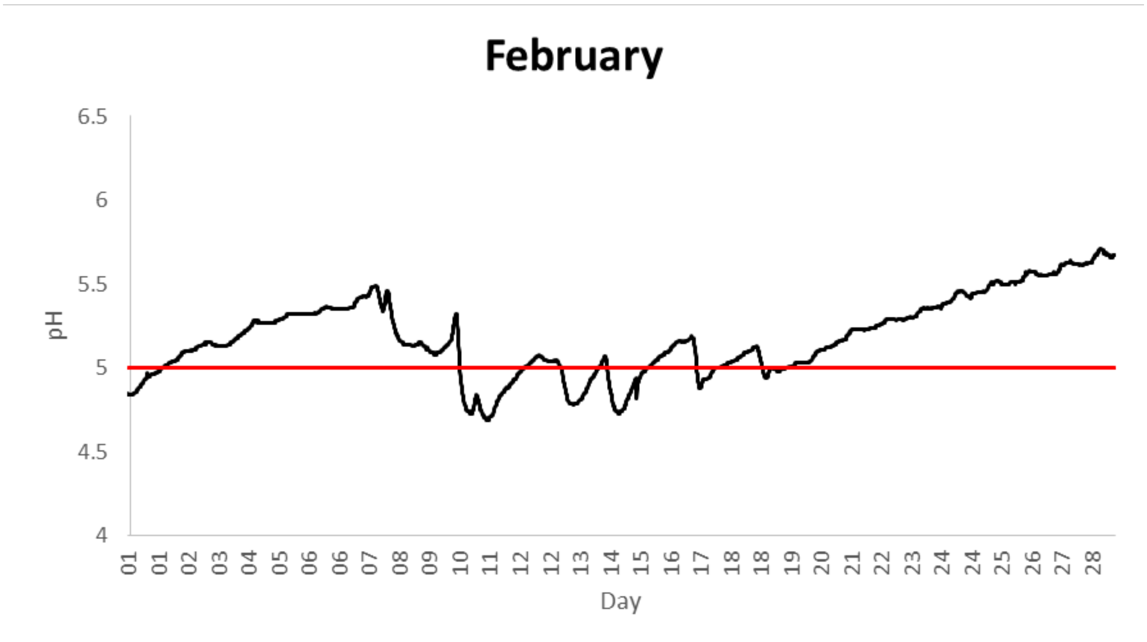

Figure 13: Time series graph from constant monitoring of pH during February 2018. Red line is the critical pH below which is detrimental to juvenile Atlantic salmon

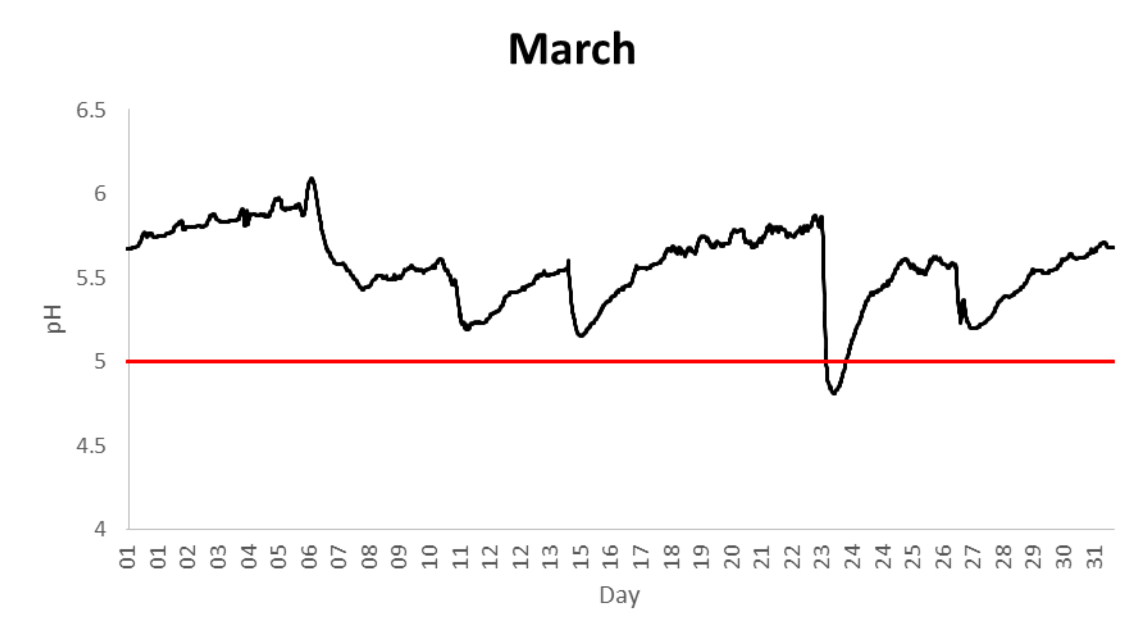

Figure 14: Time series graph from constant monitoring of pH (during March 2018). Red line is the critical pH below which is detrimental to juvenile Atlantic salmon

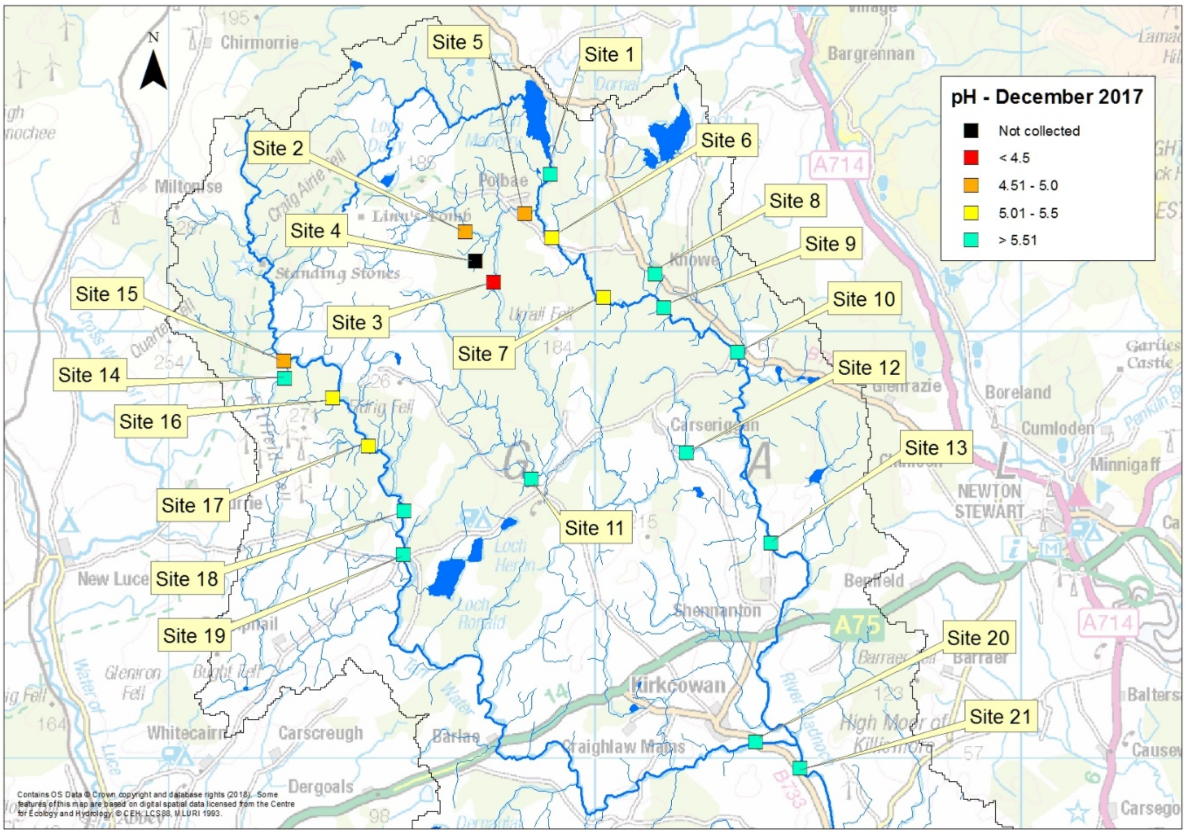

Figure 15: Spot sampling at 20 sampling locations in December 2017

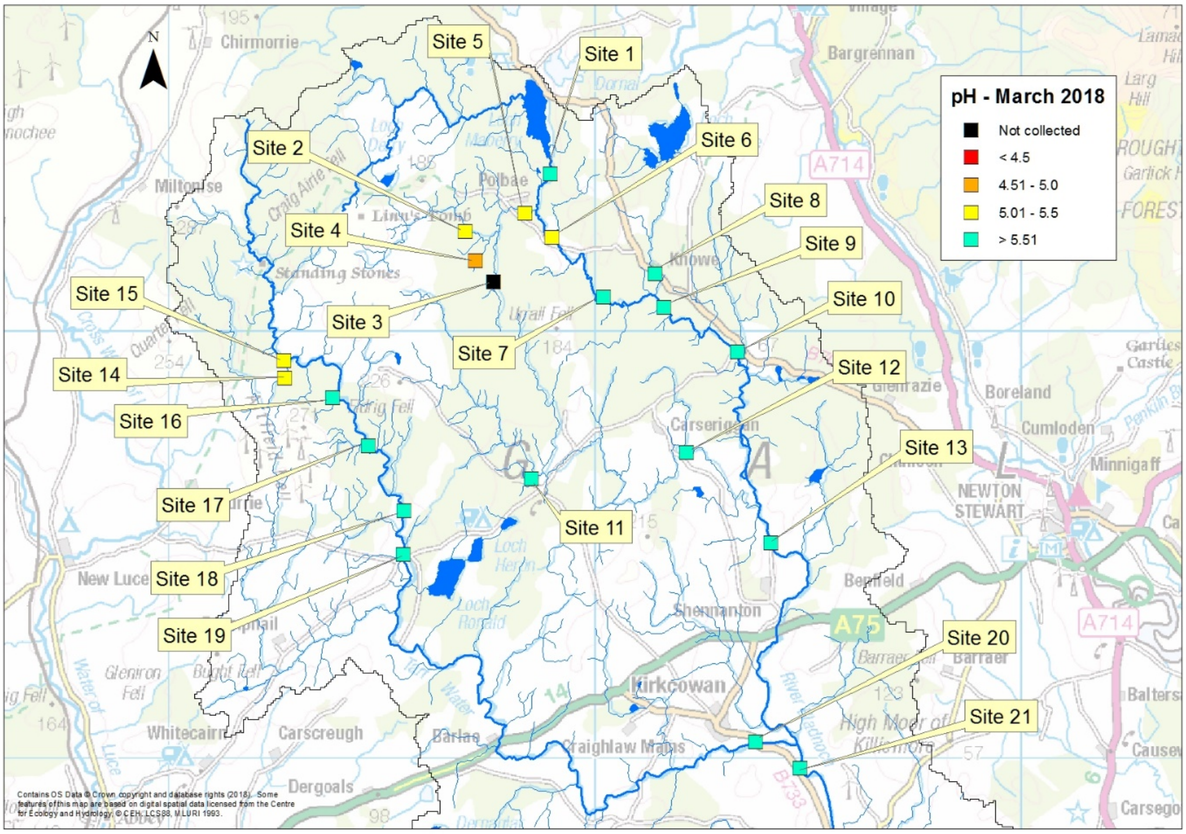

Figure 16: Spot sampling at 20 sampling locations in March 2018

Table 5: Spot sampling at 20 sampling locations in December 2017 and March 2018. Note sampling location 3A was sampled in March 2018 instead of sampling location 3 because sampling location 3 could not be accessed

Site	Watercourse	Site Location	Grid Ref	pH December	pH March
1	River Bladnoch	Outflow of Loch Maberry at forestry track bridge	228947 573681	5.7	5.94
2	River Bladnoch, Polbae Burn	Just off forestry track down steep banking	226960 574340	4.89	5.13
3	River Bladnoch, Dargoal Burn	Forestry track bridge	227631 571154	4.09	N/A
3A	River Bladnoch, Polbae Burn, unnamed tributary	Forestry track bridge	227201 576150	N/A	4.74
4	River Bladnoch	Along track towards disused quarries at Polbae	228358 572764	4.76	5.01
5	River Bladnoch	Upstream of Tannylaggie Bridge	228993 572210	5.12	5.29
6	River Bladnoch	End of forestry track at Millgrain Hill	230197 570798	5.44	5.51
7	River Bladnoch, Beoch Burn	Knowe Bridge	231415 571348	6.07	6.03
8	River Bladnoch	Through field at Barchessie	231629 570561	5.73	5.69
9	River Bladnoch	Glassoch Bridge	233347 569513	5.75	5.66
10	River Bladnoch, Black Burn	Next to Aires Windfarm	228505 566547	6.02	5.85
11	River Bladnoch, Black Burn	Downstream of Black Burn Bridge	232145 567165	6.54	6.23
12	River Bladnoch	At Metal Bridge at Shennanton	234134 565041	7.3	6.23
13	River Bladnoch, Tarf Water	Downstream from Horse Hill	222717 568895	5.52	5.49
14	River Bladnoch, Tarf Water, Mulniegarroch of Pulgatory Burn	Along forest ride at Horse Hill	222702 569314	4.93	5.48
15	River Bladnoch, Tarf Water	Down double forest ride before Horse Hill	223848 568434	5.09	5.99
16	River Bladnoch, Tarf Water	Down forest ride at The Torr	224689 567319	5.35	5.86
17	River Bladnoch, Tarf Water	Artfield at footbridge	225528 565797	5.74	5.89
18	River Bladnoch, Tarf Water	Tarf Bridge	225500 564770	5.51	5.62
19	River Bladnoch, Tarf Water	Kirkcowan downstream of bridge	233768 560372	6.59	6.45
20	River Bladnoch	Upstream of Kirkchrist lodge	234810 559766	6.34	6.53

3.2.3 Discussion

Constant monitoring of pH during winter/early spring is crucial to understand the likely survival rate of juvenile Atlantic salmon. Previous egg box experiments carried out by GFT, demonstrated egg survival varied significantly between locations separated by small geographic distances (Figure 5). The results from these egg box experiments were further supported by both previous electrofishing surveys and electrofishing surveys from this study, which both demonstrated little recruitment of juvenile Atlantic salmon in the upper River Bladnoch catchment. As water quality has been shown to be a factor which affects juvenile Atlantic salmon survival, this study used constant water quality monitoring and spot sampling during winter/early spring to investigate acidification during the most vulnerable months for juvenile Atlantic salmon.

During constant water quality monitoring, pH was found to fluctuate both daily and monthly, with pH falling below pH 5 during acid pulses (Figures 11 - 14). During these fluctuations pH often fell below pH 5 during acid pulses. A surge in surface water acidity, known as an acid pulse, is the result of increased precipitation via rain or snow melt. During the first 30% of snow melt, 50 - 80% of pollutants stored in the snow are released (Schaefer *et al.,* 1990; Evans *et al.,* 2001). Therefore, when pH of surface waters is recorded below pH 5 it would be expected water depth would have increased (Figure 11).

Constant water quality monitoring at waterside demonstrated acid pulses during December, January and February. January had the highest proportion of acidic pulses with pH recorded at or below pH 5 for 56.5% of the month. Examining constant water quality monitoring data collected by Scottish Power Renewables at Kilgallioch Wind Farm (requested for by the Scottish Environmental Protection Agency (SEPA)) between December and March 2015 - 2017 further supports the results from this study. For example, January was highlighted as the month that experienced the most acidic episodes during this study and at Kilgallioch Wind Farm on the Tarf Water, January 2016 recorded the most acidic episodes with a pH at or below pH 5 recorded for 65.8% of the month (Figure 18). Similarly, February at Waterside (River Bladnoch) and Tarf Water were acidified for a large proportion of the month (Figure 19). January and February are crucial months for juvenile Atlantic salmon and acidification would most likely result in high mortalities. Therefore, high mortalities of juvenile Atlantic salmon would be expected as Atlantic salmon eggs incubate in gravel redds and eventually emerge as alevin. Acidification, disrupts the enzyme chorionase from working correctly which would prevent alevin from emerging from the eggs and developing correctly (Peterson *et al.,* 1980). Examining water quality on the Tarf Water also highlighted yearly variation of pH, driven by precipitation and river depth. Constant water quality monitoring on the Tarf Water in 2017 recorded fewer acidic episodes than constant water quality monitoring in 2016 (Figures 17 - 20; Table 6). Thus, further highlighting the importance of monitoring water quality over several years to fully understand the frequency of acidic pulses during winter/early spring.

It is also important to investigate spatial variation in water quality as this would highlight where juvenile Atlantic salmon are unlikely to survive. Therefore, spot sampling was conducted at 20 sampling locations in December 2017 and March 2018 to investigate spatial variability of pH. During this study, pH on the River Bladnoch downstream of Beoch Burn was recorded above pH 5.5 indicating water quality was unlikely to be a limiting factor for the survival of juvenile Atlantic salmon. However, this would need to be confirmed with further water quality sampling. The outflow from Loch Maberry also had a pH above pH 5.5. On the River Bladnoch, the lower Polbae Burn and Dargoal Burn had poor water quality with pH recorded below pH 5. This could have a detrimental impact on juvenile Atlantic salmon survival. As Polbae Burn flows into the main stem of the River Bladnoch the pH is reduced to between 5 - 5.5 (Figure 16 & 17). Therefore, the acidic waters flowing form Dargoal Burn and Polbae Burn have a knock-on-effect on water quality further downstream. Similar results where demonstrated on the Tarf Water with all except one sampling location, Mulgiegarroch of

Pulgatory Burn, recording a pH of 4 - 5.5, which again could have a detrimental impact on populations of juvenile Atlantic salmon. The results from this study were further supported by water quality sampling carried out by Forest Enterprise in 1998 - 2016 (Table 7). Forest Enterprise demonstrated the lower Polbae Burn and Dargoal Burn where the most acidified watercourse. Examining the average pH of each sampling location between years showed slight fluctuations in pH but acidified watercourses remained acidified. For example, Dargoal Burn, sampled by the forestry commission 2009 - 2016 and sampled during this study, always recorded a pH below 4.5.

Due to temporal fluctuations in pH constant water quality monitoring is often used to establish the frequency of acidic episodes. However, another powerful tool which can be used for water quality monitoring is to examine changes in macroinvertebrate communities. SEPA have been monitoring water quality using presence and absence of acid sensitive macroinvertebrate species. The results of SEPA's long term water quality monitoring support the results found in this study with Polbae Burn being classified as acidified, the River Bladnoch at Waterside being classed as vulnerable to acidification and the River Bladnoch at Glassoch Bridge un-acidified (Bell *et al.,* 2014). Therefore, water quality improvement works should focus on the headwaters of the River Bladnoch and Tarf Water. Specifically, Dargoal Burn, Polbae Burn and Mulniegaroch of Purgatory Burn as the acidification from these watercourses has a continued effect on water quality further downstream in both main stem rivers.

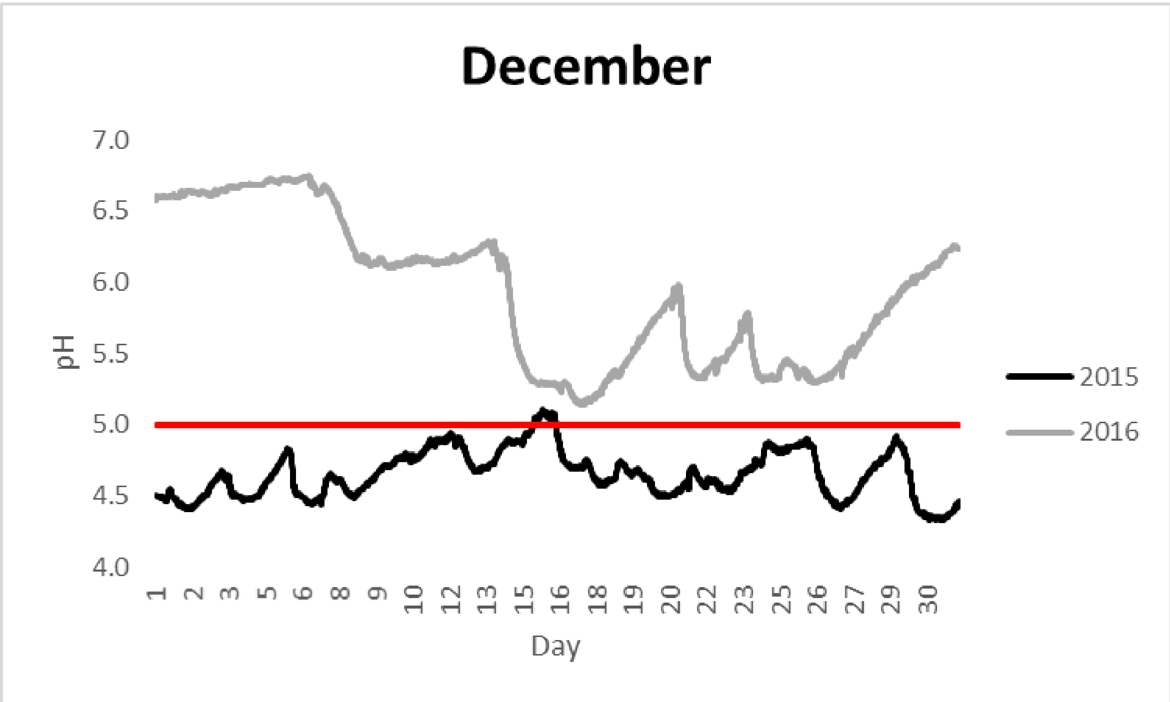

Figure 17: Time series graph from constant monitoring of water quality at Kilgallioch Wind Farm demonstrating fluctuations of pH 2015 (black line) and 2016 (grey line) during December. Red line is the critical pH below which is detrimental to juvenile Atlantic salmon. This graph highlights the temporal variability of pH with some years recording a lower pH than others

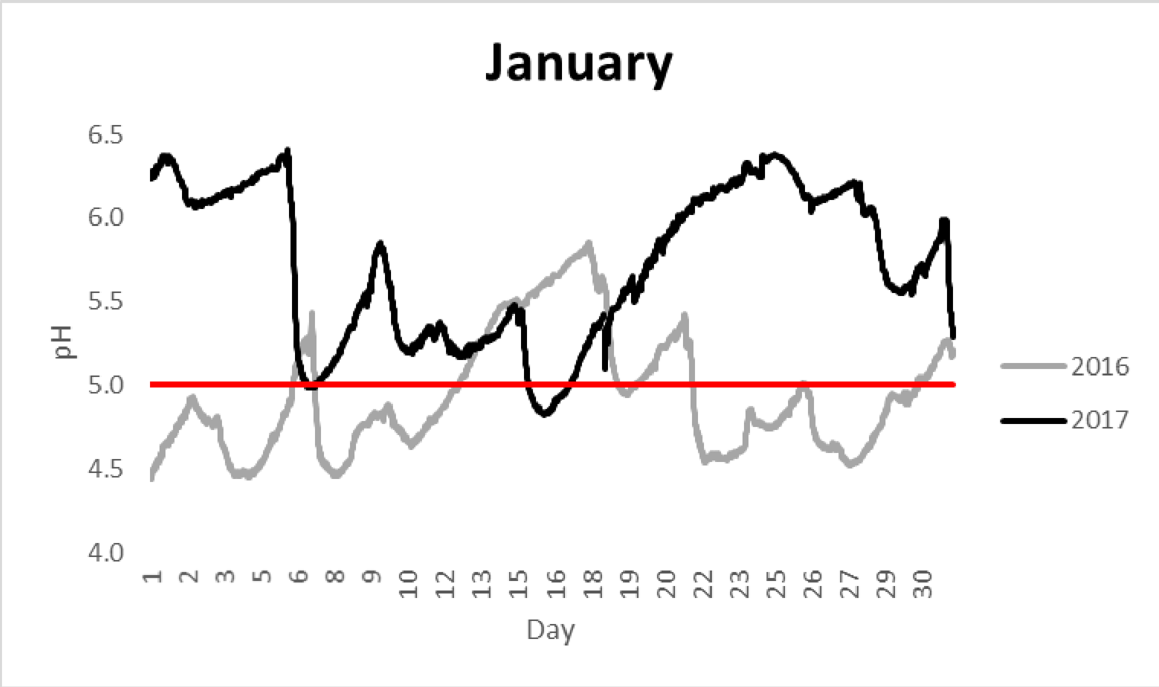

Figure 18: Time series graph from constant monitoring of water quality at Kilgallioch Wind Farm demonstrating fluctuations of pH 2016 (grey line) and 2017 (black line) during January. Red line is the critical pH below which is detrimental to juvenile Atlantic salmon

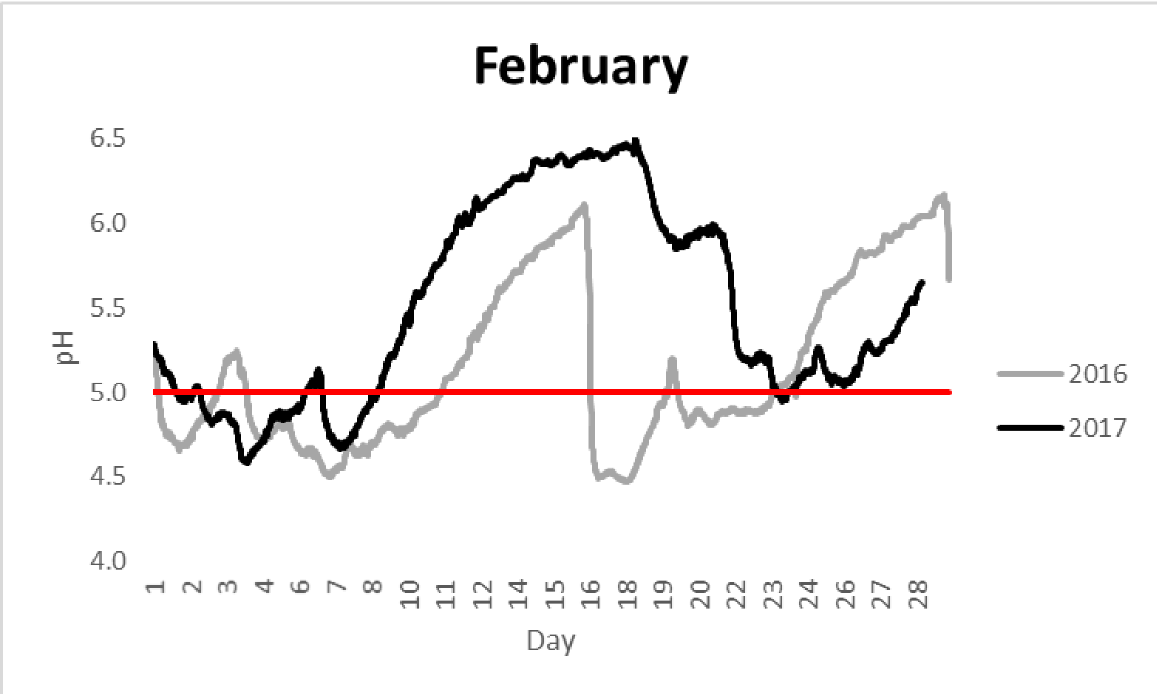

Figure 19: Time series graph from constant monitoring of water quality at Kilgallioch Wind Farm demonstrating fluctuations of pH 2016 (grey line) and 2017 (black line) during February. Red line is the critical pH below which is detrimental to juvenile Atlantic salmon

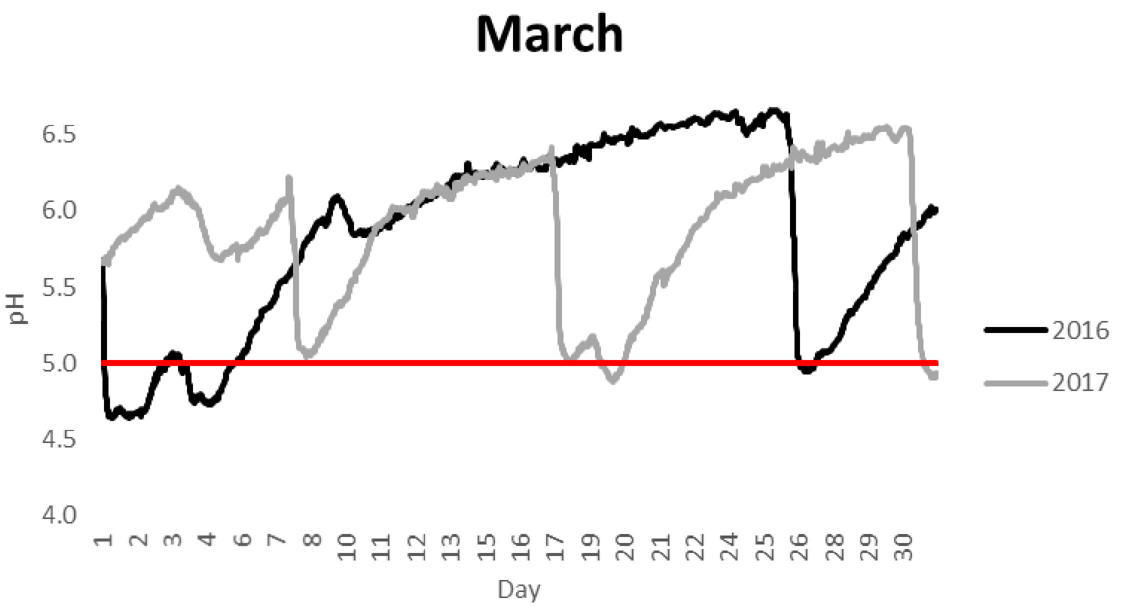

Figure 20: Time series graph from constant monitoring of water quality at Kilgallioch Wind Farm demonstrating fluctuations of 2016 (grey line) and 2017 (black line) during March. Red line is the critical pH below which is detrimental to juvenile Atlantic salmon

Table 6: Constant water quality monitoring on the Tarf Water by Scottish Power Renewables. The table displays the minimum, maximum and average pH (±SD) for December - March 2016+2017

	2015/2016			2016/2017		
	Minimum pH	**Maximum pH**	**Average pH**	**Minimum pH**	**Maximum pH**	**Average pH**
December	4.66	5.11	4.33±0.17	4.81	6.22	5.61±0.41
January	4.44	5.85	4.94±0.36	4.82	6.41	5.73±0.46
February	4.47	6.17	5.15±0.49	4.58	6.53	5.50±0.58
March	4.64	6.66	5.85±0.63	4.88	6.56	5.89±0.45

Table 7: Data collected by Forest Enterprise at four sampling locations in the upper River Bladnoch catchment from 1998 to 2016. Sampling locations were sampled on the same day each month, regardless of river height

Site	Watercourse	Minimum pH	Maximum pH	Average pH
1	Dargoal Burn	3.85	5.93	4.31± 0.36
2	Loch Maberry outflow	4.17	6.40	5.41± 0.52
3	Polbae Burn	3.88	7.57	5.57± 0.92
4	River Bladnoch at Waterside	4.35	6.68	5.31± 0.52

3.3 What does the electrofishing surveys and water quality monitoring tell us?

Acidification of watercourse has been shown to result in high mortalities of juvenile and smolting Atlantic salmon (Peterson *et al.,* 1980). Acidification, whereby pH falls below pH 5, disrupts eggs from hatching, alevin from developing properly and the metamorphosis of smolts (Grassie *et al.,* 2013). Therefore, it is vital to understand which areas of the upper River Bladnoch catchment are affected by acidification and the current abundance of juvenile Atlantic salmon in these areas. Areas which experience short term acidic flushes may support juvenile Atlantic salmon populations but juvenile Atlantic salmon populations are likely to be absent from areas with a high frequency of acid flushes.

During this study, electrofishing results demonstrated there was no recruitment of juvenile Atlantic salmon in the upper reaches of the River Bladnoch and Tarf Water in 2017. When this result is compared to water quality spot sampling results, it can be seen that these areas also have a low pH and are subject to acidification (Figures 6, 8 & 15). Electrofishing results from the mid reaches of the catchment also showed moderate to low juvenile Atlantic salmon densities. Water quality spot sampling results demonstrated these areas also had a higher pH, which pH ranging from 5.66 - 6.07. However, as was demonstrated by constant water quality monitoring, pH fluctuates daily and so acidic flushes could be preventing an increase in juvenile Atlantic salmon abundance in these areas. Therefore, the reasons for acidification in the upper River Bladnoch catchment needs to be addressed, as well as, examining other factors, such as habitat availability and barriers to migration, which could explain the absence of juvenile Atlantic salmon in the upper River Bladnoch catchment.

4 DRIVERS OF ACIDIFICATION OF THE UPPER RIVER BLANDOCH CATCHMENT

During the industrial resolution there was a rapid increase in emission of pollutants. However, it was recognised that these emissions were driving acidification of watercourses across Europe and legislation was formed with the aim of significantly reducing atmospheric emissions of pollutants, as (Evans *et al.,* 2001). As a result, emission in the UK were reduced by an estimated 75% and water chemistry analysis demonstrated watercourse in Galloway began to recover from acidification (Evans *et al,* 2001). However, the upper River Bladnoch catchment has not recovered as quickly as other catchments in Galloway and the upper River Bladnoch catchment remains acidified. There are several natural and anthropogenic factors which have led to the acidification of the upper River Bladnoch catchment. These include the underlying geology of the catchment, afforestation and peatland degradation.

4.1 Geology

Galloway is an acid sensitive area due to its underlying geology and soil composition (Evans *et al.,* 2001). It is comprised of three main geological units, Tertiary age granitic intrusions and Ordovician and Silurian age shales, mudstones and greywacke, which all have a low buffering capacity to neutralise acidic precipitation (Evans *et al.,* 2001). These main geological units divide Galloway with the north being predominantly Ordovivian age and the south predominantly Silurian age (Figure 21) (McMilan & Stone 2008). Therefore, the underlying geology of the upper River Bladnoch catchment is acid sensitive with a poor buffering capacity to neutralise acidic precipitation. Acidification of the upper River Bladnoch catchment has been further exacerbated by afforestation and peatland degradation.

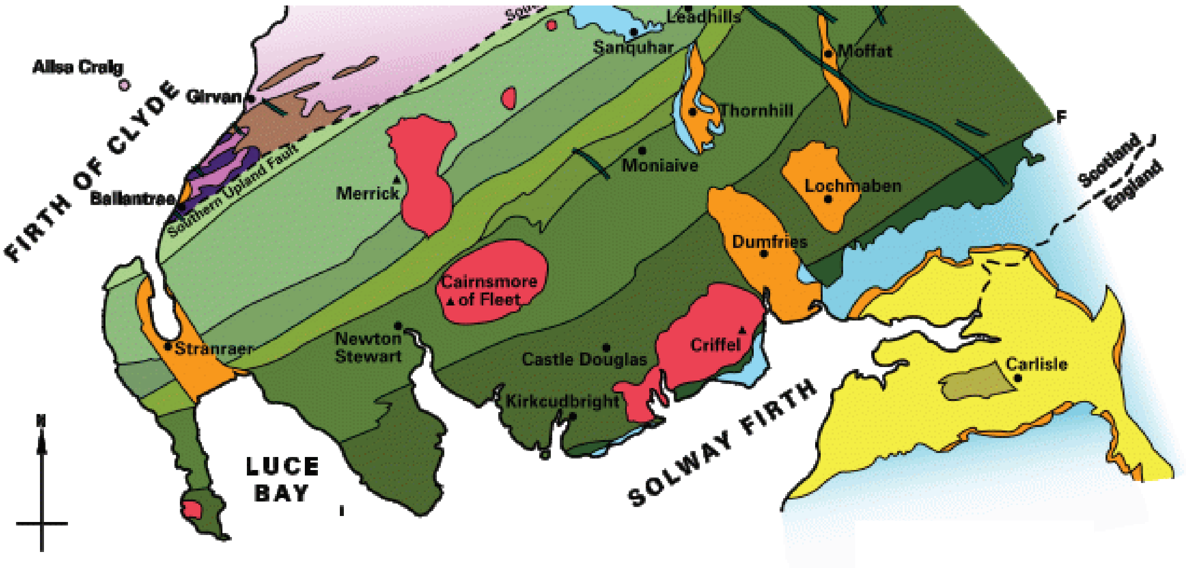

Figure 21: Geological map of Galloway. The sandstone and mudstone (green areas on map) become sequentially older towards the north-west of Galloway (McMilan & Stone 2008)

4.2 Afforestation

One of the major land uses of the upper River Bladnoch catchment is afforestation, with 71% of the catchment afforested (Figure 22) (Evans *et al.,* 2001). Afforestation does not always lead to acidification of surface waters if there is sufficient neutralising base cations present (Evans *et al.,* 2001). However, in acid sensitive regions, such as the upper River Bladnoch catchment, afforestation exacerbates acidification of surface waters. Conifer trees which are mostly non-native Sitka spruce (*Picea sitchensis*), efficiently scavenge pollutants from the air and remove base cations from the soil preventing buffering of atmospheric pollutants (Kreiser *et al.,* 1990). These scavenged pollutants are leached into burns draining the forest. This results in freshwater burns having a lower pH and higher aluminium and sulphate concentrations, which gradually increase as the forest ages (Stoner *et al.,* 1984; Kreiser *et al.,* 1990). Afforestation in Galloway began in the 1940s, with most of the River Bladnoch catchment being planted around the 1960s - 1970s, which combined with acid rain lead to acidification of the River Bladnoch catchment (Wright *et al.,* 1994; Helliwell *et al.,* 2001).

As it was recognised afforestation was having a detrimental impact on water quality, a comparative study was conducted investigating water quality of the Rivers Bladnoch, Cree and Luce catchments. This study demonstrated the Rivers Bladnoch and Cree, which drain afforested areas, where significantly more acidic than the River Luce which drains adjacent moorland (Helliwell *et al.,* 2001). Therefore, extensive forestry plays an import role in exacerbating acidification through dry and occult deposition in these catchments (Helliwell *et al.,* 2001).

Afforestation, not only decreased pH and increased aluminium in soils and surface waters but may also result in reduced light levels (Essex & Williams 1992). Heavy shading, as a result of dense forestry being planted next to burns, reduces riparian vegetation, increases bankside erosion and leads to reduced biodiversity and burns productivity (Broadmeadow & Nisbet 2004). It is estimated that it would take 50 years for the ecosystem to begin to recover but forests mature after 40+years and felled (Essex & Williams 1992). Felling also has a detrimental impact on the environment, as in extreme circumstances felling results in removal of surviving vegetation, soil damage, nutrient loss, acid flushes and increased erosion (Essex & Williams 1992). Therefore, afforestation of the upper River Bladnoch catchment has exacerbated acidification of surface waters, which has had a detrimental impact on juvenile Atlantic salmon populations.

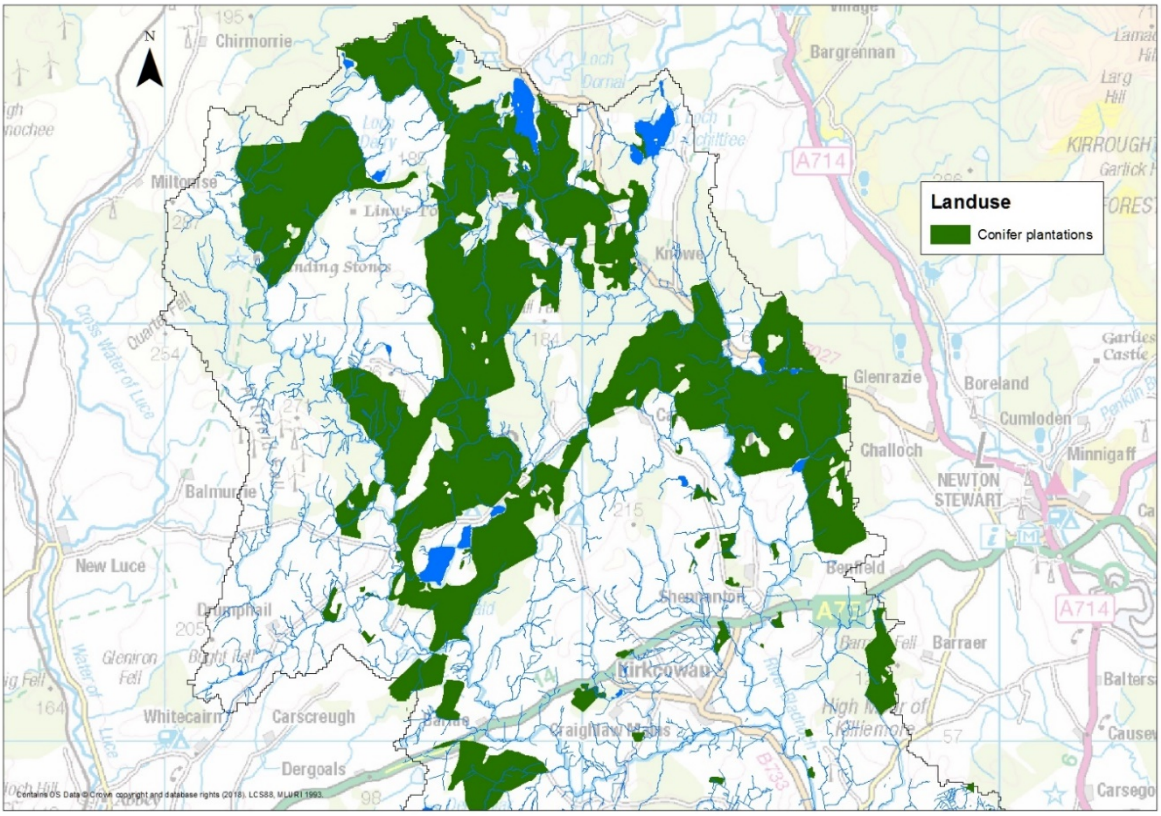

Figure 22: Afforested area of upper River Bladnoch catchment, with 71% of the catchment being planted (Helliwell *et al.,* 2001)

4.3 Peatland

One result of afforestation and agriculture on the upper River Bladnoch catchment is peatland degradation. Peatland, defined as being more than 50 cm deep (30 cm in England and Wales) and containing more than 50% organic carbon is an extremely valuable carbon store (SNH 2014). There is approximately 2.9 million hectares of peatland in the UK. However, the majority (~ 2.6 million hectares) of this peat is found in Scotland (Holden *et al.,* 2004). These peatlands are predominantly blanket peat and represent around 10 - 15% of the world's blanket peat resource (Holden *et al.,* 2004). Functional peatland is a globally import resource which acts as an effective carbon store, as the rate of production and accumulation of organic material is greater than the rate organic material is degraded and exported (Wallage *et al.,* 2006; Martin-Oretega *et al.,* 2014). Functioning peatland is also crucial for maintaining water quality, as healthy peatland stores DOC, humic acids, nutrients which can lead to eutrophication and atmospherically deposited pollutants which can lead to acidification of surface waters (Martin-Oretega *et al.,* 2014; Stimson *et al.,* 2017). Finally, peatland is an important habitat for waterfowl and other aquatic organisms (Stimson *et al.,* 2017).

Despite the importance of peatland, 80% of Scotland's peatlands are degraded (SNH 2014). There are several anthropogenic impacts, including grazing, agriculture, drainage, burning, mining and afforestation, which have led to peatland degradation by altering peatlands hydrology (Holden *et al.,* 2004; Stimson *et al.,* 2017). Thus, degradation of peatland, prevents it acting as a carbon store and instead degraded peatland acts as a carbon source, releasing carbon into the atmosphere (Stimson *et al.,* 2017). Peatland degradation also has an impact on water quality as degraded peatland no longer captures atmospherically deposited pollutants which instead are leached into watercourses. Pollutants previously stored in peat are also leached into watercourses. Ultimately, impacting organisms which occupy peatland and surrounding freshwater habitats (Holden *et al.,* 2004).

In Britain between 1945 and 1993, around 190 000 hectares of deep peat and 315 000 hectares of shallow peat has been drained and afforested with conifer plantations (Cannel *et al.,* 1993). The River Bladnoch catchment is an example of a catchment which has a high concentration of peatland, which has been degraded primarily through draining for afforestation and as a result the peatland is no longer functioning (Figure 23). The catchment also has large areas of deep peat which have been drained for afforestation and agriculture (Figures 30 & 31). For example, during peatland spot sampling conducted at Kilquhockadale flow, peat depths ranged from less than 0.5 m to over 7.51 m (Figure 24) (Scottish Government, 2018). Forest drainage, exposes mineral soils at the base and sides of the drainage ditch which releases Aluminium and Magnesium into surface waters (Holden *et al.,* 2004). There is also an increase in Dissolved Organic Carbon (DOC) and a decrease in pH (Edwards *et al.,* 1987; Holden *et al.,* 2004). This in turn has a detrimental impact on freshwater organisms, such as macroinvertebrates, salmonids and macrophytes (Evans *et al.,* 2005). Forestry drainage, also, results in erosion which can lead to siltation downstream which has a negative impact on salmonids (Holden *et al.,* 2004). For example, Atlantic salmon catches in the Ribble and Hadden catchments, Northern England, declined for eight years following drainage of peat (Stewart 1963). It has now been recognised that functioning peat is not only a valuable carbon store but also provides a valuable ecosystem for many organisms and acts as a buffer by preventing atmospherically deposited pollutants leaching into surface waters (Holden *et al.,* 2004).

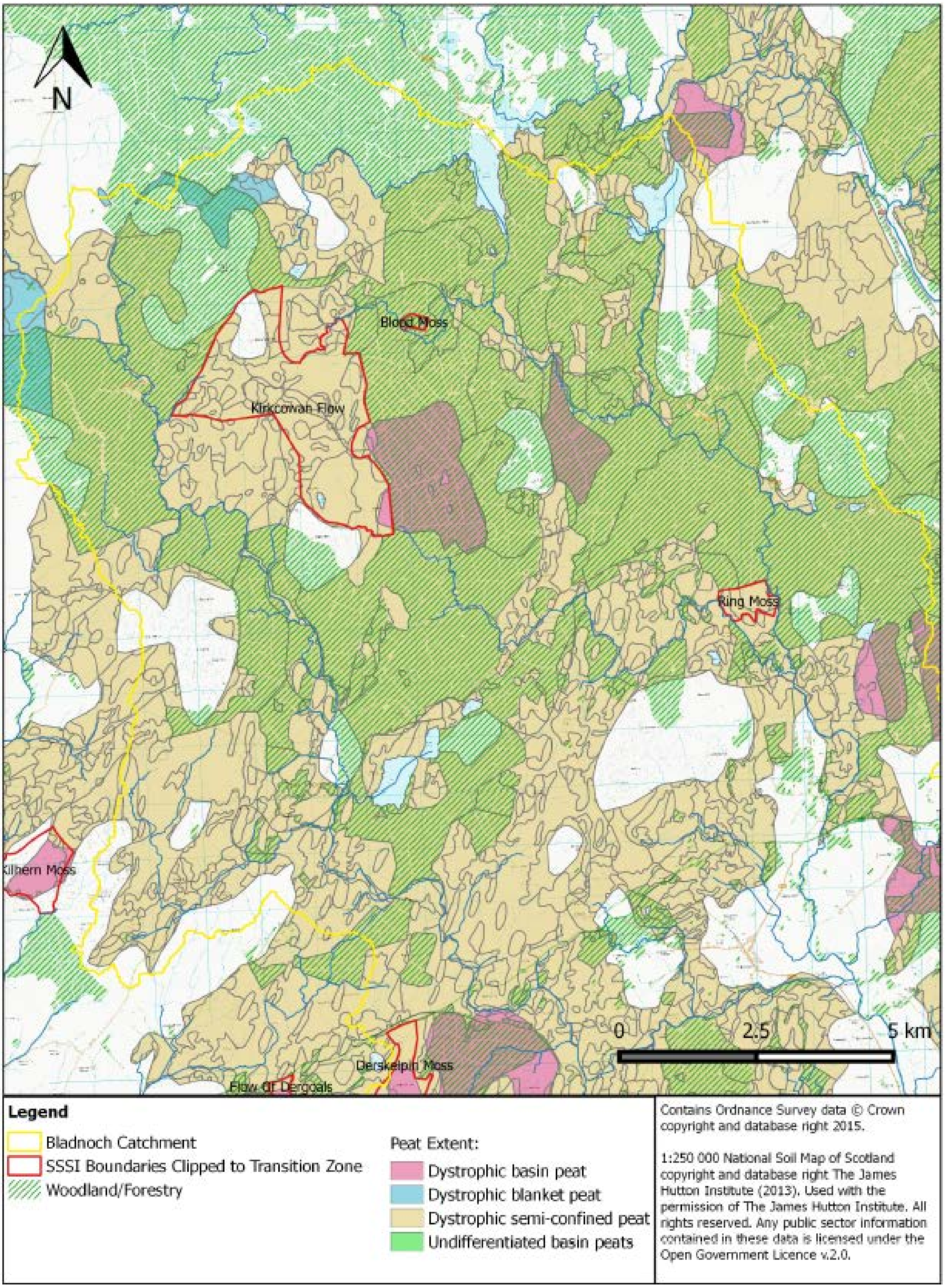

Figure 23: Map of peatland in the upper River Bladnoch catchment and its overlap with afforested areas (Taylor 2018)

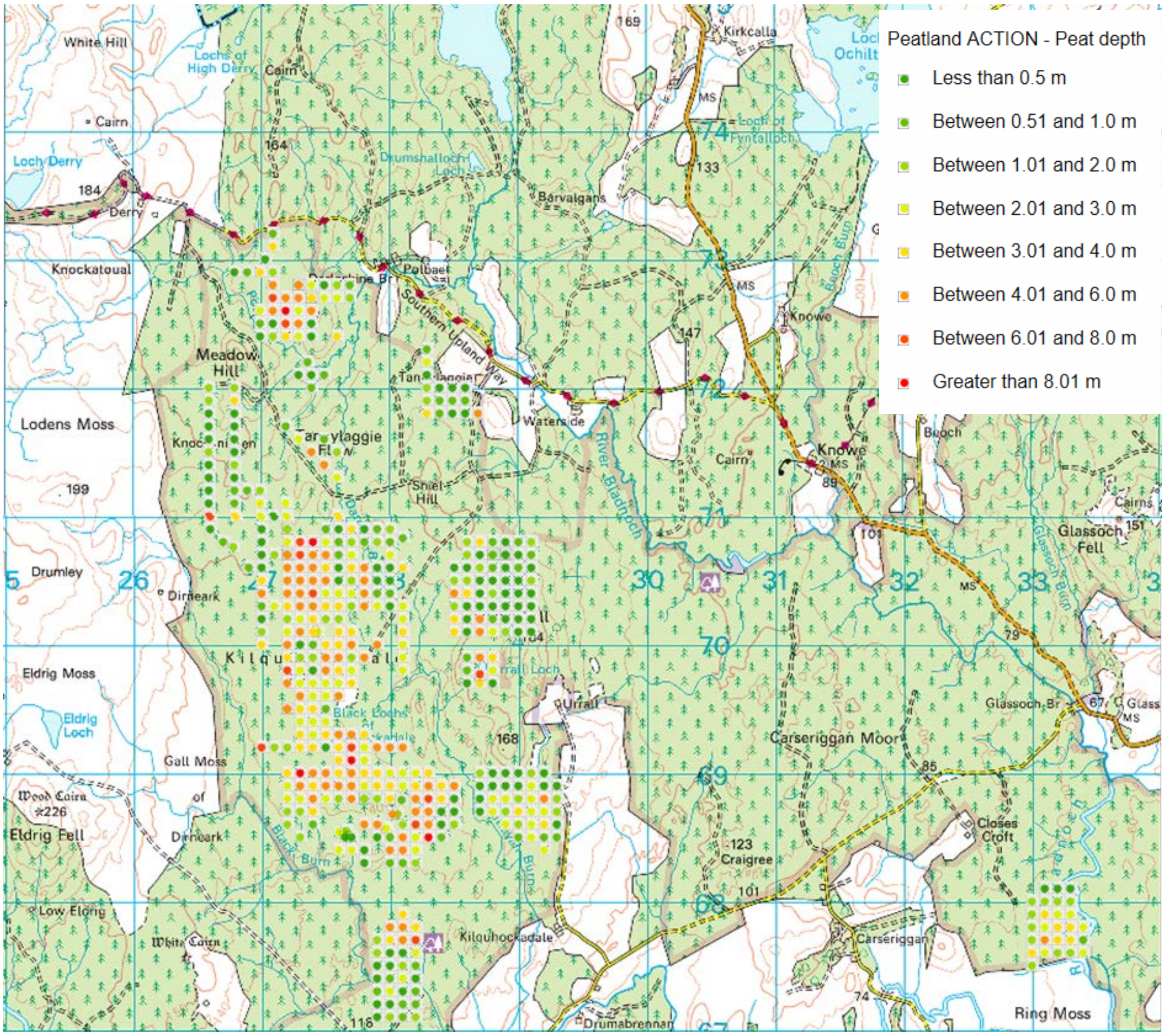

Figure 24: Peat depths collected for Peatland Action projects on the River Bladnoch catchment, including Kilquhockadale flow, Ring Moss and Blood moss (Scottish Government, 2018). All areas with peat depth greater than 0.5 m are classed as deep peat

4.4 The link between afforestation and peatland degradation of the upper River Bladnoch catchment

There are several factors which have led to acidification of the upper River Bladnoch catchment, which include the underlying geology of the catchment, afforestation and peatland degradation. Past forestry practices allowed areas of deep peat to be planted, which involved draining of the peatland to make conditions favourable for Sitka spruce. This extensive and effective drainage lowers the water table and dries out the peat. The land was also heavily fertilised, which further degraded the peat (Laine *et al.,* 1995). Poor quality waters which drain from these large areas of degraded peat enter the surrounding burns and rivers, negatively impacting fish populations. However, the role functional peatland plays in protecting watercourses from acidification, as well as, its role as a vital carbon store has now been recognised. In areas where peatland has previously been planted there is still a presumption, supported by legislation, in favour of replanting trees. There are some exceptions and where tree growth is very poor forest managers can undertake peatland restoration or plant peatland edge forest but it is not a requirement but rather a choice (Forestry Commission 2015). Therefore, addressing this relationship between peatland degradation, afforestation and water quality is vital for water quality improvements in the upper River Bladnoch catchment where extensive areas of deep peat have already been planted with Sitka and may continue to be replanted. Ultimately, improving water quality and juvenile Atlantic salmon abundance in the upper catchment requires less drainage and less conifer planting on the surrounding deep peats.

5 INSTREAM AND RIPARIAN FACTORS WHICH IMPACT JUVENILE ATLANTIC SALMON ABUNDANCE

5.1 Habitat availability

Past anthropogenic impacts often have resulted in the reduction of habitat available for juvenile Atlantic salmon (Thorstad *et al.,* 2008). For example, channelisation of a watercourse changes water depth, water flow, removes and compacts small substrates (Thorstad *et al.,* 2008). This reduces the area of habitat available to juvenile Atlantic salmon and can lead to a decline in abundance.

The upper River Bladnoch has a mixture of slow flowing deep waters, suitable for returning adult Atlantic salmon and faster flowing waters suitable for juvenile Atlantic salmon. These waters also have a high humic and Dissolved Organic Carbon (DOC) content due to degraded peatlands in the upper catchment. The main stem River Bladnoch has long sections of slow flowing deep waters and pools but there are also many sections of productive juvenile Atlantic salmon habitat. Productive juvenile Atlantic salmon habitat is defined as areas with a mixture of smaller substrates, such as gravel and cobbles, in shallow, faster flowing waters. From the confluence of the River Bladnoch and Tarf Water up to Black Burn the River Bladnoch is mostly unproductive juvenile Atlantic salmon habitat, with deep and slow flowing waters. However, from Glassoch Bridge to Knowe, productive juvenile Atlantic salmon habitat is found throughout with slightly more deep sections of slow flowing waters. The upper section of the River Bladnoch from Knowe to the outflow of Loch Maberry is predominately productive juvenile Atlantic salmon habitat with few sections of deep slow flowing waters. The upper River Bladnoch has many tributaries, the majority of which have productive juvenile Atlantic salmon habitat, such as Black Burn, Beoch Burn and Glassoch Burn (Figures 25 & 26). Beoch Burn is an ecologically important tributary of the upper River Bladnoch catchment as this burn has never been stocked and is believed to be utilised by spring salmon. Therefore, the Atlantic salmon in this burn are a truly wild population. However, Dargoal Burn which flows into Polbae Burn is deep slow flowing waters which are unproductive for juvenile Atlantic salmon. Finally, Polbae Burn has productive juvenile Atlantic salmon habitat in the headwaters and in the lower reaches. Polbae Burn flows through an extensive section of afforestation, and as it flows through the forest the burn becomes deep and very slow unproductive juvenile Atlantic salmon habitat. In general, the River Bladnoch has a good mix of productive and unproductive areas for juvenile Atlantic salmon. Productive juvenile habitat has a good mix of substrate and faster flows for fry and parr. However, there is a general lack of spawning substrate throughout the River Bladnoch which could be the result of the slow flowing nature of the river, much of the surround land being peat, and limited erosion inputting suitable substrates into the watercourse.

The Tarf Water, a major tributary of the River Bladnoch, begins at Benbrake Hill and flows downstream past Kilgallioch and Brockloch Hill towards Horse Hill where the Mulniegarroch of Purgatory Burn joins the main stem of the Tarf Water. The Tarf Water then continues downstream through forestry until Tarf Bridge (Figure 27). The Tarf Water until this point has a good amount of productive juvenile habitat mixed with deep slow pools which could be used by returning adult salmon as resting pools. The main stem of Tarf Water continues downstream until it joins the main River Bladnoch and has good quality productive juvenile habitat. The main stem Tarf Water has productive habitat throughout with plenty of spawning habitat and habitat for fry and parr. However, spawning substrate tends to be compacted as a result of siltation, peatland degradation and past forestry operations. Just below Tarf Bridge is the outflow of Drumpail Burn this burn again has productive juvenile habitat with holding pools for returning adult salmon. However, throughout the Tarf Water small un-named tributaries join the main stem which appear to be a mix of unproductive and productive habitat for juveniles (Figure 28).

Figure 25: Productive habitat for juvenile Atlantic salmon in the Beoch Burn

Figure 26: Productive habitat for juvenile Atlantic salmon in the Black Burn

Figure 27: Good productive juvenile Atlantic salmon habitat in the main stem Tarf Water upstream of Tarf Bridge

Figure 28: Example of a small tributary, Loch Strand outflow, which has productive juvenile habitat for Atlantic salmon

5.2 Barriers to migration

There are no significant barriers to migration in the upper River Bladnoch catchment. There are several barriers in the catchment but they are mostly screening to prevent stocked rainbow trout (*Oncorhynchus mykiss*) escaping lochs. There is a weir on the Tarf Water and dam at Polbae House which both contain fish passes and are passable for migratory fish (Figure 29). There is also a waterfall on the Black Burn which after an initial examination appears to be passable during favourable conditions (Figure 30). However, many culverts have been added to tributaries throughout the upper River Bladnoch catchment for road construction by forestry. Therefore, although barriers to migration do not seem to be a significant factor affecting Atlantic salmon abundance in the River Bladnoch catchment, the impact of these culverts is currently unknown. Therefore, culverts would need to be assessed in areas which could be accessed by Atlantic salmon.

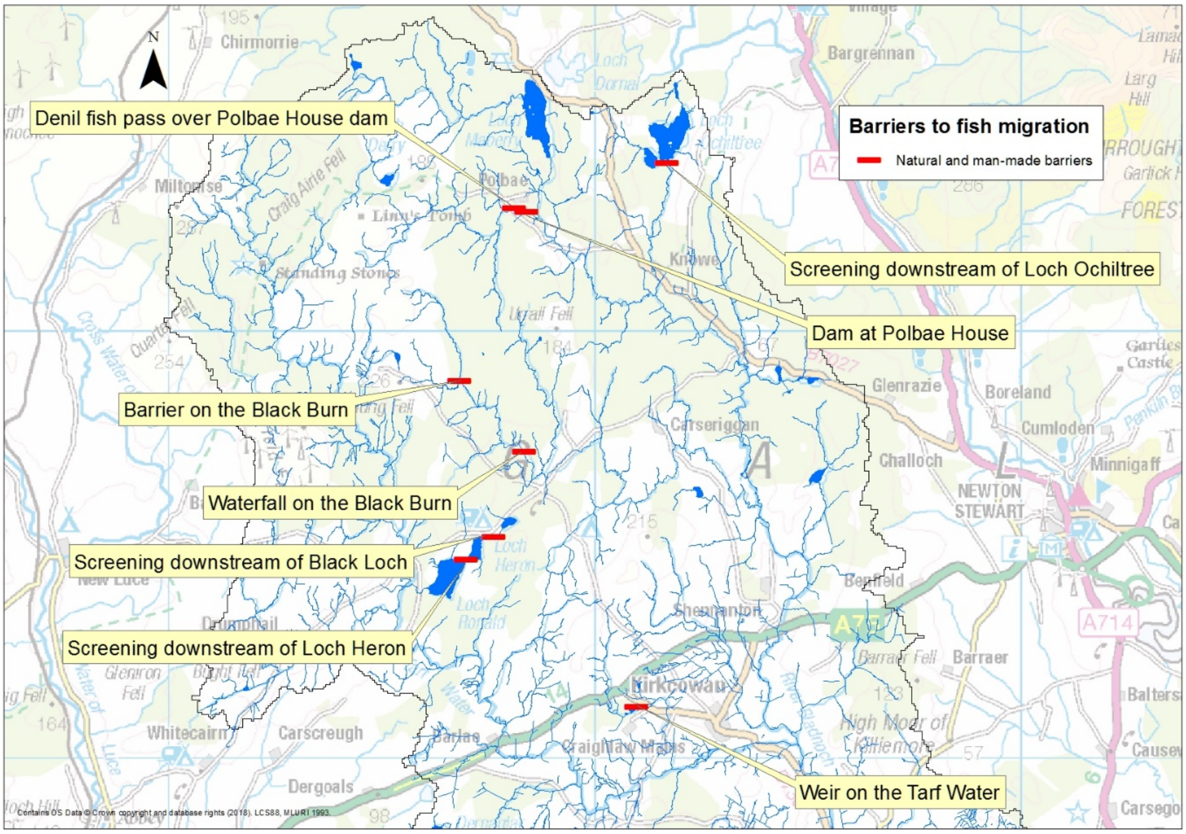

Figure 29: Natural and man-made barriers to Atlantic salmon migration. All barriers in the upper River Bladnoch catchment are passable, with the exception of screens put on Loch outflows to prevent stocked fish escaping. It is unknown if the series of waterfalls on the Black Burn are passable but after an initial inspection they would appear to be passable under the right conditions

Figure 30: Natural series of waterfalls on the Black Burn

6 RESTORATION TECHNIQUES ADDRESSING DRIVERS OF ACIDIFICATION IN THE UPPER RIVER BLADNOCH CATCHMENT

This report has demonstrated that the absence of juvenile Atlantic salmon in the upper River Bladnoch catchment is most likely to be the result of poor water quality, reduced habitat availability and habitat fragmentation. These are driven by anthropogenic impacts, such as afforestation, peatland degradation and barriers to migration, and it is important to rectify these impacts to conserve Atlantic salmon in the upper River Bladnoch catchment. Therefore, there are several restoration projects which could be completed in the catchment which should have a positive impact on the abundance of Atlantic salmon. There are several restoration techniques which could be used to improve water quality and/or Atlantic salmon abundance. These restoration techniques have been outlined below.

6.1 Restoration techniques to improve water quality

6.1.1 Liming

Water quality, specifically acidification, is one of the main limiting factors for Atlantic salmon recruitment in the upper River Bladnoch catchment. Therefore, increasing pH, decreasing the acidity of surface waters, would most likely lead to an increase in the abundance of Atlantic salmon. One restoration method which has been widely used in some European countries and North America is liming (Mant *et al.,* 2013). Liming is the addition of calcium carbonate to surface waters with the aim of temporarily increasing pH of watercourses (Mant *et al.,* 2013). Liming is not a long-term solution and the source of acidification, such as afforestation and/or peatland degradation, must be addressed for long term change (Weigmann *et al.,* 1993). Therefore, liming must be carried out on a continual basis for a reduction in water acidity to be sustained (Weigmann *et al.,* 1993). There are several different liming methods which can be used which include bulk addition of limestone into a river channel, application by mechanical doseres, lake liming or catchment liming (Mant *et al.,* 2013). Catchment liming has the potential to effectively minimise the release of toxic metal ions from catchment soils. Its effects also last longer than direct application. However, catchment liming can have detrimental impacts on the function and diversity of wetland systems, such as peatland, which are naturally acidic (Mant *et al.,* 2013). Therefore, care needs to be taken when considering liming an area to prevent further damage of degraded peatland. Another liming technique which is commonly used in Norway is liming by fine powdered limestone to improve water to ensure a self-reproducing and healthy Atlantic salmon population can inhabit the area (Staurnes *et al.,* 1995). Using meta-analysis, Mant *et al.,* (2013), examined the effect of liming on freshwater fish abundance. Most of the studies examined showed there was an increase in fish abundance after liming. However, the time needed for there to be an increase in fish abundance is species dependent. However, there were a few studies examined which showed liming had a detrimental impact on fish abundance. Liming may have a negative effect on Brown trout abundance as a result of increased abundance of Atlantic salmon and increased competition (Mant *et al.,* 2013). Negative impacts on Atlantic salmon abundance can occur through changing substrate and boundary conditions between limed sites and sites not limed as changing pH might increase aluminium toxicity (Mant *et al.,* 2013). Therefore, before liming, background information such as, hydrology, fish populations, land use, must be gathered and considered before liming to reduce the chance of negative impacts.

In order for liming to be effective, there are several riverine characteristics which need to be taken into account before deciding on the size of limestone to be added and the method to be used. These factors are: water quality and acidity, flow rate, watercourse length, watercourse gradient, water temperature, volume of precipitation and location of mixing zones (Weigmann *et al.,* 1993). The particle size of limestone is also important for liming to be effective as particles which are too small will wash away too quickly and particles which are too large will not dissolve quickly enough (Weigmann *et al.,* 1993). Particles which are too large become deactivated by algae growth (Weigmann *et al.,* 1993). It is recommended sand-size limestone is used for streams as it is easier to dissolve and to be distributed uniformly (Weigmann *et al.,* 2013). There are several different application methods which include inexpensive and simple streambed dump and expensive but long-lasting watershed application (Weigmann *et al.,* 2013).

There have been several liming projects completed in Galloway, the most famous of which was a five year liming experiment carried out on Loch Fleet in 1984 (Howells & Dalziel 1992). This experiment demonstrated that liming treatments on 40% of Loch Fleet decreased the Lochs acidity to acceptable levels which would be maintained for around 15 years (Howells *et al.,* 1992). As a result of improved water quality, Brown trout were successfully reintroduced to Loch Fleet and by 1987 had reached spawning condition (Howells *et al.,* 1992). Another example of a liming project in Galloway, was the Loch Dee project (Tervet & Harriman 1988). This project used limestone application in the White Laggan subcatchment, whereby queen scallop shells (*Chlamys opercularis*) and powdered lime were deposited (Tervet & Harriman 1988). This study showed the concentration of calcium was not changed by the addition of scallop shells due to the long time it takes for the shells to begin to dissolve (Tervet & Harriman 1988). However, the addition of limestone powder did increase the concentration of calcium but this declined throughout the year (Tervet & Harriman 1988). Therefore, to restore water quality annual liming would be needed to increase the reservoir of calcium in the sediment and increase surface water pH (Tervet & Harriman 1988).

The Wye and Usk Foundation hosted a visit from GFT and various agencies in 2010 to view the liming work undertaken on the River Wye aimed at addressing acidification. It was reported that salmon and trout had returned to many kilometres of the Wye post liming. Following this visit, it was agreed that GFT should trial two of the methods used successfully on the Wye; the addition of limestone sand (particles of <3 mm) to small forestry drainage systems and sub-catchment hydrological source liming using powered limestone (particles of <125 µg). These works took place on the upper Water of Fleet catchment. The hydrological source liming work took place at two locations during 2011 and 2012 with 350 tonnes of powdered limestone being added to recently felled areas around the Benmeal Burn, a tributary of the Big Water of Fleet. Cauto *et al.,* (2015) concluded liming of Benmeal Burn had had an overall positive impact on the localised macro-invertebrate population through increased diversity and presence of acid sensitive species compared to nearby waters which had not been limed. GFT electrofishing results, the year after liming in 2013 found Brown trout fry densities increased four-fold in Benmeal Burn. Further, follow up annual electrofishing surveys continued to record positive results although Brown trout densities have been lower than in 2013. The second part of this project involved adding 150 tonnes of limestone sand into small tributaries or ditches flowing into Cardoon Burn in 2011 and 2012. During a flood event, when acid flushes occur, water within these small drains, ditches and watercourses aggravates and moves the limestone sand which helps to dissolve it. This helps protect watercourses from these acid flushes by increasing the pH of drainage waters. Constant water quality monitoring has demonstrated pH of these watercourses increased, however, due to few spawning Atlantic salmon present, changes in salmonid densities were difficult to identify.

Finally, GFT undertook a further liming trial on the headwaters of the River Cree. Limestone gravel was added in 2010 to a small tributary of the High Cree to investigate pH changes within the gravel and to check gravel retention times. The addition of limestone gravel had no effect on water column pH but locally increasing pH of water in interstitial spaces of the gravel bed where Atlantic salmon eggs would be present (GFT 2012). This would be expected to increase egg survival in acidified waters. Based on this trial, a second project was conducted on the High Cree in 2011 and 2013 where 1 250 tonnes of limestone gravel was added, based on a geomorphologist's advice, to the river to become incorporated into five large spawning beds. Monitoring found an increase of around 1 pH unit pH within the mixed limestone/natural gravel beds. An increased in salmonid survival was also found through Egg box monitoring and electrofishing. In 2016, as a result of limestone gravel addition, 2 800 m^2 of suitable spawning riffle containing limestone gravel had been created and wild salmon fry and parr stocks had recovered over 9 km of the lower High Cree. No wild salmon spawning was found upstream of the sites where limestone gravel was added.

Acidification of the upper River Bladnoch catchment has been exacerbated by peatland degradation and afforestation of the catchment. Therefore, liming as a restoration method could be used in the short term to protect juvenile Atlantic salmon from detrimental acid flushes. This would be a short term solution as forestry restructuring and peatland restoration would be needed for long term improvements in the pH of watercourses. The method used for liming would need to be considered in detail due to the upper River Bladnoch having slow flowing waters and extensive areas on peatland. It is ill-advised to lime in areas of peatland as it is detrimental to sphagnum mosses, which are essential for the functioning of a healthy peatland (Howells & Dalziel 1992). Dead sphagnum moss and underlying peat, as a result of liming, could increase erosion of peat and the release of DOC and humic acids (Howells & Dalziel 1992). Thus, any proposed liming on the upper River Bladnoch catchment should not be undertaken on peat.

6.1.2 Peatland restoration

Peatland is an important habitat for many organisms and carbon store (Glenk *et al.,* 2017). Peatland also plays a vital role in protecting freshwater from acidification by storing pollutants (Martin-Oretega *et al.,* 2014). Therefore, in recent years there has been an increased interest in restoring degraded peatland. Currently, two thirds of Scotland's peatland is either in intermediate or bad ecological condition (Glenk *et al.,* 2017). Peatland which is in intermediate ecological condition is primarily used for livestock grazing and field sports. Intermediate condition peatland has been drained, is baron of plants and organisms, with the exception of heather and grasses, and drainage water is slightly coloured affecting downstream fish populations (Glenk *et al.,* 2017). Peatland in bad ecological condition has been drained for a long time with exposed deep gullies and drenches. Peatland in bad ecological condition also acts as a carbon source, releasing carbon into the atmosphere (Glenk *et al.,* 2017). It also no longer stores atmospherically deposited pollutants which instead are leached into surface waters (Glenk *et al.,* 2017). Therefore, peatland restoration projects in Scotland are supported by an annual fund from Peatland Action from which around 10 000 hectares of peatland has been restored in Scotland (Byg & Novo 2017). Although it will take several decades for peatland to be fully restored, within 3 - 5 years of restoration, improvements in carbon emissions, water quality and wildlife are evident (Glenk *et al.,* 2017). Therefore, peatland restoration projects are vital for peatland to be functional and protect watercourses from further acidification.

There are several techniques which can be employed for peatland restoration. One possible technique is blocking artificial drains and raising the water table to create a wetland ecosystem (Wallage *et al.,* 2006). Historically, artificial drains were used to drain peatland and improve the productivity of the land for grazing (Wallage *et al.,* 2006). However, the addition of artificial drains not only resulted in limited improvement of productivity but also resulted in increased flooding risks and release of DOC (Wallage *et al.,* 2006). Therefore, artificial drains can be blocked by damming them with wooden, plastic or metal sheets or filling the drains with peat or vegetation (Wallage *et al.,* 2006). Drain blocking has been shown to be a successful strategy for reducing DOC and water colour (Wallage *et al.,* 2006). A second technique which can be used in areas with large amounts of bare peat is revegetation. This is a process whereby, lime and fertilisers are added to bare peat to encourage growth of new vegetation (Stimson *et al.,* 2017). Peatland in bad ecological condition will erode down to the mineral layer, releasing previously stored carbon during this process. Badly eroding peat hags can also be revegetated by hag re-profiling whereby vegetation on top of the hag is pushed down the side to cover the exposed peat. Another technique, which can be used on peat which has been previously degraded by forestry, is tree removal, brash removal and mulching. This technique could be used alongside drain and ditch blocking (Andersen *et al.,* 2017). Finally, a more recent technique being trialled is stump flipping and ground smoothing. Often this is in association with the creation of shallow surface bunds. This technique has been utilised at Ring Moss peatland restoration project and Moss of Cree to successfully raise the water table and re-flood the peatland. Therefore, there are a range of peatland restoration techniques which can be used and as more peatlands are restored and monitored the success of these techniques will be established.

The upper River Bladnoch catchment has large areas of deep peat which are located in both afforested and open areas (Figure 31 & 32). However, due to the extensive afforestation much of this peatland has been degraded. Peatland restoration would improve water quality of the upper River Bladnoch and result in an increase in Atlantic salmon abundance. Therefore, the upper River Bladnoch catchment should be made a priority area for peatland restoration projects. There have been two areas of previously restored peatland, Blood Moss and Ring Moss. There is also 200 hectares of peatland set to be restored at Kilquhockadale Flow. This area was highlighted as suitable for restoration during a Peatland Action funded investigative study completed by GFT and Forest Enterprise. Forest Enterprise have recently stated that this project is on hold because of changes in guidance regarding when it is appropriate to convert conifer forest back to peatland. Dargoal Burn flows through this area and is the most acidic burn in the catchment and rarely records a pH above 4.5. This has a knock-on-effect on water quality and Atlantic salmon survival downstream of its outflow. Therefore, this peatland restoration project at Kilquhockadale Flow would improve water quality in the Dargoal Burn and downstream of its outflow. Therefore, it is vital that this project is completed soon as without this work it is unlikely Atlantic salmon will be able to thrive in the upper River Bladnoch catchment.

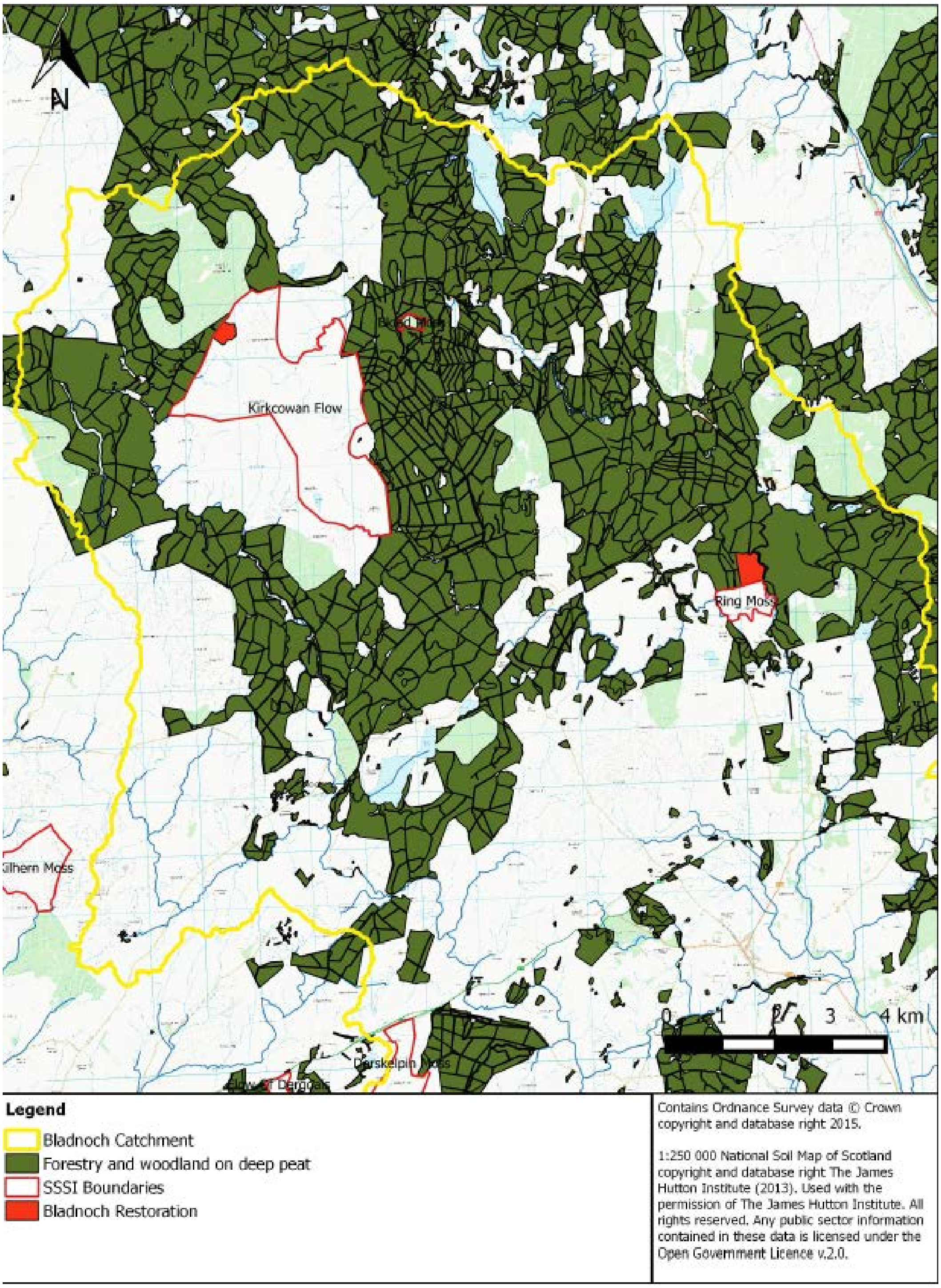

Figure 31: Map of forestry and woodland which has been planted on deep peat in the upper River Bladnoch catchment. Thus, demonstrating the vast area of peatland which has been degraded and would benefit from restoration projects (Taylor 2018)

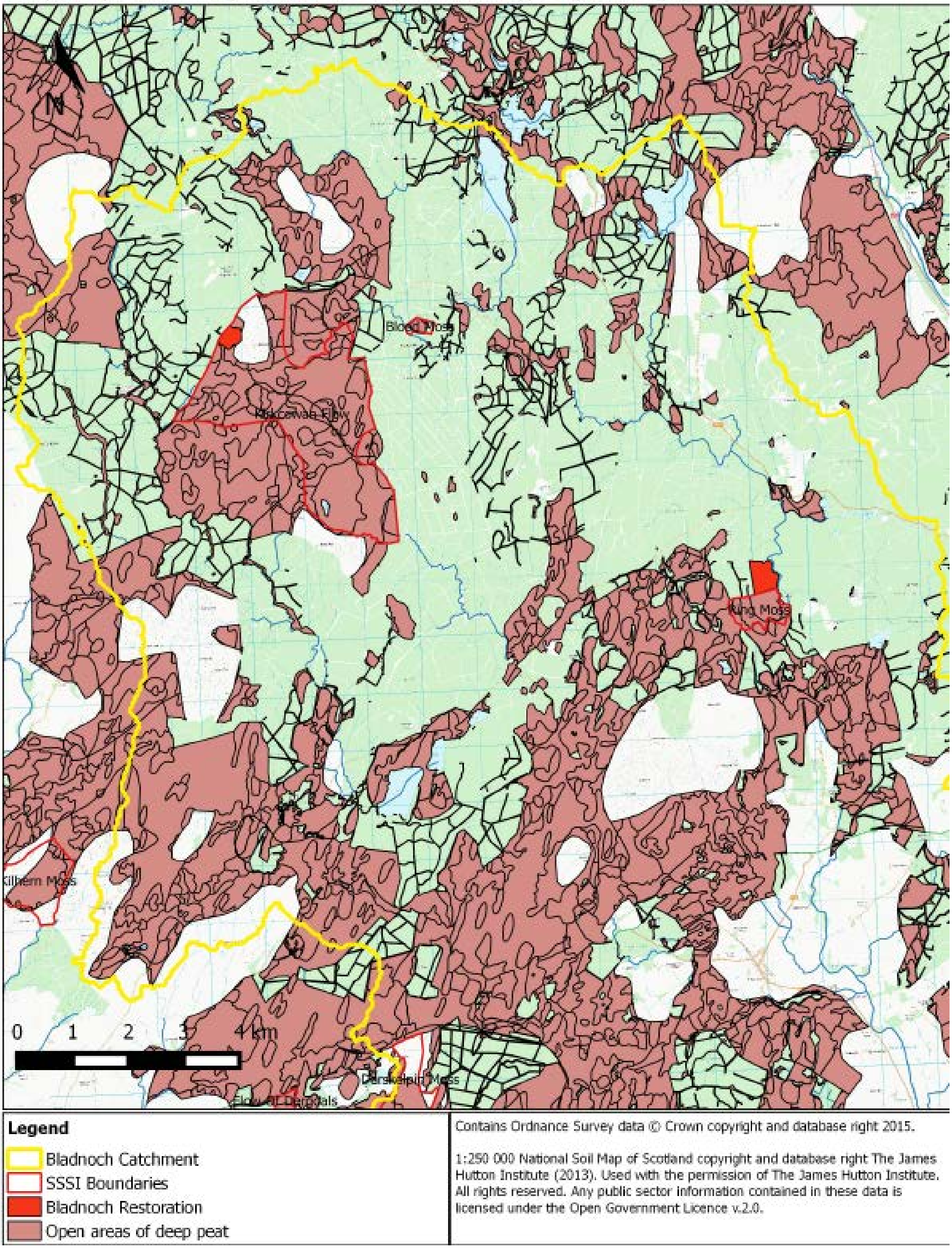

Figure 32: Map of open areas of deep peat in the upper River Bladnoch catchment, which could be restored (Taylor 2018)

6.1.3 Restructured forestry

Afforestation, with spruce plantations is the primary land-use in the upper River Bladnoch catchment. Conifer afforestation, throughout Great Britain, was concentrated in upland areas for economic reasons, rather than for environmental suitability for tree growth (Essex & Williams 1992). Therefore, peatland was drained and forests were planted near watercourse

(Essex & Williams 1992). As our understanding of the links between afforestation and water quality increases, forestry practices are adapted accordingly and increasingly consider the environment when forests are planted. There are various versions of the Forest and Water Guidelines, which outline environmental requirements which must be adhered to when replanting forests as they are a condition of forest grants (Forestry Commission 2014 a & b; Forestry Commission 2017). For example, a riparian buffer zone is implemented to protect both aquatic and riparian zones from disturbance (Broadmeadow & Nisbett 2004). This buffer zone provides erosion control by acting as a barrier to soil disturbance (Broadmeadow & Nisbett 2004). Increased riparian vegetation impedes surface run off, increasing rate of infiltration and deposition of suspended materials. The effectiveness of the buffer zone depends on several factors such as slope and soil type (Moring 1982). A study in Pennsylvannia, USA found an unfelled 30 m native riparian woodland buffer zone protected salmonid gravel redds from sedimentation (Moring 1982). The species of trees used in the riparian buffer zone is also important as species differ in their ability to retain sediment. It is, therefore, recommended that oak and alder are interspersed with birch, willow, rowan, ash, hazel, aspen and bird cherry (Broadmeadow & Nisbett 2004). Riparian buffer zones also protect watercourses from leached pollutants such as fertilisers and nitrates. When replanted the removal of mature conifers from river banks can lead to an increase in daily temperature. For example, a 10 m buffer zone in the River Tywi, Wales reduced the mean daily temperature in winter by 0.5 - 1^{o}C but increased daily temperature in summer by 0.5 - 1^{o}C, which would increase the rate of egg development and growth of salmonids (Ormerod & Weatherley 1990). Therefore, due to the importance of a riparian buffer zone, the Forestry Commission guidelines set out a minimum requirement for the width of this buffer zone. A channel less than 2 m width requires a 10 m wide buffer zone, a channel greater than 2 m wide requires a 20 m buffer zone and at abstraction points a 50 m buffer zone is required (Forestry Commission, 2011). However, the structure of the riparian buffer zone is equally as important as the width. Ideally, the structure of the riparian buffer zone will include riparian vegetation, such as grasses, which assists with retention of sediments. There would also be an area of deciduous trees planted which assists with sedimentation as they stabilise woodland soils and absorb surface run off. Finally, woody debris and tree roots also create a natural network of pools and dams which act as sediment traps and provide important habitat for salmonids (Broadmeadow & Nisbett 2004).

Forestry plantations in the upper River Bladnoch catchment have reached maturity and because planting of the catchment occurred over a short period of time, many plantations have reached maturity at around the same time. This has implications for felling operations as considerations need to be taken into how best to fell these mature plantations. Felling in acid sensitive areas will result in acid flushes which could have a detrimental impact on fragile Atlantic salmon stocks. There would also be the release of any stored toxic aluminium which had not been previously released. Therefore, felling should occur at the least sensitive time of year in areas where juvenile Atlantic salmon occur. However, due to the urgent need for restructuring of forests in the upper River Bladnoch catchment, felling should occur at an accelerated pace. When replanting these forests, Forests and Water Guidelines are much more sympathetic to the environment but will need to go further if acidification of the upper River Bladnoch catchment is going to be addressed. The current Forestry Commission guidelines for felling and replanting of acid sensitive areas advise on how best to design forestry replanting and include guidelines on the riparian buffer zone and managing open spaces (Forestry Commission 2014 a&b; Forestry Commission 2017). However, these guidelines are not a legal requirement but a condition of forestry grants and the minimum requirements may not be sufficient to benefit the surrounding environment in areas highly impacted by acidification. Forestry restructuring has been taking place in the upper River Bladnoch catchment but there has been limited improvement in water quality. Therefore, it is essential in acid sensitive areas, such as the upper River Bladnoch catchment, additional measures are taken beyond the minimum requirements. The inclusion of larger open spaces and peatland restoration would greatly benefit the environment through improvement of water quality and natural colonisation of open spaces, increasing biodiversity of plants and animals which inhabit these areas. There are examples of areas of forestry which have been replanted in the River Bladnoch catchment which have gone a step further to include open spaces or peatland restoration. For example, as previously described Kilquhockadale Flow was designated an area of peatland restoration. Although this project is currently on hold, peatland restoration in this area would greatly benefit the catchment by improving water quality in an area which currently supports no salmonids due to its acidic waters. Ring Moss, is another example of an area which was set aside in 2015 by Forest Enterprise for peatland restoration. This project converted 28 hectares of conifer woodland back to open peatland by blocking drains (Figure 33). A benefit of peatland restoration is that unlike other areas which have been designated as open spaces, Sitka spruce regeneration should not occur because conditions are unfavourable for tree establishment. However, areas designed as open spaces should be actively managed. Extensive reseeding by conifers is a problem on ground designated as an open space on the opposite side of the Polbae Burn to Blood Moss which was cleared as part of CASS Project (Figure 34). Therefore, open spaces should be actively managed to ensure natural regeneration is kept to a minimum and these areas truly benefit the environment.

Figure 33: Ring Moss, site which has been restored to open peatland by the Forest Enterprise in 2015

Figure 34: Extensive natural regeneration of confers in an area designated as an open space at Blood Moss

6.2 Restoration techniques to improve abundance of Atlantic salmon

6.2.1 Instream and riparian restoration techniques

Anthropogenic impacts on watercourses, such as dredging, straightening, barriers to migration, siltation and substrate removal, can have detrimental impacts on aquatic organisms. For example, dredging and channel straightening alters the hydrology of the watercourse which in turn affects substrate movement and natural erosion. Thus, reducing the diversity of habitats available for salmonids. Juvenile Atlantic salmon utilise different habitats depending on their size and age. For example, fine substrates, such as gravel, in shallow fast flowing sections are preferred for spawning, alevin and fry. Whereas, parr will occupy habitats which are slightly slower flowing and deeper with larger substrates, such as cobbles and boulders. Therefore, instream and riparian restoration is common practice, with the aim of restoring habitat quality and salmonid abundance (Lake *et al.,* 2007). Ideally, a river would have a mixture of spawning habitat (fine substrate in areas of shallow, fast flowing waters), fry habitat (gravel/cobble substrate in fast flowing, shallow waters), parr habitat (cobbles and boulders in slightly deeper, slower flowing waters), and resting pools (deep, slow flowing water used by returning adult Atlantic salmon during their upstream migration). The river would also have areas with tree roots and overhanging vegetation to provide shelter for juvenile Atlantic salmon. Finally, there would also be deciduous trees along the river bank providing dappled shade during the summer preventing waters from overheating (Armstrong *et al.,* 2003). There are several restoration techniques which can be employed for instream and riparian improvement. One such technique is the addition of large woody debris such as tree logs and branches to streams. The addition of woody debris slows river flow in areas and aids the deposition of gravel which would otherwise be washed downstream. Woody debris also decreases water temperature, reinforces river banks and traps organic material as a food source for aquatic macroinvertebrates (Roni & Quinn 2001). Barriers to migration is another serious factor which can impede the movement of Atlantic salmon (Kemp & Williams 2008).

Poorly designed and placed culverts for roads can impede upstream migration of Atlantic salmon and downstream migration of juvenile salmonids when excessive water velocities create adverse conditions (Kemp & Williams 2008). Therefore, the probability of Atlantic salmon to pass a culvert should be accessed and in some cases the culvert should be removed or redesigned. Designing a culvert which enables both upstream migration of adult Atlantic salmon and downstream migration of smolting Atlantic salmon is a difficult task. It has been shown when comparing uniform and complex culverts, Chinook salmon (*Oncorhynchus tshawytscha*) smolts were likely to avoid culverts that has been modified in favour of simple uniform culverts as modified culverts delayed downstream migration. Whereas, modified culverts facilitated upstream migration of adults (Kemp & Williams 2008). Therefore, culvert design must be carefully considered before installation. Another instream restoration technique is substrate addition or loosening. Whereby, boulders are added to provide shelter for larger juvenile Atlantic salmon and gravel is added to provide spawning habitat. Substrate may also have become compacted by siltation or from channel dredging. Therefore, gravel loosening can be used which allows Atlantic salmon to create redds in the area. Riparian river banks can also be enhanced by planting deciduous trees which stabilises the river bank and provides dappled shade. Larger restoration projects could include whole stream restoration or stream channel morphology restoration. Anthropogenic impacts, such as afforestation, can result in stream diversion and channel straightening. Channel straightening results in the burn losing its meanders which affects the hydrology of the watercourse, as meanders slow the flow of the water allowing substrates to be deposited. Therefore, one possible restoration technique is to add meanders back into the watercourse either naturally by placing boulders and woody debris to divert flow or by mechanically altering the watercourse. Finally, burns which have been diverted could be restored. This would involve blocking the diversion to force flow back through the natural watercourse, sediment removal, and substrate addition and channel widening. Therefore, there are many techniques which can be used to restore instream and riparian habitats. However, the effectiveness of restoration depends on many factors, such as the scale of the restoration works. Localised small-scale restoration will not have the desired effect of increasing Atlantic salmon abundance and larger scale projects may be needed for an effect on salmonid abundance to be seen. It is also important to address all limiting factors for juvenile Atlantic salmon in the stream. For example, planting deciduous trees will benefit Atlantic salmon but only if barriers are removed or altered and instream habitat improvements are made.

6.2.2 Fish relocation

Historically, fish stocking programmes were undertaken on many salmon rivers with the aim of enhancing Atlantic salmon stocks (Bacon *et al.,* 2015). These programmes aimed to achieve a higher survival rate of Atlantic salmon eggs in a hatchery than would occur naturally in the wild before being returned to river and burns. With the development of genetic studies, it has now been found that the survival rates of hatchery reared Atlantic salmon is actually far lower than totally wild fish in later life stages, especially migrating smolts, so stocked fish produce lower numbers of returning adults. Natural selection, which hatchery operations aim to reduce, is an important process to ensure the fittest smolts are produced from a river system. The marine environment appears to be an increasingly hostile environment for Atlantic salmon and it is crucial to ensure the best adapted smolts are produced to ensure the best return rates are realised.

In 2014 RAFTS undertook a detailed review of stocking literature and produced a protocol which is now recognised as best practice for stocking in Scotland (McIntyre & Kettlewhite 2014). These documents have been adopted by Fisheries Management Scotland (FMS) which represents Fisheries Trusts and District Salmon Fisheries Boards (DSFB) across Scotland. The review did not find evidence of significant increases in rod catches being produced directly by Atlantic salmon stocking programmes on any rivers. It did consider that there was a role for restoration stocking in certain circumstances to assist in kick starting a return of a breeding population where suitable habitats are present and accessible but not supporting a natural Atlantic salmon population. This could include waters recovering from acidification or following the removal of an impassable fish barrier. Any increase in rod catches is likely to only occur once natural sustainable populations are restored.

Any stocking of rivers should follow the FMS stocking protocol, which includes using the closest Atlantic salmon population for stocking, maximising the number of families created by using multiple crosses of brood stock and planting out eyed ova or releasing unfed fry to minimise selection within the hatchery (domestication). This allows 'survival of the fittest' to take place, with well adapted individuals surviving and maladapted individuals perishing (McIntyre & Kettlewhite 2014).

In recent years, there has been a growing understanding of the extensive genetic structuring and adaptation to local conditions demonstrated by Atlantic salmon populations which must be considered in any hatchery programme (King *et al.,* 2001; Consuegra *et al.,* 2005; Primer *et al.,* 2006). It is now recognised that maintaining and conserving the genetic and phenotypic variability of Atlantic salmon is key for effective fisheries management and the long term survival of salmon populations. For example, the genetic population structure of Atlantic salmon was examined in the Foyle catchment and found genetically distinct populations were separated by short geographic distances (Ensing *et al.,* 2011). Thus, Atlantic salmon populations showed extensive genetic variability. Therefore, the introduction of hatchery reared individuals would detrimentally affect this genetic structuring and result in a loss of genetic diversity (Mcintyre & Kettlewhite 2014). This loss of genetic diversity could also affect Atlantic salmon by altering life history patterning, reduced fitness and altered behavioural and morphological traits (Mcintyre & Kettlewhite 2014). In other words, using a simplified illustrative example, if Atlantic salmon were sampled from five locations within a river system, we might expect that each of these sampled locations forming a genetically distinct population (Figure 35). These genetically distinct populations form a gene pool which will be composed of genes which makes that population ideally adapted to their specific local environment (Figure 35). These adaptations could include long pectoral fins which are suited for faster flowing waters and short pectoral fins suited for slower flowing waters (Figure 35b). Differing Atlantic salmon populations could also have different tolerances to acidification with some populations surviving in acidic waters which other populations would not be able to tolerate (Figure 35a). Protecting these adapted populations is important and is why stocking should never take place where wild salmon populations are already present.

Therefore, it is important that genetic population structuring is accounted for when selecting brood stock for any stocking programme as maintaining overall genetic diversity of Atlantic salmon populations is of upmost importance. There is also a growing body of evidence which demonstrates that stocking frequently fails to increase overall Atlantic salmon production where wild fish populations and suitable habitat are already present (Bacon *et al.,* 2015). It has also been shown increasing fry production does not necessarily translate to higher parr production. Parr production is strongly density dependent due to increased competition for limited resources so there may be no overall benefit from stocking (Glover *et al.,* 2018). Therefore, stocking should only be used to re-introduce Atlantic salmon to areas which have been impacted by human activities and where there is no natural recruitment of Atlantic salmon after restoration works have taken place (Mcintyre & Kettlewhite 2014). GFT consider that a carefully designed stocking programme could be used to assist the return of salmon stocks back to areas recovering from acidification.

Another more recent methodology to re-introduce Atlantic salmon to areas where they have become extinct is translocation of wild fry. Wild fry are collected by electrofishing from the closest healthy Atlantic salmon population and are matched based on environmental variables and phenotypic traits. The fry are then translocated to the area to be stocked. This methodology saves hatchery costs but also importantly results in the stock fry being truly wild and not having been subject to domestication (Young 2017).

Therefore, in the upper River Bladnoch catchment Atlantic salmon relocation could occur, where water quality, instream and riparian improvements have been made. If any stocking or relocation of fish occurs then it would be crucial to monitor the stocked areas for at least five years to ensure stocking events have been successful in producing Atlantic salmon smolts and, ultimately, returning adults.

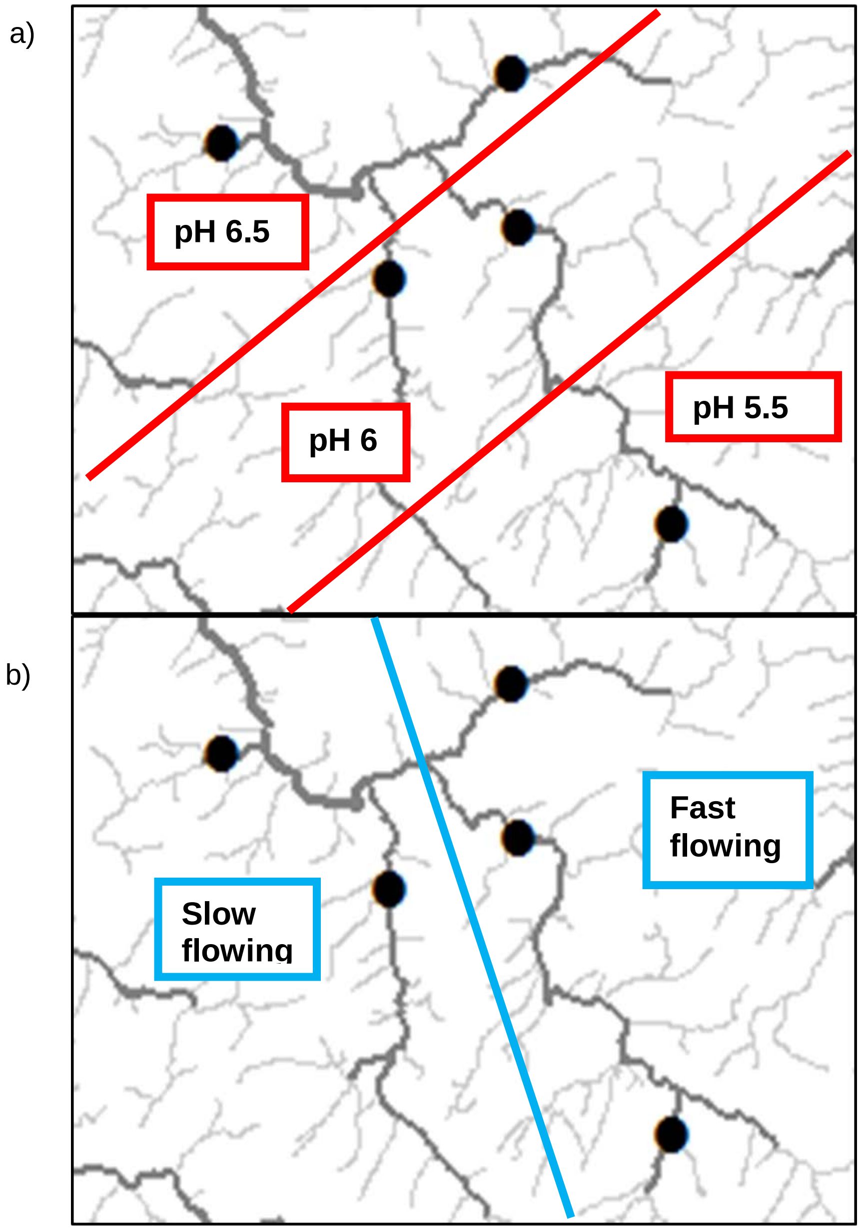

Figure 35: An illustrative example of population structure for Atlantic salmon genetic population structuring, demonstrating the extensive structuring of Atlantic salmon populations. This simplified example also demonstrated the importance of maintaining this structuring as populations are ideally adapted to their environment. a) shows five genetically distinct populations which are adapted to differing pH. However, these five populations will be adapted to many different environmental characteristics, which is illustrated in b) where five genetically distinct populations are adapted to differing water velocities

7 RECOMMENDATIONS FOR RESTORATION PROJECTS IN THE UPPER RIVER BLADNOCH CATCHMENT

This report has outlined the current status of Atlantic salmon stocks in the upper River Bladnoch catchment. There are several factors which have led to the decline of Atlantic salmon in the upper River Bladnoch catchment which includes, afforestation and peatland degradation. Despite, global legislation controlling emissions of pollutants and forestry restructuring underway, the upper River Bladnoch catchment remains acidified and is not recovering from acidification as expected. As the River Bladnoch is an SAC for Atlantic salmon and its spring run Atlantic salmon which breed in the upper River Bladnoch catchment, it is vital to improve water quality of the catchment. This report has described several restoration techniques, such as peatland restoration, forestry restructuring, liming and habitat improvements, which could be utilised for water quality improvement. Therefore, outlined below are possible restoration projects which if completed would improve water quality and/or Atlantic salmon abundance. For costings of proposed restoration works see Appendix 2.

7.1 Forestry restructure

It has been demonstrated that Galloway was afforested over a relatively short period of time with 71% of the River Bladnoch catchment being planted. Peatland was drained for these forests to be planted and as a result water quality of the upper River Bladnoch catchment declined. Forestry plantations have now reached maturity and are ready to be felled. Following forestry guidelines, once felled forests will be restructured and replanted. However, as this report has demonstrated the upper River Bladnoch catchment is an acid sensitive catchment with surface waters remaining acidified. Therefore, forestry restructuring should go a step further than following the minimum guidelines. With careful restructuring it is possible to improve water quality of the upper River Bladnoch catchment. Due to the volume of forestry needing replanted, accelerated restructuring should take place. If felling takes place during the least sensitive time of year for Atlantic salmon (summer/autumn) the negative impacts of acid flushes should be kept to a minimum. During restructuring adequate buffer zones are needed, including on small feeder streams, which if not treated appropriately, will have a negative effect on water quality of the main tributaries. Choice of deciduous trees should be carefully considered, with a mixture of species planted. Finally, areas previously planted with forestry should be considered as being left as well managed open spaces or for peatland restoration. Restoring water quality is key to improving the health of Atlantic salmon stocks in the upper River Bladnoch catchment which is only possible through large scale forestry restructuring.

7.2 Peatland restoration

As part of forestry restructuring and in open areas with degraded peatland, areas should be set aside for peatland restoration projects. Functioning peatland not only acts as a carbon store but also protects surface waters from acidification by storing pollutants. The upper River Bladnoch catchment has extensive areas of deep peat which have been drained for afforestation and agriculture (Figures 31 & 32). Current Forestry Guidelines prevent areas of deep peat from being planted. However, these guidelines also state areas which have previously been afforested must be replanted after felling. Therefore, peatland restoration is vital in the upper River Bladnoch catchment with areas being set aside during replanting for restoration. Due to most of this peatland of the upper River Bladnoch being degraded, it would all be suitable for restoration. However, it is not feasible to restore all peatland and areas should be identified which would have the biggest impact on water quality of the catchment. It could be possible to fund these peatland restoration projects through Peatland Action. However, a full scoping investigation would need to be completed to identify areas were restoration projects are feasible.

7.3 Culvert assessment

Due to extensive afforestation of the catchment, many roads have been built over the years to allow access to each forest block. Culverts used for roads to cross tributaries of the upper River Bladnoch catchment, should be assessed to determine whether they are passable for Atlantic salmon and other migratory species. Modifying culverts, ensuring that they are passable for migrating Atlantic salmon has the potential to open up areas of habitat suitable for juvenile Atlantic salmon within these tributaries.

7.4 Glassoch Burn

Glassoch Burn is a productive Atlantic salmon tributary of the River Bladnoch and runs through restructured and old mature forest (Figure 36). The old mature forest was planted along the river bank without a suitable buffer zone. This resulted in the burn being shaded with reduced productivity and water quality. Therefore, this area of forest must be restructured with an adequate buffer zone. Forestry has been restructured on one side of the burn. The riparian buffer zone of this restructured forestry would benefit from natural regeneration of Sitka spruce being removed and further planting of deciduous trees. These trees would provide dappled shade and stabilise the banks of the burn. The species of trees planted should be carefully considered, which are suitable for planting on naturally acidic peat soils.

Figure 36: This image of Glassoch Burn illustrates the lack of deciduous trees planted in the riparian zone and mature old style forestry which has been planted in close proximity to the river bank compared to the opposite bank where restructuring has occurred

7.5 Main stem River Bladnoch

The main stem River Bladnoch has several areas where restoration projects would improve both water quality and the abundance of Atlantic salmon. The lower section from Glassoch Bridge to Millgrain Hill does not have water quality issues. This section of the main stem upper River Bladnoch is comprised of a mixture of habitats, which includes slow, deep sections and good quality parr habitat. However, this section has relatively few areas with suitable spawning substrate (Figures 37 & 38). This is likely a result of the headwaters of the River Bladnoch descending from peatland, a limited gradient and lack of natural erosion. Forestry plantations stabilised the river banks to the extent no natural erosion occurs and limited substrate is deposited into the river. Therefore, there are only be a few areas with suitable spawning substrate in the main stem river. A possible restoration project is this section would be the addition of gravel or gravel raking. Gravel could be added to ten locations throughout this section and allowed to naturally disperse. Thus, increasing the availability of spawning substrate.

The next 3.5 km section of main stem River Bladnoch from Millgrain Hill to Polbae Burn outflow is adversely affected by acidification. This section of the main stem River Bladnoch also has a lack of spawning substrate. One restoration project which would temporarily improve water quality in this section is liming. Due to the River Bladnoch having extensive areas of peatland, catchment liming would not be possible. However, the addition of limestone gravel is a possibility. Limestone gravel mixed with regular gravel of appropriate size to act as spawning substrate could be added to the outflow of Polbae Burn. This would allow gravel to naturally disperse. The limestone gravel would increase the pH in the interstitial spaces protecting juvenile Atlantic salmon from acid flushes while they remain in the gravel. Before limestone gravel was added, it would be crucial to understand how gravel moves in the River Bladnoch. Therefore, trials could take place whereby gravel movement is tracked to understand how it disperses and the results of this trial would direct how limestone gravel was added.

The outflow of Loch Maberry to the outflow of Polbae Burn has again a mix of good quality juvenile Atlantic salmon habitat and this report has demonstrated water quality does not seem to be an issue. Forestry restructuring has begun in this section. Therefore, this section of river would benefit from Sitka spruce regeneration removal and planted with deciduous trees.

Finally, a stocking programme could be ran on the upper reaches of the Tarf Water, in areas which have no juvenile Atlantic salmon present. Based on this report, an area can be selected for a two-year trial stocking programme, following RAFTS protocol. This trial would be closely monitored with annual electrofishing surveys to establish if stocking had been successful. It takes three to six years for Atlantic salmon to complete their lifecycle and return as adults. Therefore, the success of each life-stage should be monitored. If stocking was successful, fry, parr and smolts should be found during electrofishing surveys.

Figure 37: River Bladnoch at Millgrain Hill which has plenty of juvenile Atlantic salmon habitat but few areas with suitable spawning substrate

Figure 38: River Bladnoch at outflow of Loch Maberry, again has plenty of juvenile Atlantic salmon habitat but few areas with suitable spawning substrate

7.6 Polbae Burn

Polbae Burn headwaters descend from sheep hill grazing into conifer plantation for most of its length (Figures 39 & 40). Forest plantations are mature forests which are planted too close to the burn. Therefore, forestry restructuring is needed on the Polbae Burn to improve water quality. Restructuring has begun and has included the addition of open spaces and peatland restoration projects. All forestry restructuring should go further than is required as the water quality of Polbae Burn affects the rest of the catchment further downstream. Open spaces have been left during recent forestry restructuring, such as that close to Blood Moss which was funded by CASS (Figure 34). These open spaces must be actively managed as they are surrounded by mature seeding conifers. This results in Sitka spruce regeneration on these open spaces which needs to be removed. The open space by Blood Moss has extensive Sitka spruce regeneration which must be removed.

Peatland restoration projects are also possible during forestry restructuring. These projects are key to restoring water quality of the upper River Bladnoch catchment. Current restructuring has including peatland restoration, such as the proposed peatland restoration project at Kilquhockadale Flow. However, this project is currently on hold but must be completed now as extensive Sitka spruce regeneration has occurred. This project once completed will help improve water quality of Polbae Burn and Dargoal Burn.

The upper Polbae Burn which is used for sheep grazing would benefit for the addition of dicideous trees. These trees would need to be planted in clusters and protected from grazing sheep by fencing. Finally, during forestry restructuring all feeder burns must be treated appropriately with buffer zones and deciduous tree planting, even if these burns do not support salmonids. Water quality will adversely affect waters downstream and their salmonid populations. Therefore, these small feeder burns should be surveyed and a programme of improvement works designed. If burns were altered during original afforestation they should be restored during forestry restructuring.

Figure 39: Polbae Burn at top of catchment before afforested area

Figure 40: Polbae Burn flowing through mature forest which was planted too close to the burn as it is completely shaded

7.7 Dargoal Burn

Dargoal Burn is a tributary of Polbae Burn and is one of the most acidified watercourses in Galloway, with a pH rarely recorded above pH 4.5. This slow, deep burn offers little suitable substrate for juvenile Atlantic salmon. However, despite not being suitable for juvenile Atlantic salmon, the water quality of this burn affects water quality further downstream and should be remedied. Unless the water quality is improved in the Dargoal Burn it is unlikely wild Atlantic salmon populations will return to the Polbae Burn. Dargoal Burn flows through degraded peatland and so peatland restoration is a priority here to improve water quality. There is currently, a peatland restoration project on hold at Kilquhockadale Flow (the headwaters of Dargoal Burn) which would greatly improve water quality. The area has been felled and is ready for peatland restoration works to begin. However, due to the delay in starting works, significant Sitka spruce regeneration has occurred which needs to be removed now (Figures 41 & 42). This peatland restoration project needs to be started urgently. Water quality will also improve as forestry is restructured and Dargoal Burn and its tributaries have appropriate buffer zones.

Figure 41: Dargoal Burn with extensive Sitka spruce regeneration along riparian buffer zone and in open spaces

Figure 42: Extensive Sitka spruce regeneration at Kilquhockadale flow

7.8 Black Burn

The Black Burn is a productive burn for juvenile Atlantic salmon, as was shown during this study. There is extensive productive habitat available for juvenile Atlantic salmon throughout the Black Burn. Therefore, there are no instream restoration projects which could take place on the Black Burn. However, the upper reaches of the Black Burn would benefit from Sitka spruce regeneration removal and deciduous tree planting. There are a series of natural waterfalls on the Black Burn (Figure 30). It is unknown if these falls are passable by Atlantic salmon during upstream migration. However, after an initial examination, it would appear, that the series of falls would be passable under the right water conditions. Further investigations would be needed to conclude if the waterfalls were passable.

The upper reaches of the Black Burn have a lower abundance of juvenile Atlantic salmon. Therefore, an Atlantic salmon stocking programme could be carried out in this area. Initially, an extensive electrofishing survey would need to be completed to conclude the distribution of Atlantic salmon on the Black Burn and identify areas which would benefit from stocking or fry translocation. A two-year trial stocking or fry translocation programme could then take place, following RAFTS protocol. This trial would be closely monitored with annual electrofishing surveys to establish if stocking or fry translocation had been successful. It takes three to six years for Atlantic salmon to complete their lifecycle and return as adults. Therefore, the success of each life-stage should be monitored. If stocking or fry translocation was successful, fry, parr and smolts should be found during electrofishing surveys. Fry translocation is recommended as the method used due to juvenile Atlantic salmon being truly wild with no hatchery or domestication effects. Therefore, fry translocation from the closest population would minimise hatchery effects and ensure survival of the fittest.

7.9 Main stem Tarf Water

The main stem Tarf Water has good juvenile Atlantic salmon habitat throughout, with the presence of deep, slow waters, boulders, cobbles and spawning substrate (Figure 43). Mature and replanted forestry are both planted back from the river. Possible improvement works would include planting deciduous trees, with the species of trees planted being carefully considered. This would provide dappled shade, woody debris input, stabilise the river bank and input nutrients into the system.

Water quality is the main limiting factor for juvenile Atlantic salmon in the main stem Tarf Water. The Purgatory Burn has poor water quality and it is likely that this has a knock-on-effect on water quality further downstream. The water quality of the main stem Tarf Water is further degraded by old style forestry plantations. All forestry should be restructured with peatland restoration and open spaces included in the redesign. A temporary restoration project while forestry restructuring occurs is liming. Due to the upper River Bladnoch catchment being predominantly peatland, catchment liming is not possible. Two possible liming projects are the addition of limestone gravel or the addition of limestone sand to forestry drains. Limestone gravel should be added in one area and allowed to naturally disperse throughout the system. It is important that the hydrology and natural dispersal of gravel is examined before limestone gravel is added. This would provide temporary protection from acid flushes for Atlantic salmon eggs and alevin. The addition of limestone sand to forestry drains would temporary increase surface water pH. The limestone sand would be added next to forestry drains and would be washed into the drains each time it rained, providing a buffer for surface water against acid flushes. The possibility of both proposed projects would need to be scoped and water quality of selected areas studies in greater detail. This would allow areas to be selected which would have the biggest impact on the catchment as a whole.

Figure 43: Main stem Tarf Water showing good productive habitat for juvenile Atlantic salmon

7.10 Un-named tributary of Tarf Water

When forestry was originally planted, small tributaries which drain into the main stem River Bladnoch and Tarf Water were diverted, channelised or straightened. An example of a tributary of the main stem Tarf Water which was diverted was an unnamed tributary at Meikle Cairns. This tributary was diverted to flow away from the forest. Restoration of tributaries like this will open up potential habitat for juvenile Atlantic salmon and improve water quality of the main stem Tarf Water. The unnamed tributary runs through an area of old style forestry and restructured forestry. The old-style forestry was planted too close to the tributary and during restructuring an appropriate buffer zone should be left and deciduous trees planted (Figure 44). This tributary should be considered for restoration to open more than a kilometre of potential juvenile Atlantic salmon habitat. This would be achieved by blocking the diverted section and force the flow of the burn back through the original channel. The burn bed of the original channel, composed of gravel, pebbles and cobbles, remains but grasses have grown in it due to the lack of flow (Figure 45). This would need to be dug out to prevent siltation problems in the main stem Tarf Water. The lower section of this tributary has been restructured and planted with Sitka spruce. Sitka spruce regeneration has occurred and should be removed from the riparian buffer zone. Where the burn meets the main stem Tarf Water, would also need to be peeled back to allow the burn to flow into the main stem. Finally, further upstream from the diverted section of river is a road culvert, which would need to be assessed to ensure it was passable for migratory fish. This would open over a kilometre of potential spawning habitat for Atlantic salmon.

Figure 44: Un-named tributary has good substrate for juvenile Atlantic salmon. Although as can be seen mature forest is planted too close to burn

Figure 45: Original burn still remains with flowing water and burn bed but grass and accumulated silts would need to be removed in restoration works

Figure 46: Original burn contains more water as it descends into replanted forestry and towards main stem Tarf Water. Forestry has either been planted too close to burn or there is extensive regrowth along burn banks

7.11 Loch Strand outflow

Loch Strand outflow has previously been monitored during electrofishing surveys and a few juvenile Atlantic salmon have been found. Therefore, improving the habitat in this burn is important. The burn is surrounded by forestry which has begun to be restructured. During this restructuring plans should consider open spaces and peatland restoration. As well as a riparian buffer being instated with deciduous tree planting. This burn has lots of potential spawning substrate and good juvenile Atlantic salmon habitat (Figure 47). However, the burn would benefit from the addition of woody debris and boulders. This would change the hydrology of the burn, creating meanders with deeper areas for juvenile Atlantic salmon to hide. The burn was channelised and straightened in the past.

Figure 47: Loch Strand outflow with good juvenile Atlantic salmon habitat evident but would benefit from the addition of woody debris

7.12 Un-named tributaries of the Tarf Water between Artfield and Horse Hill

There are many un-named tributaries which run through the mature forest and drain into the main stem Tarf Water (Figure 48). Although these tributaries are mostly narrow, slow and deep or very small and shallow this is a possible location were liming could take place. As previously mentioned there are several different techniques for liming a catchment and the best method depends of the hydrogeology of the watercourse. One possible solution would be to add powdered limestone next to these forestry burns and drains. When it rains the powdered lime would wash into the burns and drains and act as a buffer for the pollutants which will be washed into the river. This would have a knock-on effect further downstream as it would buffer against the fluctuations in pH and acid flushes.

Figure 48: Un-named tributaries on Tarf Water as they merge at culvert which is impassable for fish migration

8 CONCLUSION

This report has outlined the status of the distribution of Atlantic salmon throughout the upper River Bladnoch catchment and has shown their limited distribution is primarily attributed to acidification. This report has also highlighted, acidification of the catchment is likely the result of afforestation and peatland degradation in an acid sensitive area. Without forestry restructuring and peatland restoration it is unlikely that the water quality of the catchment will improve. Therefore, it is imperative that these works take place soon, with peatland restoration of key areas of the catchment being completed as part of forestry restructuring. Forestry structuring must consider the upper River Bladnoch catchment as an acid sensitive area and go much further than Forestry Guidelines during forestry restructuring for it to have any impact on water quality of the catchment. It is also important that all small feeder burns which have previously been planted by forestry are restored and have an appropriate buffer zone instated as poor water quality of these burns has a negative impact on the water quality of tributaries and both main stem watercourses. This is even more important when considering the status of Atlantic salmon in a catchment which has been designated an SAC for Atlantic salmon and spring run Atlantic salmon. There are areas of forestry which have been replanted and gone a step further than current planting guidelines to leave open spaces and have completed restoration projects. However, in open spaces and riparian buffer zones which are supposed to be free of Sitka spruce, extensive regeneration has occurred. These trees must be removed immediately, and open spaces and buffer zones actively managed. Due to felled forests being replanted these areas will have to be actively managed by forestry to prevent the extensive regrowth that has been demonstrated in this report. However, while forestry restructuring and peatland restoration takes place, there are several restoration projects which can take place which will contribute to the improvement of water quality and/or Atlantic salmon abundance. These projects include: deciduous tree planting, gravel addition or raking and the addition of limestone/ gravel or sand, which will improve habitat availability and temporarily water quality. It is hoped after extensive forestry restructuring and peatland restoration, water quality of the upper River Bladnoch catchment will improve and result in an increased abundance of Atlantic salmon.

9 REFERENCES

Anderson, R., Farrell, C., Graf, M., Muller, F., Calvar, E., Frankard, P., Caporn, S., Anderson, P. (2017). An overview of the progress and challenges of peatland restoration in Western Europe. *Restoration Ecology*, **25**, 271-282.

Armstrong, J.D., Kemp, P.S., Kennedy, G.J.A., Ladle, M. & Milner, N.J. (2003). Habitat requirements of Atlantic salmon and Brown trout in rivers and streams. *Fisheries Research*, **62**, 143-170.

Bacon, P.J., Malcolm, I.A., Fryer, R.J., Glover, R.S., Millar, C.P. & Youngson, A.F. (2015). Can conservation stocking enhance juvenile emigrant production in wild Atlantic salmon. *Tranactions of the American Fisheries Society*, **144**, 642-654.

Bell, A., SEPA (2014). Acidification Summary for the Upper River Bladnoch Catchment 1994-2013. (Report No. DF14/02)

Broadmeadow, S. & Nisbet, T.R. (2004). The effects of riparian forest management on the freshwater environment: a literature review of best management practice. *Hydrology and Earth System Sciences*, **8**, 286 - 305.

Byg, A. & Novo, P. (2017). Peatland Action Programme - lessons learned. *James Hutton Institute*

Cannel, M.G.R., Dewar, R.C. & Pyatt, D.G. (1993). Conifer plantations on drained peatlands in Britain: a net gain or loss of carbon? *Forestry*, **66**, 353-369.

Consuegra, S., Leániz, D., García, C., Serdio, A. & Verspoor, E. (2005). Selective exploitation of early running fish may induce genetic and phenotypic changes in Atlantic salmon*. Journal of fish biology*, **67,** 129-145.

Couto, A., Ribbens, J., Graham, J. & Beevers, N. (2015). The effect of 'liming' as a technique to mitigate acidification upon the macro-invertebrates of the River Fleet catchment, Galloway Scotland. *Sparsholt College Harmpshire, University of Portsmouth*.

Cresser, M. & Edwards, A. (1988). Natural processes in freshwater acidification. *Endeavour*, **12**, 16-20.

Edwards, A., Martin, D. & Mitchell, G. (1987). Colour in upland waters. *Proceedings of Yorkshire Water/Water Research Group Centre Workshop*

Ensing, D., Prodöhl, P.A., McGinnity, P., Boylan, P., O'Maoiléidigh, N. & Crozier, W.W. (2011). Complex pattern of genetic structuring in the Atlantic salmon (*Salmo salar* L.) of the River Foyle system in northwest Ireland: disentangling the evolutionary signal from population stochasticity. *Ecology and Evolution*, **1**, 359-372.

Environment Agency (2015). The river basin management plan for the Solway Tweed river basin district: 2015 update. 20-21.

Essex, S. & Williams, A. (1992). Ecological effects of afforestation: a case study of Burrator Dartmoor. *Applied Geography*, **12**, 361-379.

Evans, C., Jenkins, A., Helliwell, R., Ferrier, R. & Colins, R. (2001). Freshwater Acidification and Recovery in the United Kingdom, *Wallingford, England: Centre for Ecology and Hydrology*.

Evans, C.D., Monteith, D.T. & Cooper, D.M. (2005). Long-term increases in surface water dissolved organic carbon: Observations, possible causes and environmental impacts. *Environmental Pollution*, **137**, 55-71.

Forestry Commission (2014a). Managing forests in acid sensitive water catchments. *Forestry Commission Practice Guide*. (ISBN: 978-0-85538-911-6)

Forestry Commission (2014b). Managing open habitats in upland forests. *Forestry Commission Practice Guide* (ISBN: 978-0-85538-913-0)

Forestry Commission (2015). Deciding future management options for afforested deep peatland. (ISBN: 978-0-85538-927-7)

Forestry Commission (2017). The UK Forestry Standard: The government's approach to sustainable forestry. (ISBN: 978-0-85538-999-4)

Galloway Fisheries Trust (GFT) (2008). Egg box experiments at 16 sites within the River Bladnoch Catchment, examining survival rates of Atlantic salmon (*Salmo salar* L.) ova in 2008. (Report No. A4/BLA13/07)

Galloway Fisheries Trust (GFT) (2013). Upper Bladnoch salmon egg box studies. *Unpublished*

Galloway Fisheries Trust (GFT) (2012). Limestone addition in the High Cree, Year 2.

Glenk, K., Martin-Ortega, J. & Byg, A. (2017). Online Condition Assessment Support Tool. *Peatland Action, Scottish Natural Heritage.*

Glover, R.S., Fryer, R.J., Soulsby, C., Bacon, P.J. & Malcolm, I.A. (2018). Incorporating estimates of capture probability and river network covariance in novel habitat- abundance models: Assessing the effects of conservation stocking on catchment- scale production of juvenile Atlantic salmon (*Salmo salar*) from a long-term electrofishing dataset. *Ecological Indicators*, **93**, 302-315.

Godfrey, J. D. (2006). Site Condition Monitoring of Atlantic salmon SACs: *Report by the SFCC to Scottish Natural Heritage*, (Report No. F02AC608).

Grassie, C., Braithwaite, V.A., Nilsson, J., Nilsen, T.O., Teien, H.C., Handeland, S.O., Stefansson, S.O., Tronci, V., Gorissen, M., Flik, G. & Ebbesson, L.O. (2013). Aluminium exposure impacts brain plasticity and behaviour in Atlantic salmon (*Salmo salar*). *Journal of Experimental Biology*, **216**, 3148-3155.

Helliwell, R.C., Ferrier, R.C., Johnston, L., Goodwin, J. & Doughty, R. (2001). Land use influences on acidification and recovery of freshwaters in Galloway, south-west Scotland. *Hydrology and Earth System Science*, **5**, 451-458.

Hendry, K. & Cragg-Hine D. (2000). Ecology of the Atlantic salmon. *Conserving Natura 200 River,* series 7. English Nature, Peterborough.

Hendry, A. & Stearns, S. (2003). Evolution Illuminated: Salmon and their Relatives. *Oxford University Press*, 92–125.

Holden, J., Chapman, P.J. & Labadz, J.C. (2004). Artifical drainage of peatlands: hydrological and hyrdochemical process and wetland restoration. *Progress in Physical Geography*, **28**, 95-123.

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

Howells, G., Dalziel, T.R.K. & Turnpenny, A.W.H. (1992). Loch Fleet: liming to restore a brown trout fishery, *Environmental Pollution*, **78**, 131-139

Ikuta, K., Suzuki, Y. & Kitamura, S. (2003). Effects of low pH on the reproductive behaviour of salmonid fishes, *Fish Physiology and Biochemistry*, **28**, 407-410.

Kemp, P.S. & Williams, J.G. (2008). Response of migrating chinook salmon (*Oncorhynchus tshawytscha*) smolts to instream structure associated with culverts. *River Research and Applications*, **24**, 571-579.

Klemetsen, A., Amundsen, P.A., Dempson, J.B., Jonsson, B., Jonsson, N., O'connell, M.F. & Mortensen, E. (2003). Atlantic salmon *Salmo sala*r L., brown trout *Salmo trutta* L. and Arctic charr *Salvelinus alpinus* L.: a review of aspects of their life histories. *Ecology of Freshwater Fish*, **12**, 1–59.

King, T.L., Kalinowski, S.T., Schill, W.B., Spidle, A.P. & Lubinski, B.A. (2001). Population structure of Atlantic salmon (Salmo salar L.): a range-wide perspective from microsatellite DNA variation. *Molecular Ecology*, **10**, 807-821.

Kreiser, A.M., Appleby, P.G., Natkanski, J., Rippey, B. & Battarbee, R.W. (1990). Afforestation and lake acidification: a comparison of four sites in Scotland. *Philosophical Transactions of the Royal Society B*, **327**, 377-383.

Kroglund, F., Rosseland, B.O., Teien, H.-C., Sabu, B., Kristensen, T. & Finstad, B. (2007). Water quality limits for Atlnatic salmon (*Salmo salar* L.) exposed to short term reductions in pH and increased aluminium simulating episodes, *Hydrology and Earth System Science Discussions*, **4**, 3317-3355.

Lacroix, G.L., Gordon, D.J. & Johnston, D.J. (1985). Effects of low environmental pH on the survival growth, and ionic composition of postemergent Atlantic salmon (*Salmo salar*). *Canadian Journal of Fish and Aquatic Sciences*, **42**, 768-775.

Laine, J., Vasander, H. & Sallantaus, T. (1995). Ecological effects of peatland drainage for forestry. *Environmental Review*, **3**, 286-303.

Lake, P.S., Bond, N. & Reich, P. (2007). Linking ecological theory with stream restoration. *Freshwater biology*, **52**, 597-615.

Laudon, H. & Bishop, K.H. (2002). The rapid and extensive recovery from episodic acidification in northern Sweden due to declines in SO_4^{2-} deposition. *Geophysical Research Letters*, **29**, 1594.

Maitland, P.S. (1992). The status of Arctic charr, *Salvelinus alpinus* (L.), in southern Scotland: a cause for concern, *Freshwater forum*, **2**, 212-227.

Mant, R.C., Jones, D.L., Reynolds, B., Ormerod, S.J. & Pullin, A.S. (2013). A systematic review of the effectiveness of liming to mitigate impacts of river acidification on fish and macro-invertebrates. *Environmental Pollution*, **179**, 285-293.

Marine Scotland (2018). Salmon Fishery Statistics- 2017 Season. (ISBN: 978-1-78851-820-8)

Martin-Ortega, J., Allott, T.E.H., Glenk, K. Schaafsma, M. (2014). Valuing water quality improvements from peatland restoration: Evidence and challenges, *Ecosystem Services*, **9**, 34-43.

McIntyre, C. & Kettlewhite, A. (2014). Stocking of Atlantic salmon in Scotland. Technical reference paper in relation to RAFTS policy. *RAFTS* (Report No. RAFTS technical paper series 1/2014).

McMilan, A. & Stone, P. (2008). Southwest Scotland- A landscape fashioned by Geology. *Perth: Scotland, Scottish Natural Heritage.*

Milner, B.J. & Varallo, P.V. (1990). Acid Waters in Wales. *Effects of Acidification on fish and fisheries in Wales*, **8**, 121-143

Moring, J.R. (1982). Decrease in stream gravel permeability after clear-cut logging: an indication of intragravel conditions for developing salmonid eggs and alevins. *Hydrobiologia*, **88**, 295-298.

Neal, C., Reynolds, B., Stevens, P.A., Hornung, M. & Brown, S.J. (1990). Dissolved inorganic aluminium in acidic streams and soil waters in Wales. *In Edwards, R.W., Gee, A.S., Stoner, J.H. (eds). Acid Waters in Wales,* London: Kluwer Academic Publishers, 173-188.

Ormerod, S.J. & Weatherly, N.S. (1990). Forests and the Temperature of Upland Streams in Wales: A Modelling Exploration of the Biological Effects. *Freshwater Biology*, **24**, 109-122.

Peterson, R.H., Daye, P.G. & Metcalfe, J.L. (1980). Inhibition of Atlantic salmon (*Salmo salar*) Hatching at Low pH. *Canadian Journal of Fish and Aquatic Science*, **37**, 770-774.

Primmer, C.R., Veselov, A.J., Zubchenko, A., Poutukin, A., Bakhmet, I. & Koskinen, M.T. (2006). Isolation by distance within a river system: genetic population structuring of Atlantic salmon, *Salmo salar*, in tributaries of the Varzuga River in northwest Russia, *Molecular Ecology*, **15**, 653-666.

Roni, P. & Quinn, T.P. (2001). Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. *Canadian Journal of Fisheries and Aquatic Sciences*, **52**, 282-292.

Sayer, M.D.J., Reader, J.P. & Dalziel, T.R.K. (1993). Freshwater acidification: effects on the early life stages of fish, *Reviews in Fish Biology and Fisheries*, **3**, 95-132.

Schaefer, D.A., Driscoll, C.T., Van Dreason, R. & Yatsko, C.P. (1990). The Episodic Acidification of Adirondack Lakes during Snowmelt, *Water Resources Research*, **26**, 1639-1647.

Schindler, D.W. (1988). Effects of Acid Rain of Freshwater Ecosystems. *Science*, **239**, 149-157.

Schofield, C.L. (1976). Acid Precipitation: Effects on Fish. *Ambio,* **5**, 228-230.

Scottish Government (2018). Scotland's Soils; part of Scotland's environment. *Peatland Action- peat depths*, http://map.environment.gov.scot/Soil_maps/?layer=10#

Scottish Natural Heritage (SNH) (2007). River Bladnoch SAC- Atlantic salmon Catchment Management Plan.

Scottish Natural Heritage (SNH) (2014). Scotland's peatland- definitions and information resources (Report No. 701).

Scottish Fisheries Coordination Centre (SFCC) (2018). Electrofishing. *Available at: www.sfcc.co.uk/resources/electrofishing.html*

Staurnes, M., Kronglund, F. & Rosseland, B.O. (1995). Water quality requirement of Atlnatic salmon (*Salmo salar*) in water undergoing acidification or liming in Norway. *Water, Air and Soil Pollution*, **85**, 347-352.

Stimson, A.G., Allott, T.E.H., Boult, S., Evans, M.G., Pilkington, M. & Holland, N. (2017). Water quality impacts of bare peat revegetation with lime and fertiliser application. *Applied Geochemistry*, **85**, 97-105.

Stewart, A.J.A. (1963). Investigations into migratory fish propagation in the area of the Lancashire River Board. *Barber: Lancashire River Board*.

Stoner, J.H. & Gee, A.S. (1985). Effects of forestry on water quality and fish in Welsh rivers and lakes. *Journal of Institute of Water Engineer Scientists*, **39**, 27-45.

Tervet, D.J. & Harriman, R. (1988). Changes in pH and calcium after selective liming in the catchment of Loch Dee, a sensitive and rapid-turnover loch in south-west Scotland. *Aquaculture Research,* **19**, 191-203.

Thorstad, E.B., Økland, F., Aarestrup, K. & Heggberget, T.G. (2008). Factors affecting the within-River Spawning Migration of Atlantic salmon, with Emphasis on Human Impacts. *Reviews in Fish Biology and Fisheries*, **18**, 345-371

Thorstad, E.B., Whoriskey, F., Rikardsen, A.H. & Aarestrup, K. (2011). Aquatic nomads: the life and migrations of the Atlantic salmon. *Atlantic salmon ecology*, **1**, 1-23.

Wallage, Z., Holden, J. & McDonald, A.T. (2006). Drain blocking: An effective treatment for reducing dissolved organic carbon loss and water discolouration in a drained peatland. *Science of the Total Environment*, **367**, 811-821.

Weigmann, D.L., Helfrich, L.A. & Downey, D.M. (1993). Guidelines for Liming Acidified Streams and Rivers. *Virginia Water Resource Research Centre*, *Virginia*

Wright, R.F., Cosby, B.J., Ferrier, R.C>, Jenkins, A., Bulger, A.J. & Harriman, R. (1994). Changes in acidification of lochs in Galloway, southwestern Scotland, 1979-1988: The MAGIC model used to evaluate the role of afforestation, calculate critical loads and predict fish status. *Journal of Hydrology*, **161**, 257-285.

Young, A. (2017). Approaches to minimising unintended negative consequences to wild Atlantic salmon populations from hatchery and stocking activities. *Understanding the risks and benefits of hatchery and stocking activities to wild Atlantic salmon populations,* 17-32

10 APPENDIX 1

Presented here are detailed results from 16 electrofishing surveys conducted in October 2017, which are summarised in Table 3.

Site 1 River Bladnoch **Grid Reference 234523 564748**

Moderate densities of Atlantic salmon fry and low densities of Atlantic salmon parr were recorded at this survey site. No trout were present and an eel was noted.

The wetted area of this sampling site was 77.0 m^2 with an average wet width of 12.8 m (Figure 49). The depth at the sampling site was mostly ranged from 1 – 50 cm. The substrate composition was predominantly boulder, cobble, and pebble (95%) with some gravel also present. The surveyed site had riffle/run flow characteristics, which is ideal for juvenile Atlantic salmon. Instream cover was good, however, no cover was provided by bankside vegetation and instead was provided by some instream vegetation. There were a few trees present at the survey site providing shaded areas.

Figure 49: Electrofishing survey site 1 on the river Bladnoch at Shennanton looking upstream

Site 2 River Bladnoch **Grid Reference 233549 566559**

A low density of Atlantic salmon fry and very low density of Atlantic salmon parr was recorded at this sampling site. Low densities of Brown trout fry and parr were also noted. An eel was also noted.

The wetted area of this sampling site was 91.6 m^2 with an average wet width of 9.7 m (Figure 50). The depth at the sampling site was mostly 11 – 40 cm. The substrate composition was predominantly boulder and cobble (90%) with some pebble present. The surveyed site had riffle/run flow characteristics, which is ideal for juvenile Atlantic salmon. Instream cover was excellent with cover for fish provided by bankside vegetation and undercut banks. A large amount (70%) of instream vegetation was also noted. There were a few trees present at the survey site providing shaded areas.

Figure 50: Electrofishing survey site 2 on the River Bladnoch at Barfield looking upstream

Site 3 River Bladnoch (Glassoch Bridge)   Grid Reference 233333 569522

A high density of juvenile Atlantic salmon fry and moderate density of Atlantic salmon parr were recorded at this site. However, juvenile Brown trout (fry and parr) were absent and no other fish species were recorded. Atlantic salmon and Brown trout often occupy slightly different habitat niches. For example, Atlantic salmon tend to be found in shallow fast flowing waters, whereas, Brown trout prefer slightly deeper slower flowing waters. Atlantic salmon will also outcompete Brown trout. Thus, when good densities of Atlantic salmon are found, low densities of Brown trout would be expected as this survey targeted habitat juvenile Atlantic salmon would utilise as they were the focal species of this study.

The wetted area of this sampling site was 71.9 m^2 with an average wet width of 11 m (Figure 51). The depth at the sampling site was mostly 10 – 40 cm and substrate composition was predominantly cobble and pebble (65%) with some gravel and boulders present. The surveyed site had riffle/run flow characteristics, which is ideal for juvenile Atlantic salmon. Instream cover was moderate with cover for fish provided on the left bank by trees (mostly willows) and an undercut bank. No cover was provided by the right bank. A small amount of instream vegetation was also present. The site also benefited from canopy cover providing shaded areas.

Figure 51: Electrofishing survey site 3 at Glassoch Bridge looking upstream

Site 4 River Bladnoch **Grid Reference 231600 570600**

A high density of Atlantic salmon fry and very low density of Atlantic salmon parr were recorded at this site. Low densities of Atlantic salmon parr would be expected at the time of year the survey took place as they drop lower down the system for better food resources. Brown trout fry were present at this site in low densities. Brown trout parr and other fish species were absent from this site.

The wetted area of this sampling site was 147.6 m^2 with an average wet width of 12.3 m (Figure 52). The depth at the sampling site was mostly 10 – 40 cm and substrate composition was predominantly cobble, boulder and pebble (100%). The surveyed site had riffle/run flow characteristics, which is ideal for juvenile Atlantic salmon. Instream cover was good with cover for fish provided by undercut banks and bankside vegetation, as well as, a small amount of instream vegetation. There was no canopy cover to provide shaded areas for fish but there was a conifer plantation on the right bank.

Figure 52: Electrofishing survey site 4 on the River Bladnoch looking upstream

Site 5 River Bladnoch **Grid Reference 230129 570819**

Again, a high density of Atlantic salmon fry was present at this site. Atlantic salmon parr were absent. Low densities of Brown trout fry and parr were also present.

The wetted area of this sampling site was 63.5 m^2 with an average wet width of 7.5 m (Figure 53). The depth at the sampling site was mostly 10 – 50 cm and substrate composition was predominantly boulder, cobble and pebble (65%). The surveyed site had riffle/run flow characteristics, which is ideal for juvenile Atlantic salmon. Instream cover was good with cover for fish provided by trees roots, bankside vegetation and undercut banks, as well as, a small amount of instream vegetation. There was no canopy cover present at this site.

Figure 53: Electrofishing survey site 5 on River Bladnoch looking upstream

Site 6 River Bladnoch (Waterside) **Grid Reference 229100 572100**

No Atlantic salmon fry were present at this survey site and Atlantic salmon parr were found at a very low density. However, Brown trout fry and parr were recorded at low densities.

The wetted area of this sampling site was 63.0 m^2 with an average wet width of 5.4 m (Figure 54). The depth at the sampling site was mostly 10 – 40 cm and substrate composition was predominantly cobble and pebble (80%) with some gravel and boulders present. The surveyed site had run flow characteristics. Instream cover was moderate with cover for fish provided by bankside vegetation and undercut banks, as well as, a small amount of instream vegetation. There were no trees present at this site to provide canopy cover.

Figure 54: Electrofishing survey site 6 at waterside looking upstream

Site 7 River Bladnoch (Polbae Burn outflow)   Grid Reference 228625 572831

No Atlantic salmon fry were recorded during this survey and a very low density Atlantic salmon parr was recorded. However, a good density of Brown trout fry and low density of Brown trout parr was recorded at this sampling location.

The wetted area of this sampling site was 56.1 m^2 with an average wet width of 6.1 m (Figure 55). The depth at the sampling site was mostly 10 – 30 cm and substrate composition was predominantly boulder, cobble and pebble (90%) with some gravel present. The surveyed site had riffle/run flow characteristics, which is ideal for juvenile Atlantic salmon. Instream cover was moderate with cover for fish provided on the right bank by bankside vegetation and an undercut bank. There was no cover provided by the left bank. A small amount of instream vegetation was also present. There were no trees at the site to provide canopy cover.

Figure 55: Electrofishing survey site 7 on river Bladnoch downstream of Polbae Burn outflow (picture taken looking upstream)

Site 8 River Bladnoch (Loch Maberry outflow) **Grid Reference 222600 569350**

No Atlantic salmon were recorded at this site. However, low densities of Brown trout fry and parr were recorded. An eel was also recorded during this survey.

The wetted area of this sampling site was 88.0 m^2 with an average wet width of 6.7 m (Figure 56). The depth at the sampling site was mostly 20 – 40 cm and substrate composition was predominantly boulder and cobble (80%) with some pebble present. The surveyed site had complex flow characteristics, which was predominantly deep slow gliding run. Instream cover was good with cover for fish provided by bankside vegetation and undercut banks, as well as, a small amount of instream vegetation. There were no trees present at the survey site to provide shaded areas.

Figure 56: Electrofishing survey site 8 at Loch Maberry outflow looking upstream

Site 9 River Bladnoch, Polbae Burn **Grid Reference 228500 572800**

No Atlantic salmon were recorded at this sampling location. However, low densities of Brown trout fry and parr were recorded. One pike was also present.

The wetted area of this sampling site was 46.4 m^2 with an average wet width of 3.9 m (Figure 57). The depth at the sampling site was mostly 10 – 30 cm and substrate composition was predominantly cobble and pebble (65%) with some boulders and gravel present. The surveyed site had predominantly run flow characteristics, with some riffle and slow glide characteristics also noted. Instream cover was moderate with cover for fish provided by bankside vegetation and undercut banks, as well as, a small amount of instream vegetation. There were a few trees present at the survey site which provide some shaded areas.

Figure 57: Electrofishing survey site 9 on Polbae Burn looking upstream

Site 10 River Bladnoch, Black Burn **Grid Reference 232255 567146**

Excellent densities of Atlantic salmon fry and parr were recorded at this sampling site. However, no other fish species, including Brown trout, were recorded.

The wetted area of this sampling site was 51.7 m^2 with an average wet width of 6.6 m (Figure 58). The depth at the sampling site was mostly 1 – 20 cm. The substrate composition was predominantly cobble, and pebble (70%) with some boulder and gravel present. The surveyed site had riffle/run flow characteristics, which is ideal for juvenile Atlantic salmon. Instream cover was moderate with cover for fish provided by bankside vegetation and undercut banks. A small amount of instream vegetation was also noted. There were a few trees present at the survey site providing shaded areas.

Figure 58: Electrofishing survey site 10 on Black Burn looking downstream

Site 11 River Bladnoch, Tarf Water **Grid Reference 225497 564771**

A moderate density of Atlantic salmon fry and a high density of Atlantic salmon parr fry where found at this sampling location. Brown trout fry were also present at an acceptable density but Brown trout parr were absent. Two eels were also noted.

The wetted area of this sampling site was 77.6 m^2 with an average wet width of 9.7 m (Figure 59). The depth at the sampling site was mostly 11 – 20 cm but ranged from 1 – 40 cm. The substrate composition was predominantly cobble and pebble (80%) with some boulders and gravel present. The surveyed site had riffle/run flow characteristics, which is ideal for juvenile Atlantic salmon. Instream cover was moderate with cover for fish provided on the right bank only by bankside vegetation and an undercut bank. A small amount of instream vegetation was also noted. There were a few trees present at the survey site providing shaded areas.

Figure 59: Electrofishing survey site 11 at Tarf Bridge looking upstream

Site 12 River Bladnoch, Tarf Water **Grid Reference 225246 566167**

A low density of Atlantic salmon fry and no Atlantic salmon parr were found at this survey location. Low densities of Brown trout fry and parr were also recorded. No other fish species were present.

The wetted area of this sampling site was 146.5 m^2 with an average wet width of 8.1 m (Figure 60). The depth at the sampling site was mostly 11 – 30 cm. The substrate composition was a mixture of boulder (25%), cobble (35%), pebble (20%) and gravel (20%). The surveyed site had riffle/ run flow characteristics, with small sections of deep, slow glide. Instream cover was good with cover for fish provided by bankside vegetation and undercut banks. A small amount of instream vegetation was also noted. There were no trees present at the survey site to provide shaded areas.

Figure 60: Electrofishing survey site 12 on Tarf Water looking upstream

Site 13 River Bladnoch, Tarf Water **Grid Reference 225107 566751**

A very high density of Atlantic salmon fry was recorded at this sampling site which was the result of stocking in early 2017. This site will require further monitoring to establish if stocking was successful. Low densities of Atlantic salmon parr and Brown trout fry were recorded. No Brown trout parr were present.

The wetted area of this sampling site was 77.4 m^2 with an average wet width of 7.4 m (Figure 61). The depth at the sampling site was mostly 1 – 40 cm and substrate composition was predominantly boulder, cobble and pebble (95%) with some gravel present. The surveyed site had complex flow characteristics, which was predominantly deep slow gliding run with a small section of riffle. Instream cover was good with cover for fish provided by bankside vegetation and undercut banks, as well as, a small amount of instream vegetation. There were no trees present at the survey site to provide shaded areas.

Figure 61: Electrofishing survey site 13 on Tarf Water looking upstream

Site 14 River Bladnoch, Tarf Water **Grid Reference 224744 567206**

A low density of Atlantic salmon fry was recorded at this sampling site. However, no Atlantic salmon parr, Brown trout fry or Brown trout parr were recorded at this sampling location.

The wetted area of this sampling site was 66.7 m^2 with an average wet width of 7.4 m (Figure 62). The depth at the sampling site was mostly 11 - 30 cm but ranged from 1 – 40 cm. The substrate composition was predominantly cobble and pebble (75%) with some boulders and gravel present. The surveyed site had complex flow characteristics, which was a deep, slow gliding run with some riffle present. Instream cover was good with cover for fish provided by bankside vegetation and undercut banks. A small amount of instream vegetation was also noted. There were no trees present at the survey site to provide shaded areas.

Figure 62: Electrofishing survey site 14 on the Tarf Water looking upstream

Site 15 River Bladnoch, Tarf Water **Grid Reference 223851 568448**

No Atlantic salmon fry or Brown trout parr were recorded at this sampling location. However, very low densities of Atlantic salmon parr and Brown trout fry were recorded at this sampling site.

The wetted area of this sampling site was 87.5 m^2 with an average wet width of 5.1 m (Figure 63). The depth at the sampling site was mostly 11 – 20 cm but ranged from 1 – 40 cm. The substrate composition was predominantly cobble, pebble and gravel (90%) with some boulder present. The surveyed site had run flow characteristics. Instream cover was moderate with cover for fish provided by bankside vegetation and undercut banks. A small amount of instream vegetation was also noted. There were no trees present at the survey site to provide shaded areas.

Figure 63: Electrofishing survey site 15 on Tarf Water looking upstream

Site 16 River Bladnoch, Tarf Water, Purgatory Burn **Grid Reference 222685 568873**

No fish species were recorded at this sampling location.

The wetted area of this sampling site was 33.8 m^2 with an average wet width of 1.8 m (Figure 64). The depth at the sampling site was mostly 1 – 30 cm. The substrate composition was predominantly boulder, cobble and pebble (90%) with some gravel present. The surveyed site had complex flow characteristics, which were predominantly riffle/run with some deep slow flowing sections. Instream cover was moderate with cover for fish provided by bankside vegetation and an undercut on the right bank. No instream vegetation was noted and there were no trees present at the survey site to provide shaded areas.

Figure 64: Electrofishing survey site 16 on the Tarf Water looking upstream

11 APPENDIX 2: COSTINGS OF POSSIBLE RESTORATION PROJECTS

Table 8: Estimated cost of restoration projects which can be conducted on the upper River Bladnoch to improve water quality and/or Atlantic salmon abundance. These costs are estimates and all projects would need to be accurately costed before funding applications are submitted. Costings are broken down to show cost of materials and management costs. Management costs include work such as getting permissions, organising projects, materials, contractors and volunteers, completing RAMS etc

No.	**Watercourse**	**Restoration Techniques**	**Length / Area**	**Benefits of project**	**Estimated costs (exc. VAT)**		
					Materials/ Contractors	**Management fee**	**Volunteers (V) or Contractors (C)**
1	Glassoch Burn	Deciduous tree planting	1.43 km	Planting along river bank to provide shade, woody debris and nutrient input	£460 for 200 trees	£1000	V
		Sitka regeneration removal		Removal of Sitka to improve water quality	£2500	£500	C
2	Main stem Bladnoch (Glassoch bridge-Millgrain Hill)	Gravel addition or raking at 10 sites	5 km	Increase available spawning substrate/beds	£8000	£2000	C
		Deciduous tree planting		Planting along river bank to provide shade, woody debris and nutrient input	£690 for 300 trees	£1000	V
3	Main stem Bladnoch (Millgrain Hill- Polbae outflow)	Limestone gravel addition	3.58 km	Increase available spawning substrate/beds with improved water quality to protect juveniles from acid flushes	£30 000	£7000	C
		Forestry restructure		See No. 14			
		Peatland Restoration		See No. 13			
4	Main stem River Bladnoch (Loch	Sitka regeneration removal	1.45 km	Removal of Sitka to improve water quality	£2500	£500	C

	Maberry outflow-Polbae Burn outflow)	Deciduous tree planting		Planting along river bank to provide shade, woody debris and nutrient input	£460 for 200 trees	£1000	V
5	Polbae Burn	Head waters deciduous tree planting	2.2 km	Planting along river bank to provide shade, woody debris and nutrient input, trees must be planted in enclosures to provide protection from sheep	£460 for 200 trees and £3880 for 4 fenced enclosures	£1000	V and C
		Middle and lower reaches extensive forestry restructuring	5 km (main stem only)	See No. 14			
		Peatland regeneration	n/a	See No. 13			
		Sitka regeneration removal	18 ha	Removal of Sitka to improve water quality	£27000	£500	C
		Small streams running through forest assessed and restored	n/a	Improve water quality	£2000	£1000	C
6	Dargoal Burn	Forestry restructuring	n/a	See No. 14			
		Peatland regeneration	n/a	See No. 13			
7	Black Burn	Fry translocation programme	n/a	Move fry from healthy population in Black Burn upstream to areas with no Atlantic salmon	£2000	£1000	C
		Deciduous tree planting	18 km	Planting along river bank to provide shade, woody debris and nutrient input-trees should be concentrated in the upper 5 km	£690 for 300 trees	£1000	V

8	Main stem Tarf Water	Stocking	n/a	Stock in areas with no Atlantic salmon to help river recover from past acidification	As part of BDSFB and GFT arrangement		
		Peatland restoration	n/a	See No. 13			
		Forestry Restructuring	n/a	See No. 14			
		Deciduous tree planting	8.5 km	Planting along river bank to provide shade, woody debris and nutrient input	£1150 for 500 trees	£1000	V
9	Un-named Tributary (Meikle Cairns)	Whole stream restoration	1 km	Increase available habitat and improve water quality	£25 000	£500	C
10	Loch Strand outflow	Addition of woody debris and boulders	0.4 km	Naturally encourage river to meander and provide habitat	£7000	£3000	C
11	Un-named tributaries at Horse Hill, Tarf Water	Liming	n/a	Temporarily improve water quality	£10 000	£5000	C
		Forestry Restructuring	n/a	See No. 14			
12	Upper Tarf Water	Peatland Restoration	n/a	See No. 13			
13	All	Peatland Restoration	Target 200ha	Improve water quality with target areas which will have the biggest impact	£ 600 000	£5000	C
14	All	Forestry Restructuring	n/a	Improve water quality	n/a	£2000 for consultation, campaigning and raising awareness of forestry issues	C
15	All	Culvert assessment	Whole catchment	Assess all culverts to ensure passable and provide advice on redesign	£2000	£1000	C