An Analysis of Suitable Juvenile Salmon Habitat within the River Annan Catchment

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Abstract

Wild Atlantic salmon stocks are in decline across Scotland, one of the areas affected is the river Annan catchment in Dumfries and Galloway. One of the best means of assisting in the salmons' recovery is the improvement of suitable freshwater habitat, assisting in youth survival, and increasing the rate of births. At the request of the River Annan Trust, historical electrofishing and habitat survey data was analysed with the intention of better understanding the relationships that exist between habitat quality and salmon density. The results of these findings were then used to assess each main tributary within the Annan catchment and prioritise them for restoration work, suggesting means for their management. The results showed that the Milk, the Kinnel and the Mein were the three tributaries most in need of restoration, with problems being found in substrate composition, flow and siltation. It was also found that there is a lack of suitable riparian habitat near catchment wide. It is the recommendation of this study the restoration work be undertaken to improve the Milk, Kinnel and Mein, and that changes be made to current electrofishing and habitat survey protocol to assist with future studies of this nature.

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1. Introduction and Review of Literature

The River Annan is located in Dumfries and Galloway in the south west of Scotland. It begins slightly north of the town of Moffat, flowing from the southern uplands, the same hills that birth the Tweed and the Clyde. It is joined by nine main tributaries as it makes its way south towards the coast, eventually ending near the town of Annan, where it joins the Solway Firth (The River Annan Trust and District Fisheries Board, 2018). The river's catchment encompasses 650 square kilometres and is split into smaller sub-catchment areas, one for each of the nine main tributaries and a tenth covering the River Annan ("the Annan") itself (The River Annan Trust and District Fisheries Board, 2018). The Annan is one of the many rivers and fisheries across Scotland that attracts not only local but also international anglers due to the quantity and quality of fish it contains. A particularly prized catch within the Annan and other Scottish rivers is the Atlantic salmon, *Salmo salar.* Atlantic salmon angling generates around £90 million a year for rural economies in areas such as Dumfries and Galloway, and creates over 2000 jobs (Scottish Government, 2018c). The species is valuable not just to modern Scotland, carvings of salmon found at multiple locations across the country dating from the times of Picts and Celts demonstrate its importance to the nation's early culture (Scottish National Heritage, 2018). Indeed the species historically played such an important role in the formation of some locations in Scotland that it can be seen in their names, such as Laxdale on the Isle of Lewis and the River Laxford in Sutherland which both contain the Norse word for salmon, "Lax" (Scottish National Heritage, 2018).

In part due to its continued growth in popularity for food and sport, wild stocks of the species have been in decline for decades and the drop in their numbers has been noticed in all of Scotland's salmon bearing rivers. Some rivers have lost their population entirely and others such as the Annan are reporting record low catch numbers (The River Annan Trust and District Fisheries Board, 2018). Scotland's rivers provide 75% of the UK's wild Atlantic salmon, and as such the Scottish Government has taken steps to help protect this valuable species within its waters (Scottish Government, 2018a). Implemented in 2016, the Conservation of Salmon (Scotland) Regulations prohibited the retention of any salmon caught within Scotland's coastal waters, or caught in any rivers that were classified as category 3 meaning that their salmon populations were likely to be at an unsustainable level (Scottish Government, 2018a). Despite the implementation of this policy salmon numbers within Scottish rivers have shown a continued decline. In 2016, 82 rivers were classed as category 3; of the 171 rivers assessed in 2018 that number had risen to 123 one of which was the Annan (Scottish Government, 2018a). As a direct result of this decline the Scottish Government has broadened that initial policy and as of 2018 there is a nationwide catch and release policy in place, banning the retention of salmon caught in any Scottish river regardless of its category (Scottish Government, 2018c).

The River Annan Trust (RAT), inaugurated in 2010, works alongside the River Annan District Salmon Fishery Board in support of its work to maintain the health of the Annan's catchment area, the extent of which is illustrated in Figure 1. One of RAT's key roles has been to continue the Board's ongoing work conducting electrofishing and habitat surveys within the catchment area. These surveys are conducted to monitor salmon levels and the condition of their available freshwater habitat and have been compiled into a dataset. Following the 2017 salmon season this dataset now holds information from around 1,150 electrofishing events recorded at almost 200 sites dating from 1997 to 2017. RAT believe that by increasing the availability and quality of suitable habitat within the catchment they may assist local Atlantic salmon populations in their recovery. They have therefore requested that a project be undertaken to analyse their dataset and that available salmon habitat be assessed in order to determine which areas of the catchment are most in need of restoration work. This project aims to address that request. It will initially analyse the RAT dataset to search for relationships between salmon numbers and the recorded instream and bankside habitat variables. It will also analyse the habitat survey data collected by RAT in 2017 and rank each of the main tributaries based on their habitat condition relative to the findings of the initial analysis. Using the results of these analyses, suggestions will be made as to which areas of the catchment could potentially best benefit from restoration efforts and the suggested methods of management. Finally, the project will suggest changes to the current electrofishing and habitat survey collection protocol, in order to assist with future monitoring of the health of the catchment area.

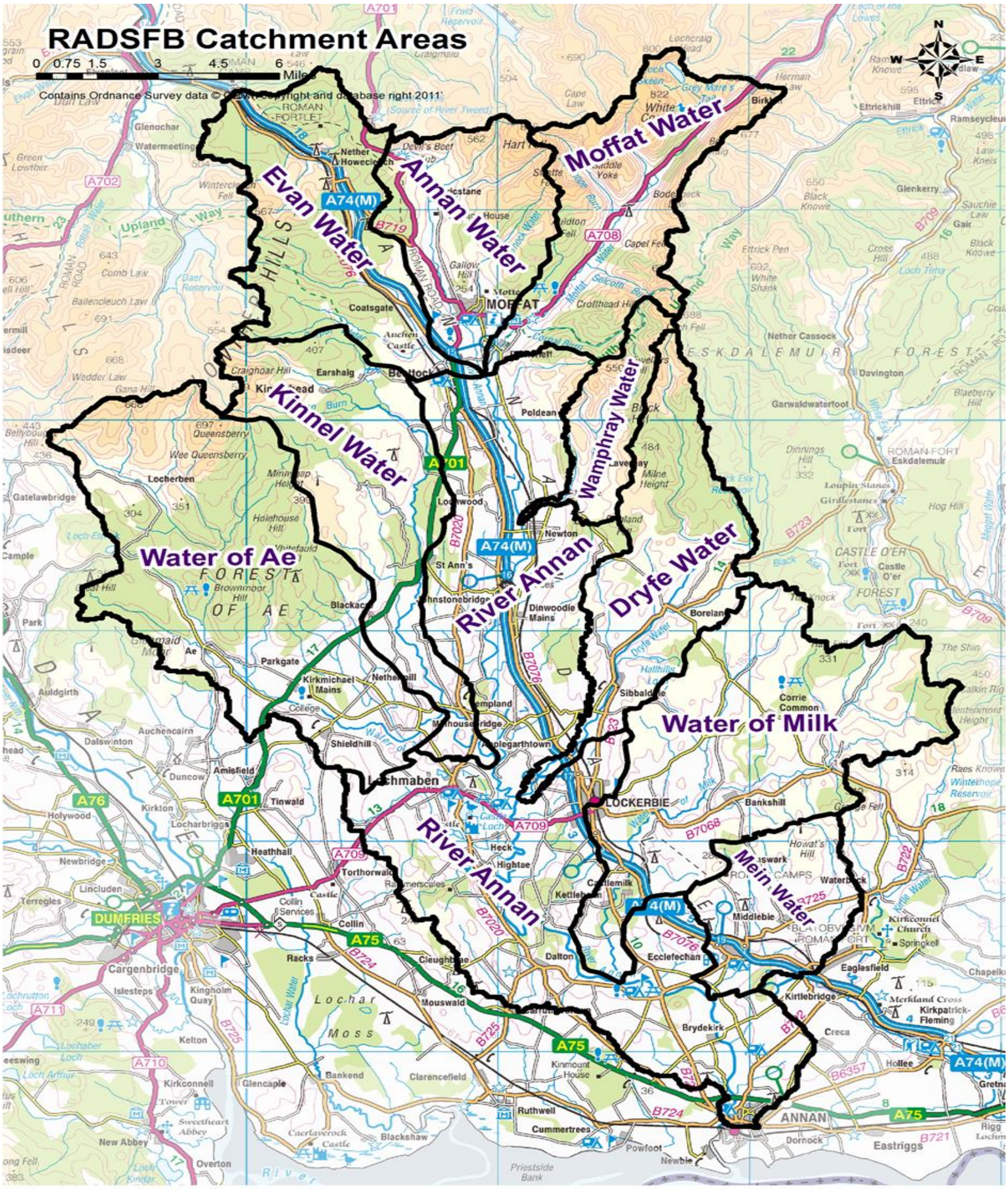

Figure 1: The River Annan catchment area, including the boundaries of sub-catchment areas.

1.1 Species Ecology

1.1.1 Lifecycle

Though it draws its name from the Atlantic Ocean where it feeds and matures, the Atlantic salmon begins its life in inland rivers and streams. It is an anadromous fish, moving between fresh and saltwater at different stages in its life (Lacroix and McCurdey, 1996). In autumn or winter adult females use their tails to create small indents in the riverbed substrate into which they lay their roe of eggs, these nests are known as "redds" and each female can produce around 1,100 eggs per kg of body weight (Louhi *et al*., 2008, Moir *et al*., 2002). The eggs are immediately fertilised by a male, and then covered by a protective layer of gravel as debris is discarded during the creation of more redds upstream, the spent females then retreat downstream and the males stay to try to fertilise more eggs (Crisp, 2000). Salmon prefer to create their redds amongst gravel beds in areas of fairly shallow and relatively fast flowing clean water to provide a steady oxygen supply to the eggs (Bardonnet and Baglinière, 2000; Louhi, *et al*., 2008). The eggs remain in the redd developing through the winter before hatching the following spring (Rimmer *et al*, 1983).

The newly hatched salmon, known as "alevins", initially stay close to the nest relying on their yolk sack for nutrition, but after around a month they develop into "fry" and begin to venture out from the nest in search of food. After the end of their first summer in the river the young salmon have grown substantially and are known as "parr" (Bardonnet and Baglinière, 2000; Jonsson, 2016). After up to three years in the river the parr begin to change in behaviour and appearance in order to prepare for migration. They also develop the ability to moderate the salt content within their body, allowing them to survive at sea, this process is known as osmoregulation (Aas, 2011). After undergoing this change the fish are known as "smolts" and begin to leave the rivers in shoals, heading towards their feeding grounds in the North Atlantic Ocean and the Barren Sea just off the coast of Norway. Once they have left the rivers they become known as "post-smolts" (Youngson *et al*, 1983). After their first winter feeding at sea the now adult salmon are known as "grilse" and they undergo rapid growth due to changes in morphology and diet. Following their second winter at sea they are known as "multi-sea-winters" or MSW's (Lacroix and McCurdy, 1996). The salmon will feed at sea for a further one to three years before being compelled to attempt the long journey back to the river of their birth to themselves spawn and begin the cycle again. After spawning the spent salmon are known as "kelts" (Crisp, 2000; Jonsson, 2016; Lacroix and McCurdy, 1996).

Due to the Atlantic salmon's migration and anadromous lifecycle the species must deal with a range of threats and pressures not experienced by most fish. Their reliance on freshwater habitats for breeding and early development limits the species to only the available and accessible environments within its range, habitats which have been steadily in decline due to urban expansion and industrialisation (Eggilshaw *et al*, 1986). The journey to reach these shrinking spawning grounds is vast and dangerous and will eventually claim the life of almost all the salmon that undertake it (Flemming, 1996; Thorpe, 1994). They become almost frenzied in their urgency to spawn, and as a result most salmon do not feed during the journey, relying instead on the fat reserves they have accrued whilst feeding at sea (Crisp, 2000; Jonsson, 2016). This fasting combined with the rigours of the journey and the physical exertion it requires results in many of the salmon losing a significant portion of their body mass, sometimes as much as 40% (Aas, 2011). Those that manage to successfully battle upstream and traverse any natural and man-made barriers and survive predation often have very little remaining strength when they eventually reach their spawning grounds (Jonsson, 2016; Thorpe, 1994). In this weakened state should the salmon be unable to find suitable spawning grounds in the area of the river they have been drawn to they may not have the strength to move on in search of a another site. As a result some will die without being able to reproduce (Youngson *et al*., 1983). Once they have spawned the vast majority are left so weak that they die and consequently only a very small number, around 3 – 6%, survive to attempt the return journey to sea (Flemming, 1996; Jonsson, 2016, Mills, 1989).

By better defining the relationships that exist between salmon and habitat within the Annan catchment, this project will provide information to assist RAT in their aim to improve and expand available salmon habitat within the Annan and its tributaries. By improving the availability and quality of these habitats it may be possible to alleviate some of the pressures created by the species' ecology and reliance on freshwater environments.

1.1.2 Biological Importance of Species

The Atlantic salmon is a keystone species, meaning that similar to the keystone at the centre of a bridge it plays a vital role in the support and maintenance of its surrounding ecosystem (Butler *et al*., 2009). As the fish is also anadromous it plays an important if not essential role in both the fresh and saltwater environments to which it belongs. As the adults die off in large numbers following spawning their bodies decompose in the water, enriching the environment for their young and for other species that share the river (Jonsson, 2016). While in the rivers the young parr moderate the numbers of insects and smaller species of fish on which they feed, while fry and parr both provide an excellent source of food for brown trout and heron (Butler *et al*., 2009). Once at sea the post-smolts and grilse feed on numerous species such as sand eels again moderating their numbers and in turn are fed upon by large cod and Greenland sharks. Larger salmon provide a food source for dolphins and both grey and common seals (Atlantic Salmon Trust, 2018). When returning to Scottish rivers to spawn the species is predated upon by birds and by otters, in many cases the otters are unable to finish the adult salmon in one meal and as a result the remains left on the bankside are then fed upon by other species such as small birds, rodents or badgers (Butler *et al*., 2009, Buck and Hay, 1984). In the past when bears inhabited Scotland they too would catch the returning salmon, often carrying them far from the river into wooded areas to feed upon them. The remains would then decompose enriching the soil, and benefiting surrounding plant life, this ecosystem service is now to a degree carried out by otters and larger birds which may sometimes carry caught salmon away from the water before feeding (Buck and Hay, 1984, Klemetsen *et al*., 2003).

Further to these roles in both fresh and saltwater, the Atlantic salmon also has a special relationship with the freshwater pearl mussel, playing a vital role in its development. The larvae of the pearl mussel have a semi parasitic relationship with the fish, attaching themselves to its gills from summer until spring (Smith, 1995). This appears to have no ill effects on the fish and recent research suggests the relationship may in-fact be symbiotic with both species helping each other; the salmon during the mussels' larvae stage, and the mussels later in their life by filtering the water in the river system improving the water quality for the salmon (Smith, 1995). The importance of the Atlantic salmon to biodiversity both on land and in fresh and saltwater, is why it is recognised and listed in annexes II and V of the European Union Habitats Directive as a species of European importance. Further to this as a member state of the Convention on Biological Diversity, the UK is committed to do all it can to avoid any further loss of biodiversity (JNCC, 2016).

The decline in wild Atlantic salmon numbers poses a risk to more than just the salmon itself, the integral role it plays in its environment and in the lives of other species that share that environment mean that its loss or even decline could have wide ranging consequences. If improving habitat within the Annan catchment is successful in increasing the number of young salmon born within the river system and consequently the number of adults returning then it will enhance the benefits that this species brings to all environments in its lifecycle and the species that share them.

1.2 Species Distribution and Decline

Historically the species was widely distributed across all countries whose rivers entered the North Atlantic Ocean. However as was briefly mentioned in the previous section the available freshwater habitat for the species has been steadily shrinking due to anthropogenic pressures (Friedland *et al*., 2000). This is particularly due to a decrease in water quality and available habitat caused by changes in industrial and agricultural practices, urban expansion and an increase in man-made barriers to migration such as dams (Youngson *et al*., 1983, Louhi *et al*., 2008). This has resulted in a reduction in available habitat for the species with a consequent decline in fish numbers and in some extreme cases has resulted in the species becoming locally extinct in rivers that previously supported healthy populations such as the River Mersey and other industrial rivers in England (Todd *et al*., 2008). Despite this reduction in available freshwater habitat, many rivers across the species' range have been able to maintain thriving wild fish populations, and its distribution still spans from Portugal to North America, including rivers in Spain, the UK, Ireland, France, Norway, Sweden and some Canadian provinces (Parrish *et al*., 1998). Within Britain the Atlantic salmon historically had a very wide and abundant distribution, in Scotland in particular virtually all rivers are important to the species and at one time supported a salmon population (Eggilshaw and Shackley, 1985). Despite its historic abundance in Scotland habitat loss and degradation have caused salmon to disappear from some rivers entirely, and a great many others are showing salmon populations that are in steep decline (Millar *et al*., 2016).

The decline in species numbers first began to draw increased attention in the 1980's, the total declared salmon catch (net and rods) in England and Wales declined from approximately 119,200 fish in 1983, to about 43,200 fish in 1998. Similarly the total reported catch in Scotland fell from around 500,000 fish in 1975 to below 190,000 fish per year in the mid 1990's (NASCO, 2018). Though this decline in net and rod catches can in part be explained by a decline in effort, that is to say less fishing took place due to an increase in the availability of farmed Atlantic salmon, the Atlantic Salmon Trust (AST) report that wild stock numbers have fallen from around 9 million in the 1980's to around 4 million in 2016 (Atlantic Salmon Trust, 2018). This could in part be explained by the reduction in freshwater habitat quality and availability, however it would appear that larger problems may be occurring while the salmon are at sea. While monitoring the decline in wild stock numbers the AST also observed a decline in adult return rates (adults surviving their time at sea and returning to rivers to spawn) from over 15% on the 1980's to less than 5% in 2016 (Atlantic Salmon Trust, 2018).

The increased rate of mortality at sea has been attributed to several key drivers: overfishing, global warming and the expansion of aquaculture. Though legislation such as the E.U. Common Fisheries Policy and bans on coastal netting are designed to protect wild stocks against overfishing, illegal netting does still occur (Butler *et al*,. 2009). As does the overfishing of other species such as sandeel and blue whiting both of which are a staple food source for the salmon, their overfishing has led to a decline in food abundance and an increase in competition (NASCO, 2018). Climate change has amongst other factors resulted in warmer sea temperatures, this has upset the trophic cascade and the salmon's position within it, and this in turn has resulted in a decreased food supply for the species and an increase in competition and predation against it (Friedland *et al*., 2000, Todd *et al*., 2008). The final and perhaps biggest driver in wild stock decline is the expansion of offshore aquaculture and the subsequent inappropriate and bad management of coastal fish farms (Costello, 2009).

Aquaculture is one of the fastest growing industry sectors in Scotland, with Atlantic salmon production dominating the sector and accounting for around 95% of all finfish production (Scottish Government, 2018b). The speed at which the industry is growing is almost entirely due to the popularity of farmed Scottish salmon which sells across the world, production in 2005 was 129,588 tonnes but by 2015 this had increased by over 30% to 171,722. Aquaculture in Scotland is now estimated to generate around £1.86 billion in revenue a year (Scottish Government, 2018d). Although this provides a substantial contribution to Scotland's economy, farmed Atlantic salmon aquaculture creates 3 main threats to wild fish: disease and parasites, habitat loss and lastly the problems caused by escaped farmed fish. Keeping a large number of salmon in very close quarters has created a near perfect breeding ground for potentially fatal salmonid diseases and parasites such as the sea louse (Murray *et al*., 2003, Costello, 2009). Though sea lice regularly feed on the salmon in the wild they do so in very small numbers, huge populations of lice are able to breed within the fish farms (Costello, 2009). When wild salmon swim near the farms, the lice are able to feed on them in far larger numbers than would usually occur, this can often prove fatal to the salmon particularly when they are young (Aas, 2011).

Environmental damage also occurs around badly managed fish farms as waste, food and chemical treatments for disease and parasites pass through the fish cages to the sea floor beneath (Thorpe, 1994). This can greatly upset the local ecosystem, killing plant life and affecting any fish that pass through the area (Murray *et al.,* 2003). Escapees from the fish farms present two threats to wild fish, firstly by competing with them for food resources and secondly through genetic dilution of the wild stock (Thorpe, 1994). Genetic dilution occurs when the escapees breed with wild fish as they are genetically different having been bred to grow and fatten quickly. This dilution weakens the wild stock lessening their chance of survival (Aas, 2011). By positioning many fish farms in estuaries or along salmon migratory paths the aquaculture industry exacerbated the negative impacts the farms had upon wild stocks by increasing the likelihood of wild fish coming into contact with the farms and the problems they presented. In response to these problems the Scottish Government is moving to ban "open net" fish farms, which will reduce the number of escapees, and to tighten legislation regarding farm positioning and management, however combatting these problems may not in itself be enough to allow the species to recover.

The decline in available freshwater habitat may not be one of the current main drivers in the decline of the species, however it has over time limited the species' range and therefore numbers (Millar *et al*., 2015). With so many threats faced by the species while at sea it is important that the fish have a large number of good condition breeding grounds to ensure a high rate of births and also youth survival. This is a major factor in ensuring that fish leave rivers in sufficient numbers to endure the high rate of mortality experienced at sea and still return to rivers in adequate numbers to maintain their population (Armstrong *et al*., 2003). Should the salmon's available habitat in rivers such as the Annan continue to shrink and decline in quality then the number of young fish surviving to leave those rivers may reach an unsustainable level. By identifying which sub-catchments within the Annan catchment are most in need of restoration and suggesting means by which to improve them, this project will assist in combatting Atlantic salmon habitat loss, increasing its range and assisting the species in its recovery.

1.3 Statistical Modelling to Determine Catchment Health.

Currently several possible methods exist to determine catchment health relative to wild fish production. The HABSCORE system developed for England and Wales by the National Rivers Authority and Environment Agency utilises statistical modelling to predict ideal population densities based on pre-established habitat variables. Once predicted this density can then be compared to the rest of the catchment to give an idea of its relative health (Milner *et al*., 1998). Though proven to be successful in England and Wales, HABSCORE is not currently compatible with Scottish rivers as it requires information on variables that are not currently included in the Scottish Fisheries Co-Ordination Centre (SFCC) habitat survey method that is used by fisheries across Scotland (Millar *et al*., 2015, Malcolm *et al*., 2016). A paper published by Millar *et al* in 2015 attempted to address this, proposing and developing a two stage likelihood modelling approach for the "R" statistical software package. This model similar to the HABSCORE method could be used to understand, characterise and predict Atlantic salmon fry density in Scottish rivers using Geographic Information System (GIS) derived covariates such as distance from sea or altitude (Malcolm *et al.*, 2016; Millar *et al*., 2015). The approach was proved to be successful and in 2016, Millar attempted to expand the model further to allow it to assess density for multiple species and life stages simultaneously, however as of yet this work remains incomplete (Malcolm *et al.*, 2016; Millar *et al*., 2016).

Later studies have developed upon Millar's model and it has now been used with some success to determine the health of salmon fry populations in rivers around Scotland (Malcolm *et al*., 2016). In 2016, a study in the River Dee catchment area in Aberdeen, Scotland, used the model to assess the health of Atlantic salmon fry populations. It used the model to determine a catchment reference level against which individual sites or tributaries could be compared (Malcolm *et al*., 2016; Millar *et al*., 2015). The Dee study ran sites from across the catchment through *Millar et al*'s model to create an overall estimate of catchment density, from which it was able to find the average density figure (Malcolm *et al*., 2016). Individual site densities could then be compared to this average to provide an idea of their "health" relative to the rest of the catchment similar to the HABSCORE method (Malcolm *et al*., 2016). The method was found successful in determining catchment and juvenile population health, but as with Millar's model it is limited in scale, assessing only a single species and life stage at a time (Malcolm *et al*., 2016). Though these studies have found some success in the application of Millar's national density model it is not yet fully developed; also some of the variables/covariates required to fit the model are not obtainable without the use of advanced GIS software that cannot itself be accessed without the appropriate licenses.

As neither the HABSCORE method nor Millar's national density model can currently be used to assess the river Annan and its catchment area, it is necessary to develop a method to achieve this. By looking for the patterns that exist between density and habitat and then determining a list of ideal site conditions against which other sites can be compared, this project will attempt to develop a means to assess the catchment's health. It will also try to suggest changes to the electrofishing and habitat survey systems currently in use within the Annan catchment to assist with future studies into this topic.

2. Research Questions & Objectives

1. What patterns exist between instream and bank side habitat quality and salmonid density specific to the River Annan catchment area?

2. What is the current habitat condition within each of the main tributaries (sub-catchments) within the River Annan catchment area relevant to salmonid production?

3. Which areas of the catchment should be prioritised for restoration/remedial works and what are the suggested management options?

4. In what ways could electrofishing and habitat survey procedures be improved to allow more effective monitoring of the catchment in future?

Decreasing salmon levels within the River Annan catchment area have made it necessary to take further steps to better understand and protect this international resource and if possible assist with its recovery. By better defining the existing relationships between habitat and density, and prioritising areas for restoration, this project will assist the River Annan Trust in its mission to maintain and improve the River Annan catchment area making it a better environment for salmonids.

3. Methods

This project is an entirely desk-based study, utilising pre-existing data. Two datasets were made available to the researcher for this project, firstly electrofishing results and habitat survey data collected by RAT and secondly salmon fry and parr density estimates provided by SEPA, those estimates having been derived from the electrofishing results collected by RAT. The SEPA density estimates were created using the capture probability model created in 2015 by Millar *et al,* as was previously explained they provide a more accurate estimation of salmon population sizes than those derived simply using electrofishing catch results and the area fished. The project's first aim is to attempt to find any relationships that exist between salmon density and habitat quality within the catchment. Its second aim is to assess suitable salmonid habitat within the catchment and prioritise which sub-catchments are most in need of restoration and suggest means by which to do so.

3.1 Data Preparation

The original dataset provided by the RAT for analysis consisted of three Microsoft Excel spreadsheets, the first contained information from 1150 electrofishing events conducted between 1997 and 2017 (Appendix 1). The second contained their corresponding habitat surveys (Appendix 2) and the third was a compilation of both sets of results, which from here on is referred to as the RAT master spreadsheet (Appendix 3). The density estimates provided by SEPA consisted of one spreadsheet containing 479 density estimates for electrofishing events within the Annan Catchment between 1997 and 2015 (Appendix 4).

The electrofishing and habitat survey results contained within the RAT master spreadsheet were collected over a 21 year period by a variety of different team members and for a variety of purposes. Therefore following consultation with the current RAT team, it was decided that all data collected before 2011 would not be used during analysis as they could not guarantee its accuracy. Also at the direction of the RAT team, all results from 2015 were removed as they were not entirely representative of the catchment or of true conditions having been compiled specifically to assess the impact of windfarms which had been constructed in the local vicinity. This part of the data cleansing process reduced the dataset from the original number of 1150 electrofishing events to 540.

Next, any results that RAT deemed to be not indicative of true conditions at the site were identified and removed, as were any events that had been incorrectly recorded or were missing data values. Any events carried out for any purpose other than regular catchment monitoring were removed as it was a concern to RAT they may have been conducted for reasons that could introduce bias. Any sites that had multiple events recorded within a single year were then identified and the first event of the year was kept, any subsequent visits to the same site in that year were deleted. The next stage was to combine the remaining RAT dataset with the SEPA density estimates, this involved filtering through the remaining RAT dataset and matching each habitat survey to the correct fry and par density estimate using their unique event ID codes, any habitat surveys conducted between 2011 and 2014 inclusive that did not have a corresponding density estimate were at this point removed as they could not be used for analysis as were any density estimates from before 2011.

The dataset now contained electrofishing, habitat survey and density values from between 2011 to 2014 and electrofishing and habitat survey results for the years 2016 and 2017. As the second stage of analysis for this project required an assessment of the most recent catchment condition the 2016 results were at this point removed from the dataset, they lacked density estimates and therefore could not be used for analysis and they did not represent the most up to date conditions within the catchment. The remaining dataset, from here on referred to as the final dataset (Appendix 5), contained 240 rows and 88 columns all containing information related to fish density, habitat conditions and event details such as equipment used.

This project contains two sets of analyses, each one using subsets of the final dataset. First, various habitat variables are compared to salmonid density to draw out any patterns that exist. Second, referring to any patterns found in the first stage, the habitat variables for each of the main tributaries to the river are assessed to determine their condition relative to salmonid production.

The first stage of analysis makes use of only those events with a corresponding density estimate against which variables can be compared. Therefore all events from the year 2017 which will be used during the second stage were removed to a separate dataset, now referred to as the habitat assessment dataset (Appendix 7). Next any data that was recorded at sites that had been listed as being affected by anthropogenic variables stronger than other habitat conditions were removed as these could skew results. This removed any sites that were not accessible to salmon or were not known to be, any sites that had been stocked and any that were recorded within the dataset as suffering from pollution or siltation. This left 67 individual electrofishing events with corresponding habitat variables and fry and parr density estimates that were not affected by strong anthropogenic drivers. The 88 columns contained information on density, habitat and event details, any that were irrelevant to the project or any variables that were recorded as not being present at all electrofishing events were removed before analysis. The remaining set of data formed an excel spreadsheet containing 67 rows and 52 columns and from here on is referred to as the pattern analysis dataset (Appendix 6).

As the intention of the second stage is to assess each of the main tributaries, all survey results contained within the habitat assessment dataset were organised by sub-catchment area (each representing the catchment for one of the main tributaries). As some habitat surveys had been conducted within the main river Annan sub-catchment these were removed as they did not pertain to any of the main tributaries.

3.2 Data Analysis

For the first stage of analysis R data analysis software was selected, specifically RStudio version 3.4.4, created by the R Foundation for Statistical Computing. In 2017 the IEEE (Institute of Electrical and Electronics Engineers) ranked the R package as the 6th best programming language in the world, of the top 6 languages ranked R is the only one designed specifically for data analysis as opposed to app or program creation (IEEE Spectrum: Technology, Engineering, and Science News, 2018). R is also designed to be very compatible with Microsoft Excel, which is used to store all datasets used in this project, further R is totally free to download and use and there are many online guides and tutorials as to its use. Consequently R was decided to be an appropriate vehicle for data analysis for the first stage of this project.

The analysis consisted of correlation calculations and the creation of scatterplot matrices. For the correlation calculation Spearman's method of correlation was selected over Pearson's or Kellog's. Spearman's was chosen as the variables were predicted to have a curved relationship with density as opposed to linear, for which Spearman's method is recommended (Artusi *et al*., 2002).

The formula required for Spearman's correlation is as follows (where *x* and *y* represent the variables which are to be compared).

"cor(x, y, method = "spearman")"

The formula required to create a matrix of scatterplots is as follows (where *x* and *y* represent the number columns (*x*) and rows (*y*) to be contained within the matrix).

"par(mfrow = c(x,y))"

The formula required to fit each scatterplot within the matrix is as follows (where x and y represent the variables being compared, *xx* and *yy* represent the minimum and maximum values for the y axis variable and *xy, yx* the minimum and maximum for the x axis).

“plot(x, y, main= "Scatterplot Title", ylab = "Y Axis Title", xlab = "X Axis Title", ylim = c(xx, yy), xlim = c(xy, yx))”

The second stage of analysis is observation based and is conducted entirely within Microsoft Excel. Any patterns or ideal ranges suggested by the results of the first stage are compared to reported conditions at each site within each sub-catchment. Next the percentage of sites within each sub-catchment within the suggested ideal range for each variable is calculated giving an approximation of each sub-catchment’s condition relative to each variable. Once this is completed a total percentage for all variables is created for each sub-catchment, this allows them to be ranked relative to each other. Those with the lowest percentages are deemed overall to be the furthest away from suggested ideal conditions. Once this ranking is established the lowest ranking sub-catchments/tributaries can be assessed in greater detail to determine which areas of bankside and instream habitat variables are most in need of restoration/remedial work. Based on these findings suggested management options will be made.

3.3 Project Limitations

Following the advice of the RAT team only four years’ worth of data was included in the pattern analysis dataset. This limited the effectiveness of the pattern analysis data stage, and to a degree the conviction of its findings. Ideally the dataset would be significantly larger and would consist only of results from years where salmon populations within the catchment were at a fully stocked level ensuring no influences other than habitat were affecting density. As salmon population levels within the catchment have been in decline for several years this was not possible.

4. Results and Discussion

4.1 Relationships between Density and Habitat in the Annan Catchment

As explained in the methods section (Section 3), the first stage of analysis in this project is comparing salmon density estimates to on-site habitat variables, this is broken into two stages, instream habitat and bankside habitat.

4.1.1 Density and Instream Habitat

For the purpose of analysis instream habitat variables have been grouped into three subcategories, general instream habitat, substrate composition and flow.

4.1.1.1 Density and General Instream Habitat

Figures 2 and 3, display the comparison between salmon fry and parr densities and four general instream habitat variables. Two of these variables pertain to substrate condition, one refers to the percentage of the site that has instream vegetation and the last describes the quality of the instream cover available at the site.

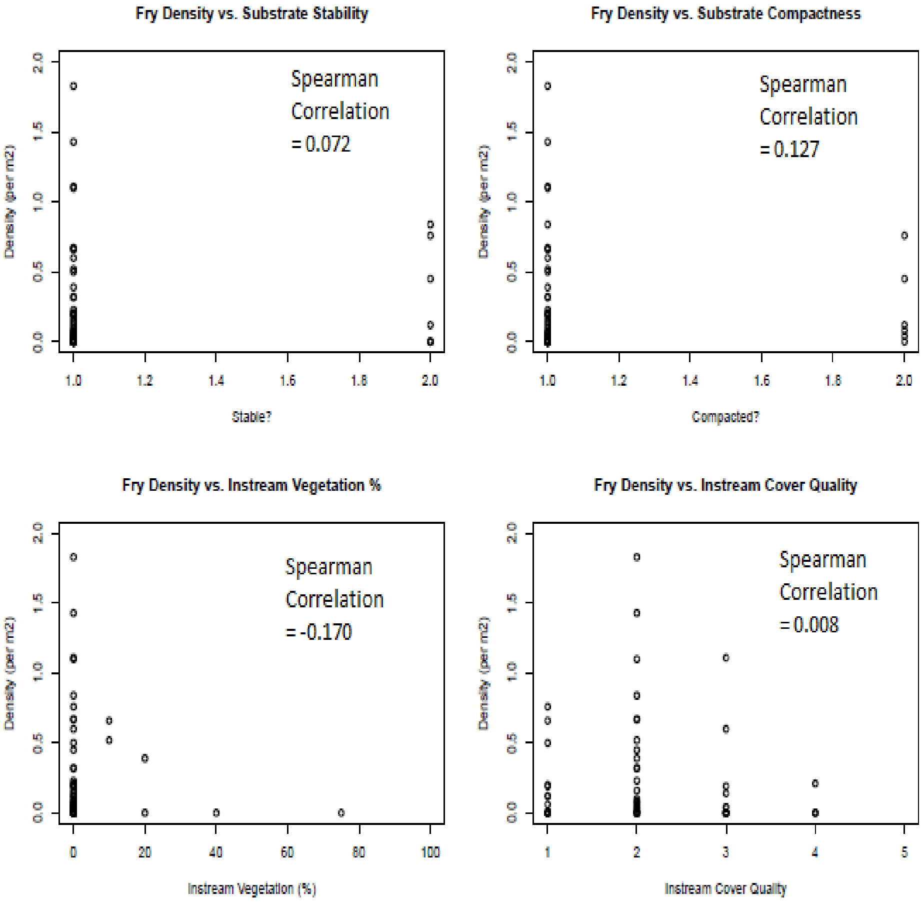

Figure 2. Fry Densities Compared to General Instream Habitat.

Substrate Stability	
1	Stable
2	Unstable
Compactness	
1	Uncompacted
2	Partly Compacted
Instream Cover	
1	Excellent
2	Good
3	Moderate
4	Poor
5	None

Key for Figures 2 and 3.

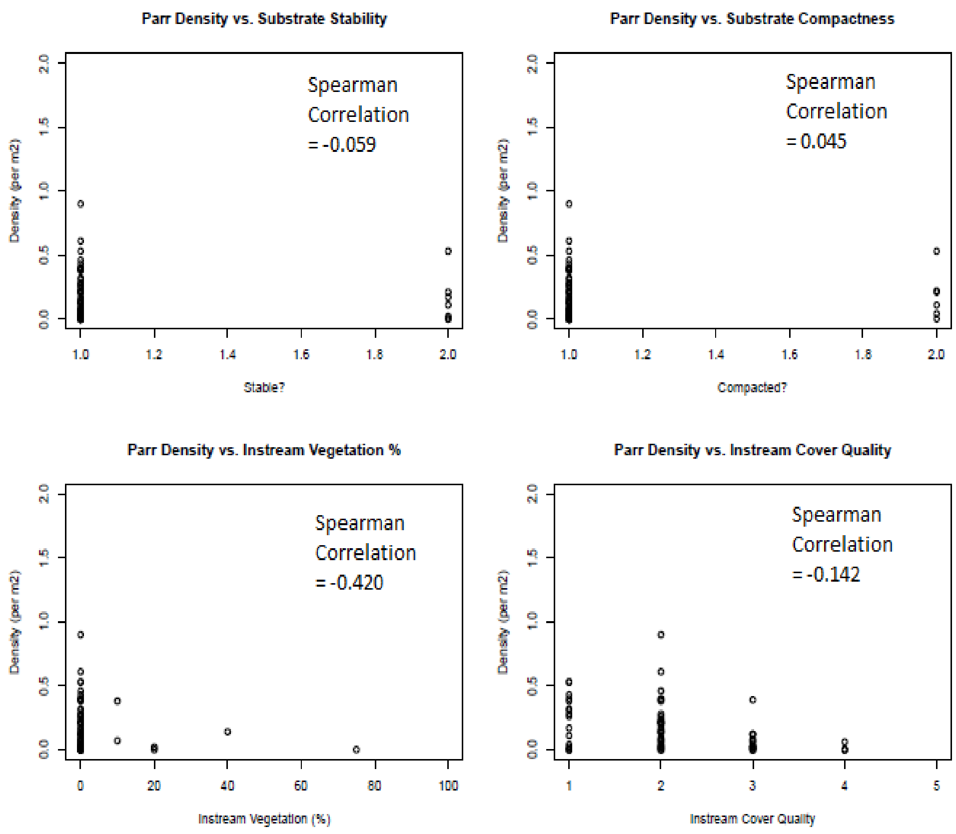

Figure 3. Parr Densities Compared to General Instream Habitat.

Figures 2 and 3 each contain four scatterplots, one for each of the four aforementioned general instream habitat variables. The corresponding calculation of correlation for each relationship has been added to the top right of each scatterplot. Viewing figures 2 and 3 it is apparent that both the stability and compactness of the substrate may have an effect on both fry and parr density. Though no relationship is found through the Spearman correlation calculations this may be as in the dataset there are significantly more events recorded at sites that are stable and sites that are un-compacted than those that are unstable and compacted (61 versus 6). However when assessing the scatterplots by eye, it seems that a stable and un-compacted substrate results in higher fish densities for both fry and parr but particularly at the fry life stage. A more even distribution of results would be needed in order to confirm this relationship through correlation calculations. The findings of the visual assessment of the plots concurs with the currently accepted beliefs on preferred salmon habitat, a stable and un-compacted substrate provides a very suitable environment for spawning (Armstrong *et al.*, 2003). As the substrate is un-compacted the salmon are able to dig redds into it, as it is also stable it will not be easily washed away following rain or an increase in flow rate, providing a very suitable spawning environment (Rimmer *et al.*, 1983).

The instream vegetation percentage for each site is determined by what percentage of the surveyed area contains plant life. The Spearman correlation calculations for both fry and parr show a minor negative correlation between fish density and the degree of instream cover present, showing -0.170 and -0.420 respectively. Though this would initially suggest that there is a negative relationship in place, that is to say that as the presence of instream vegetation increases the number of fish decreases, this would challenge the currently accepted position that the presence of some instream cover is in fact beneficial to salmon habitat (Louhi *et al*., 2008). Instream vegetation can provide shelter from the sun, river flow and predators and it can provide a source of food as insects that live in the portion of the plant above the water line can fall in (Bardonnet and Baglinere, 2000). Further its presence in the river can also change the substrate make up, as gravel and small stones collect around the base of the vegetation forming gravel banks. These gravel banks are utilised during spawning for the creation of redds and can also create riffles in the water flow providing a prime environment for parr to hide (Gard, 2013). The potentially non-representative relationship displayed by the Spearman calculation, may have occurred as similar to the findings of the previous paragraph the instream vegetation values are unevenly distributed with 62 of the 67 events contained within the pattern analysis dataset reporting 0% instream vegetation. This imbalance could skew results as it makes it appear as though a lack of instream vegetation results in higher densities. However a visual scan of the scatterplot shows that there are also many low densities found at sites with no instream cover. As a result it is believed that the instream cover percentage at these sites is not the variable responsible for the corresponding high densities. Therefore based on the data within the pattern analysis dataset no relationship can be identified between the presence of instream vegetation and salmon density within the Annan catchment and it will therefore be removed from the next stage of analysis.

Instream cover quality is ranked as one of five possible categories: excellent, good, moderate, poor and none. When compared to fry and parr densities using Spearman's correlation no significant relationship is found at either life stage, however a visual appraisal of the "Density vs. Instream Cover" scatterplots shows that the best densities are found at sites ranked either good or excellent as was expected. Instream cover is very useful for protecting the salmon from predation therefore sites with good – excellent cover should be able to support and offer protection to larger salmon populations (Moir *et al*., 2002). As a result this is suggested as the ideal range.

4.1.1.2 Density and Substrate Composition

Figures 4 and 5 display the analyses of substrate composition vs density. For the surveys of the instream habitat at each site the substrate composition was recorded as a combination of nine potential constituent categories: high organic, silt, sand, gravel, pebble, cobble, boulder, bedrock and obscured. The surveyor allocated a percentage to each of these categories according to the makeup of the substrate with the value for all categories totalling 100% when combined. Two of these categories, high organic and obscured have been removed from this stage of analysis as neither were recorded as being present at any of the sites included in the pattern analysis dataset. As a result only seven variables will be assessed at this point with regards to substrate composition.

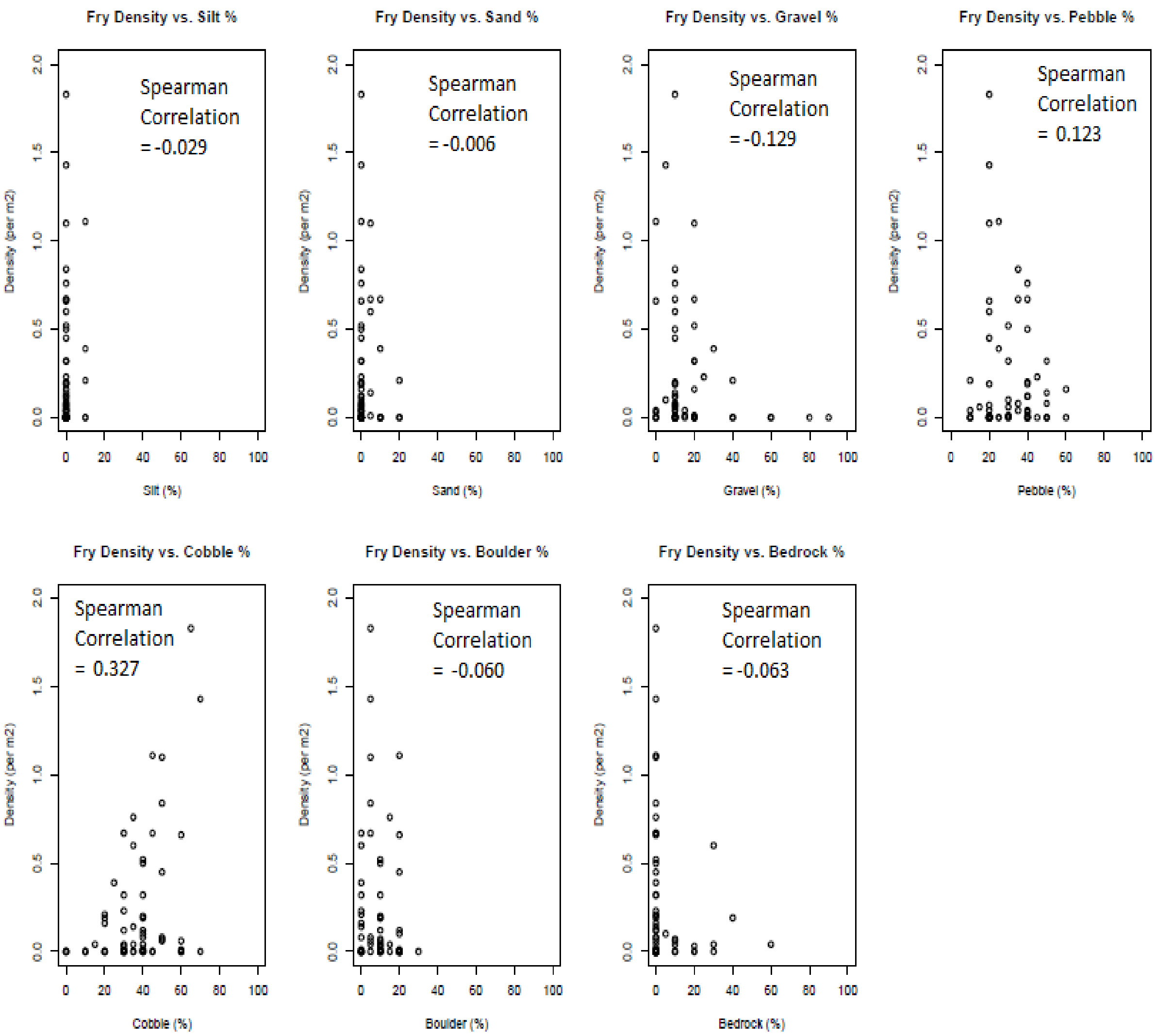

Figure 4. Fry Densities Compared to Substrate Composition.

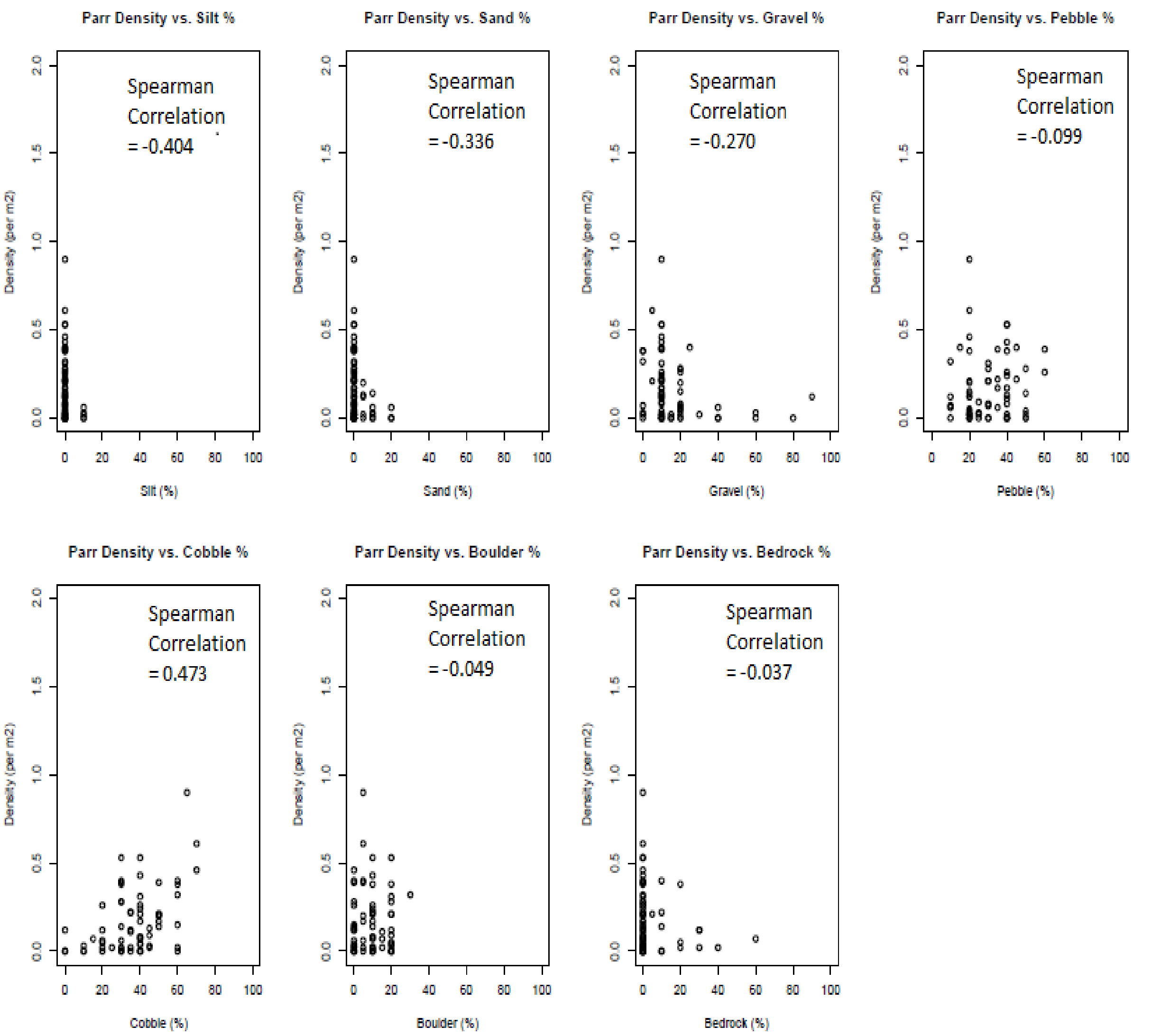

Figure 5. Parr Densities Compared to Substrate Composition.

Both fry and parr favour a substrate consisting of a variety of different sized stones and gravel, the stones provide shelter and the gravel is the perfect environment for aquatic invertebrates on which the young fish feed (Louhi et al., 2008). As these variables each play a unique role for the salmon when the substrate becomes mainly or even entirely composed of one and not the others, it can have a negative effect on local salmon populations. Alternatively the presence of some variables such as sand or silt in even small amounts can also have an equally negative effect on salmon populations. Sand and silt can fill the gaps between the gravel on the riverbed, cutting off one of the main food sources for young salmon (Gard, 2013). When silt and sand have filled in the substrate in this way it also creates problems for adult salmon when excavating redds as it can prevent them from being able to dig sufficiently deep to keep the eggs protected (Rimmer *et al*., 1983). Redds that are built too close to the surface or in silt or sand can easily be washed away following rain. Studies have shown that if sediment or silt enters a redd it can often result in the suffocation of the salmon within and should the sediment/silt level within the redd reach 13% it was found that no young would survive (Moir *et al*., 2002).

As very few entries within the pattern analysis dataset were conducted at sites where silt or sand was present the strength of this relationship is not immediately visible when viewing their scatterplots, similar to the issues encountered while analysing the influence of instream vegetation on density. The Spearman's correlation calculation failed to find any strong patterns between fry density and the presence of silt or sand, whereas parr density showed two reasonably strong negative correlations, -0.404 and -0.336 for silt and sand respectively. This difference in results between fry and parr can possibly be explained again by the distribution of values within the pattern analysis dataset; the fry density values in the scatterplot are more widely dispersed along the y axis than those of parr for which the vast majority lie between 0 and 0.5 (salmon per square metre). Therefore parr indicate a stronger relationship than fry. Based on these results the acceptable range for both sand and silt content within a substrate is less than 5%.

Gravel is essential for the spawning process of the Atlantic salmon and as mentioned earlier it also provides an environment for aquatic invertebrates that offer a great source of food for fry and young parr (Bardonnet and Bagliniere, 2000). However as is visible in the scatterplots displaying density vs gravel, when a substrate becomes primarily or even entirely composed of gravel it can have a negative effect on species numbers. Though offering some benefits to the young salmon it does not provide the same cover or shelter from predation and heavy river flow that larger stones do. As a result a negative correlation was found for both fry and parr for this variable, when viewing the scatterplots however it is apparent that when gravel content makes up between 10 – 30% of the substrate salmon populations are at their most dense. Therefore this suggests that this range may offer preferable conditions for the young salmon. As a result it is suggested that the ideal percentage of gravel within substrate composition is around 10 - 30%.

Pebbles and cobbles form a vital part of the young salmon's habitat, salmon can hide amongst them or take shelter in the broken water behind larger stones (Gard, 2013). Spearman calculations show very minor relationships between fry and parr density and pebbles, 0.123 for fry and -0.099 for parr. A visual assessment of their scatterplots however reveals the best density results for both fry and parr occur when pebbles account for between 20 and 40% of the substrate. The Spearman correlation results for density vs cobbles show some of the strongest correlation of any results so far, fry show a positive 0.327 and parr a stronger yet 0.473. These results combined with a visual appraisal of the cobble scatterplots confirm a positive relationship between cobble presence and salmon density at both life stages. By viewing the scatter plots there are indications that both fry and parr densities are at their highest when cobbles make up 30 to 50% of the substrate. Therefore it would appear that ideally pebbles should account for around 20 - 40% of the substrate and cobbles around 30 - 50%.

Boulders can provide good breaks in river flow, salmon hiding behind them are able to take respite from the river flow. Boulders that also break the surface of the water create riffles or broken water, these riffles hide the salmon from any bankside or airborne predators (Armstrong *et al*., 2003). Neither fry nor parr appear to have a strong relationship with the presence of boulders in the substrate with both Spearman calculations returning a result of less than -0.1. The boulder vs fry scatterplot however shows similarities to the fry vs gravel scatter plot as do their parr counterparts. From this it would appear that similar to gravel, boulders should ideally make up a portion of the substrate but a relatively minor one, around 10 – 30%, the range at which the best densities correspond. As the best densities are found within this range and boulders provide an important role in improving habitat quality for the fish, it would appear that boulders should ideally account for around 10 - 30% of the substrate.

Similar to sand and silt, bedrock does not offer the range of advantages to salmon that cobbles or gravel provide. Bedrock often forms a solid sheet along the river bed, depriving the salmon of hiding places, shelter and underwater food sources. Adults cannot create redds in areas of bedrock as they are unable to dig into it, also a smooth river increases flow speed, sweeping away food and shelter from the area (Gard, 2013). The Spearman correlations both show a very slight negative relationship between bedrock and density, but viewing the scatterplots it is apparent that this may simply be because the vast majority of sites assessed did not have bedrock present therefore in the pattern analysis dataset there is very little evidence of the negative effects it can have on density. Viewing the small number of results recorded at sites with even as little as 10% bedrock it is possible to see the effect bedrock can have. Of the 14 sites where bedrock was present only one fry and two parr densities are recorded at over 0.25 fish per square metre. From the results of this project it would appear that ideally bedrock should compose less than 5% of the substrate.

4.1.1.3 Density and Flow

Similar to the assessment of a site's substrate, when recording the river flow at a site this is determined by considering eight variables each of which is allocated a percentage of the total flow. These variables are: still/marginal (<10cm deep, smooth surface, water flow is still and silent), deep pool (>=30cm deep, smooth surface, water flow is slow and silent), shallow pool (<30cm deep, smooth surface, water flow is slow and silent), deep glide (>=30cm deep, smooth surface, water flow is moderate/fast and silent), shallow glide (<30cm deep, smooth surface, water flow moderate/fast and silent), run (unbroken standing surface waves, water flow fast and silent), riffle (broken standing surface waves, water flow fast and audible) and torrent (white water, chaotic and turbulent flow, noisy). Just as with the section comparing substrate composition and density, this section will look to establish at what range of each flow variable the best densities occur, thereby developing an ideal or preferred range for each, relative to salmon density.

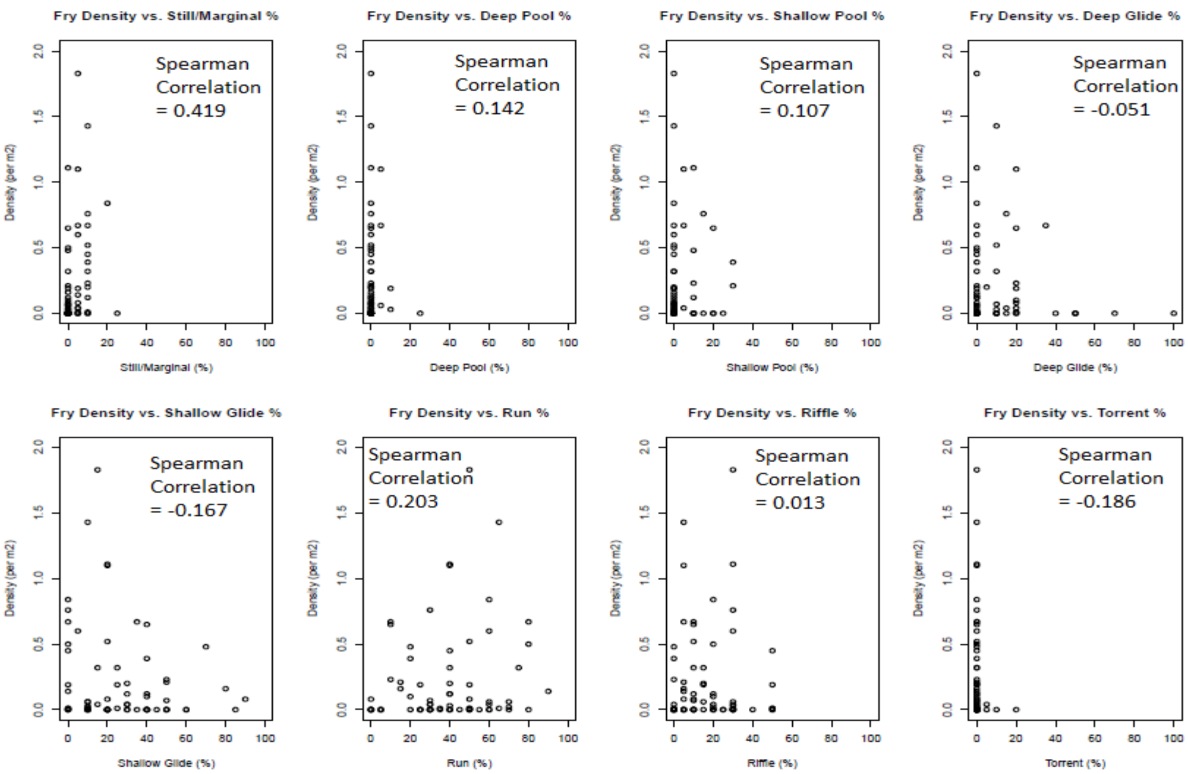

Figure 6. Fry Densities Compared to Flow.

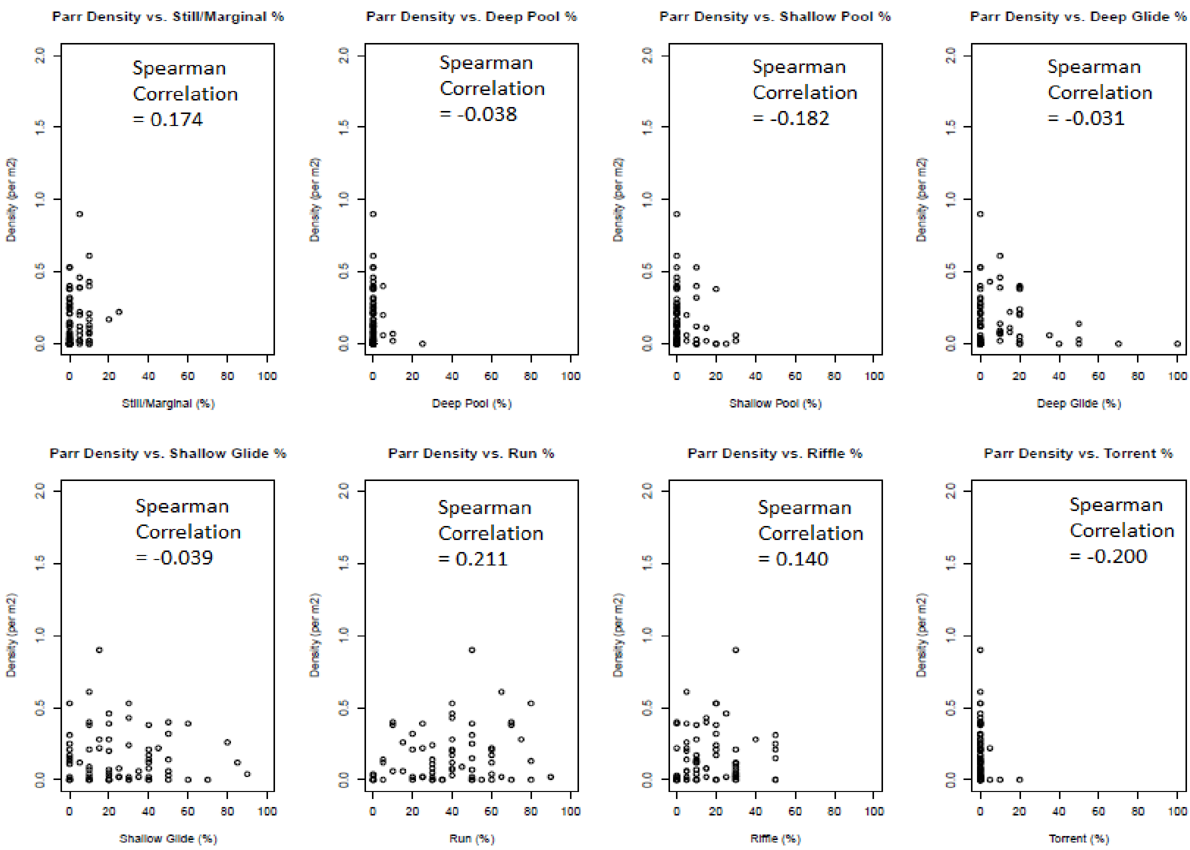

Figure 7. Parr Densities Compared to Flow.

Areas of slow flow within a river system such as those described by the still/marginal variable though providing little to no cover, do allow some respite from faster flowing sections (Gard, 2013). This can be advantageous to young salmon that spend most of their time in relatively fast flowing water fighting against the current (Louhi *et al.*, 2008). These young salmon are often small enough to be able to hide on the riverbed amongst the substrate, thereby negating the lack of cover created by still or slow moving shallow water. The results of the Spearman correlation show a fairly strong positive relationship between fry densities and still/marginal flow, 0.419, and a less strong 0.174 for parr. From all events contained within the pattern analysis dataset only two were recorded at locations with over 20% still/marginal flow, as a result the strong positive correlation is most likely situational, due to the dataset containing no evidence of what occurs at a site with a high percentage of still/marginal. Despite this, the scatterplots display that densities are at their best when between 5-10% of the river flow is still/marginal, therefore within the confines of this study it can be concluded that the preferred range for still/marginal is less than 10%.

Pools also provide shelter from the flow of a river for young salmon and adults alike, unlike still/marginal however they also provide a degree of cover from predation allowing the salmon to hide deeper beneath the surface. For adults returning to the river to spawn these pools provide a rest and hiding place as they make their way upstream to spawning grounds (Youngson *et al*., 1983). Though these pools play a very important role for adult salmon while migrating, they are not as essential during the young salmon's time in the river. While young and significantly smaller than the returning adults, fry and parr are able to hide within the substrate and shelter from the flow within shallow areas of the river that the adults cannot. This may be why no strong relationships appear to exist between fry or parr and deep pools, 0.142 and -0.038 respectively, though it is also worth mentioning that as with several previous stages of analysis very few events were recorded at sites where deep pools are present, possibly skewing results. Despite this lack of relationship the deep pool scatterplots suggest that best densities occur when less than 10% of the river flow consists of deep pools. Similar results are found when analysing shallow pools and density. The Spearman correlation found a slight positive 0.107 and a slight negative -0.182 for fry and parr respectively. The shallow pool scatterplots show that based on this dataset the best fish densities occur between 0 and 15%. Based on these results the preferred range for deep pools is less than 10% and shallow pools less than 20%.

Shallow glides are most commonly utilised during the salmon spawning process and the first year of the salmon's life (Gard, 2013, Moir *et al*., 2000). The shallow and fast flowing water creates a clean and well oxygenated environment in which the eggs are able to develop, sweeping away any silt or sediment that passes through the area (Gard, 2013). As fry the salmon also favour areas of shallow fast flowing water, this flow again clears away sediment from the substrate allowing the salmon to feed on the insects within it (Bardonnet and Bagliniere, 2000). As the salmon grow to become parr they still favour fast-flowing well oxygenated water but prefer it to be deeper allowing them to hide with more ease (Armstrong *et al*., 2003). Both fry and parr show weak negative relationships with both deep and shallow glides, the strongest occurring between fry and shallow pools. This appears to stand opposed to the previously mentioned known relationships that exist between fry and parr and glides. However as with substrate composition, the salmon require a variety of different flow types within a river system and therefore densities from sites with a large portion of glides are often very low, resulting in the negative correlation. Based on the glide vs density scatterplots the best densities occur between 5 and 20% for deep glides and 5 – 30% for shallow ones, this seems in keeping with what is already known about the salmon. As a result it would appear that the best range for deep glides is less than 20% and for shallow 10 – 30%.

Runs provide a good environment for both fry and parr, the fast flowing water maintains a steady supply of oxygen and also carries food sources with it in the form of insects caught in the current (Rimmer *et al*., 1983). Further, the waves created on the surface by the flow provide a break in the clear water surface providing cover from predators (Gard, 2013). The Spearman correlation found that both fry and parr showed a positive relationship of around 0.200 to the presence of runs within the river system and both the fry and parr scatterplots show the suggestion of a bell curve, each climbing to a peak at around 40%. This indicates that between 30 - 50% is the ideal percentage for runs within a river's flow relative to young salmonid density.

Riffles are very similar to runs, they are sections of fast flowing water that provide oxygen and possible food sources for the salmon (Crisp, 2000). The key difference is that the surface water flows unevenly with broken waves which create further cover for the salmon and also introduce more oxygen into the water system improving its quality. Despite these potential advantages, no significant relationship was discovered at either the fry or parr life stage by the Spearman correlation. The density vs riffle scatterplots however indicate that densities are at their best between the ranges of 10 and 30% riffle presence suggesting that this range would be most beneficial for salmon.

Torrents are very turbulent, fast-flowing stretches of water and can in some cases sweep away substrate and food sources from an area of a river (Gard, 2013). Torrents near bends in the water system can increase bank erosion, though bank erosion can introduce cover such as fallen trees creating an improved fish habitat it can also destroy and change habitats if occurring regularly (Buck and Hay., 1984). Despite providing oxygenated water and surface cover, torrents create a chaotic environment for fish and, other than finding refuge in small calm areas of water behind large boulders, it is a demanding area for them to be in (Gard, 2013). Therefore it is not surprising that both fry and parr show a slight negative correlation to torrents, -0.186 and -0.200 respectively. It could also be assumed that were more surveys conducted at sites with stronger torrents, creating a wider spread in results, this relationship would be found to be significantly stronger. Based on these relationships and the extremely low densities displayed on the scatterplots of relatively low strength torrents, it can be concluded that the ideal range for torrents within a river flow is less than 5%.

4.1.2 Density and Bankside Habitat

For the purpose of analysis bankside habitat variables have been grouped into three subcategories, general bankside cover, bankside cover composition and bankside vegetation and land use.

4.1.2.1 Density and General Bankside Cover

In this investigation general bankside cover is composed of four variables: canopy cover (percentage of cover provided by the canopy of trees growing on the bankside), fish cover (the percentage of the bank that provides fish cover), undercut (the percentage of the bank that is undercut) and overhanging boughs (percentage of the wetted area covered by overhanging branches).

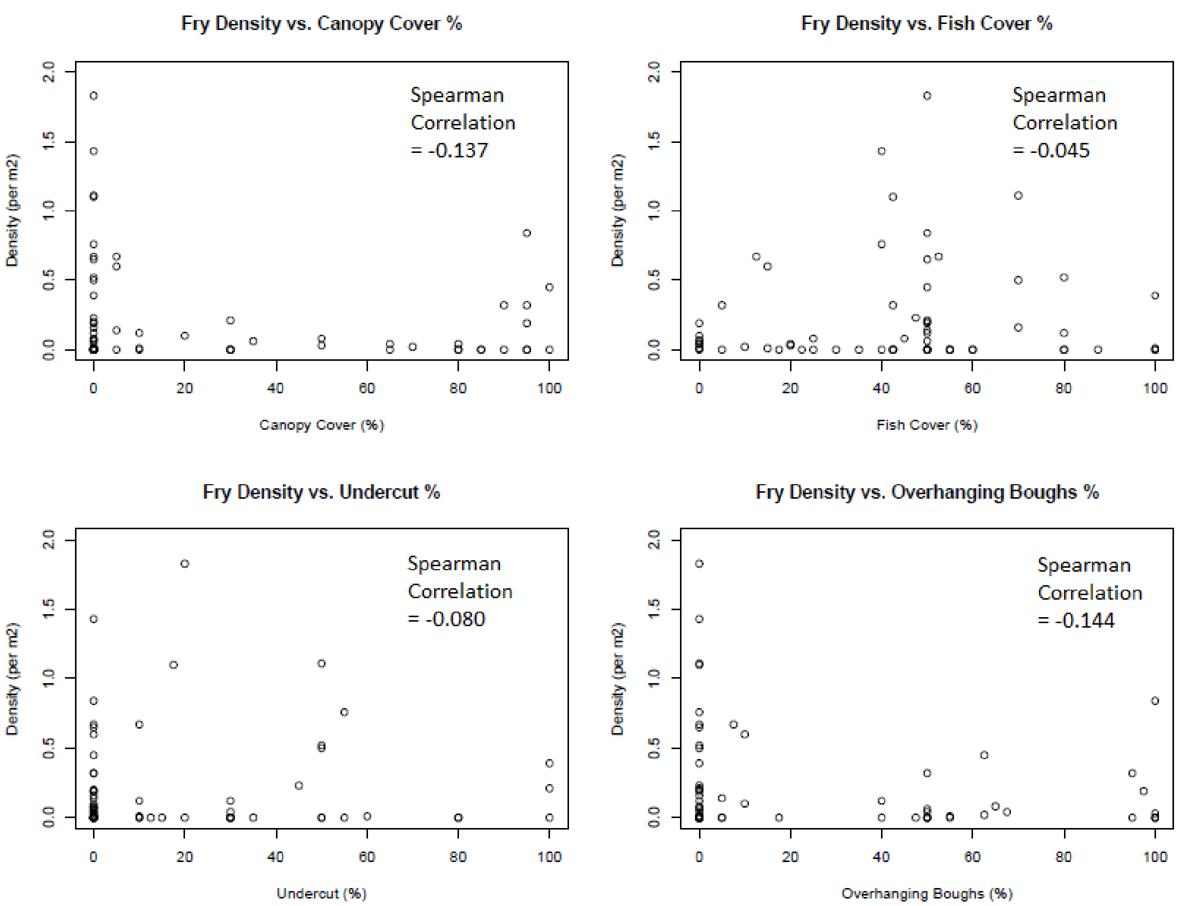

Figure 8. Fry Densities Compared to General Bankside Cover

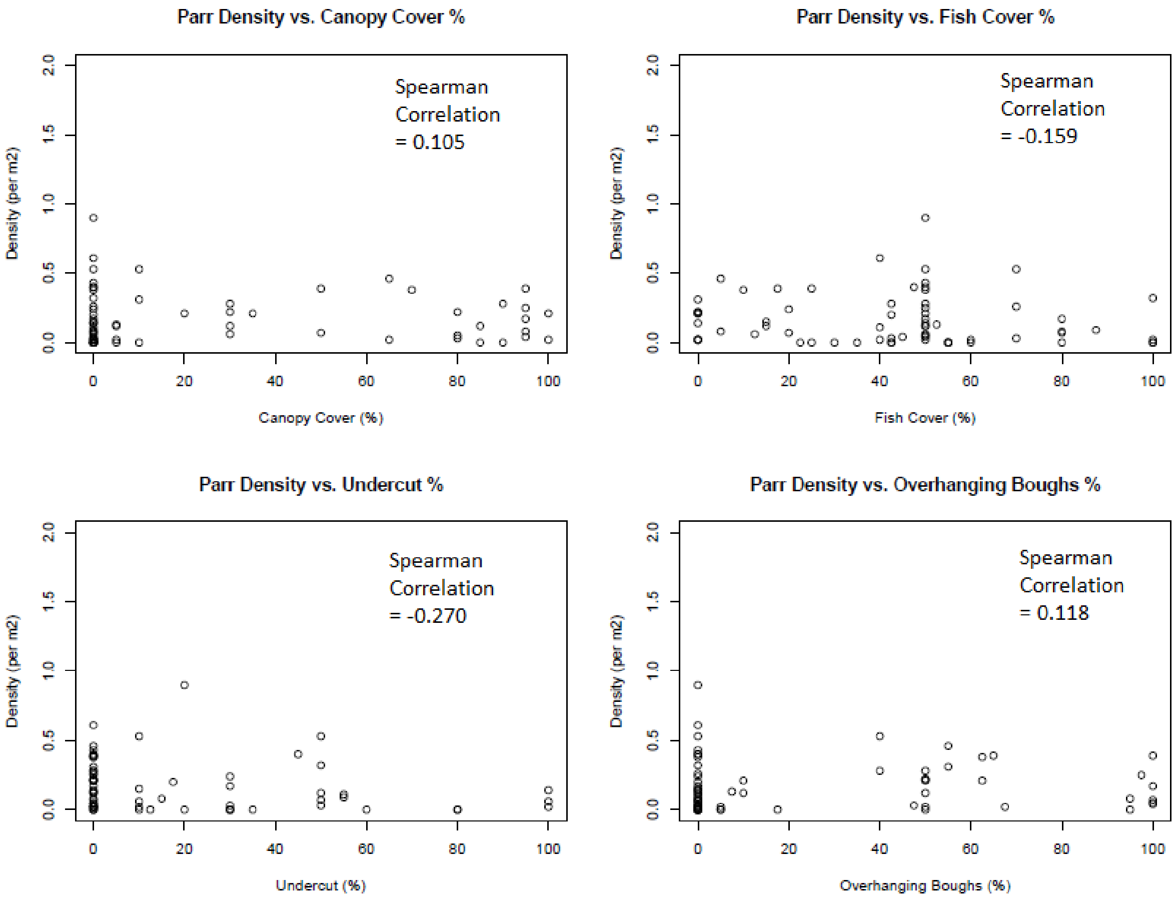

Figure 9. Parr Densities Compared to General Bankside Cover

The relationship between salmon and cover is, to some degree, pre-established. Cover provides the fish with shade, shelter from predators and an occasional food source as insects living in overhanging vegetation or on undercut banks fall into the water system (Johnson, 2016). Therefore a significant and positive correlation was expected between fry and parr densities and all forms of general bankside cover. However based on Spearman's correlation calculations no significant positive relationships exist between fry and parr densities and any of the general bankside cover categories, the strongest result was a negative correlation of -0.270 between parr and undercut %. There are several possible reasons for this, similar to the problems experienced while searching for relationships between instream habitat and density, it could be the case that there are simply not enough events in the dataset to confirm pre-established relationships. Alternatively it could be due to the vast number of variables affecting each site, for example, a site with a high percentage of fish cover may show a very low density not because of the cover present but because of poor flow or substrate conditions. This could create a false impression of the relationship between cover and density. Further sites that show very little cover but high densities could be due to cover provided instream in the form of substrate the fish are able to hide in, making up for the lack of overhead cover (Armstrong et al., 2013).

Visual appraisals of the scatterplots contained within figures 8 and 9, concur with the correlation calculations, displaying very little suggestion of patterns between the variables and density. However a slight spike in densities for both fry and parr between 80 and 100% canopy cover suggests that higher densities are encouraged by the presence of good canopy cover therefore it is suggested that the ideal range be upwards of 50% canopy cover.

The scatterplots displaying fry and parr densities vs fish cover both show a spike in densities at around 50% fish cover, then a slight decline. This decline however is quite gradual and is interlaced with several good density results, this suggests that these densities may be more greatly affected by factors other than fish cover. However based on the findings of this analysis 50% fish cover would appear to be the ideal range.

The slight negative correlation discovered between undercut and density suggests that if a site has upwards of 50% undercut banks it may result in a decline in densities. Excessively undercut banks can result in regular collapses, resulting in increased sediment levels within the substrate (Eggilshaw *et al*., 1986). As a result it is suggested the ideal range for undercut be 10 – 50%. The inconsistencies displayed in the scatterplots for overhanging boughs vs density (spikes in density at 0%, 50% and between 80 and 100%) mean that very few confident conclusions can be drawn. Therefore the strongest statement that can be made is there are indications that a percentage upwards of 50% may be the ideal range for overhanging boughs.

4.1.2.2 Density and Bankside Cover Composition

Similar to the flow and substrate, the data for bankside cover composition is recorded across six possible variables, each of which is awarded a percentage, with all values totalling 100% when combined. These six variables are: draped vegetation (cover provided by vegetation growing out from the bankside over the river), bare (no cover), marginal (cover provided by vegetation that is rooted in the river bed near the bank), roots (cover provided by exposed roots growing out of the bank), rocks (cover provided by rocks embedded in the bankside) and other. Only two events recorded the presence of “other” forms of cover but for completeness a scatterplot has been created. As there is no information on what the cover actually was it will not be analysed as it would not be possible to draw recommendations from it. For this section left and right bank results from each event have been combined and averaged to provide an overall assessment of bankside cover composition at each site.

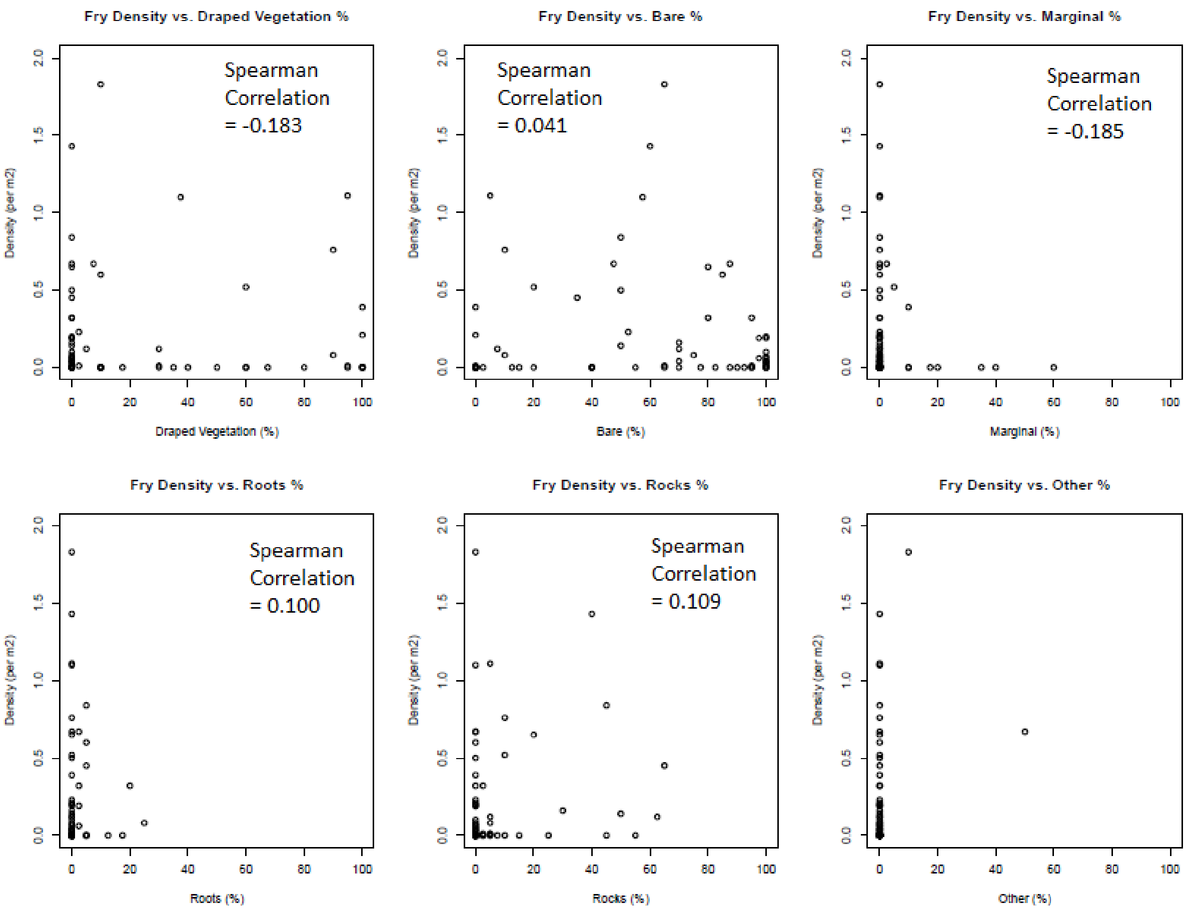

Figure 10. Fry Densities Compared to Bankside Cover Composition

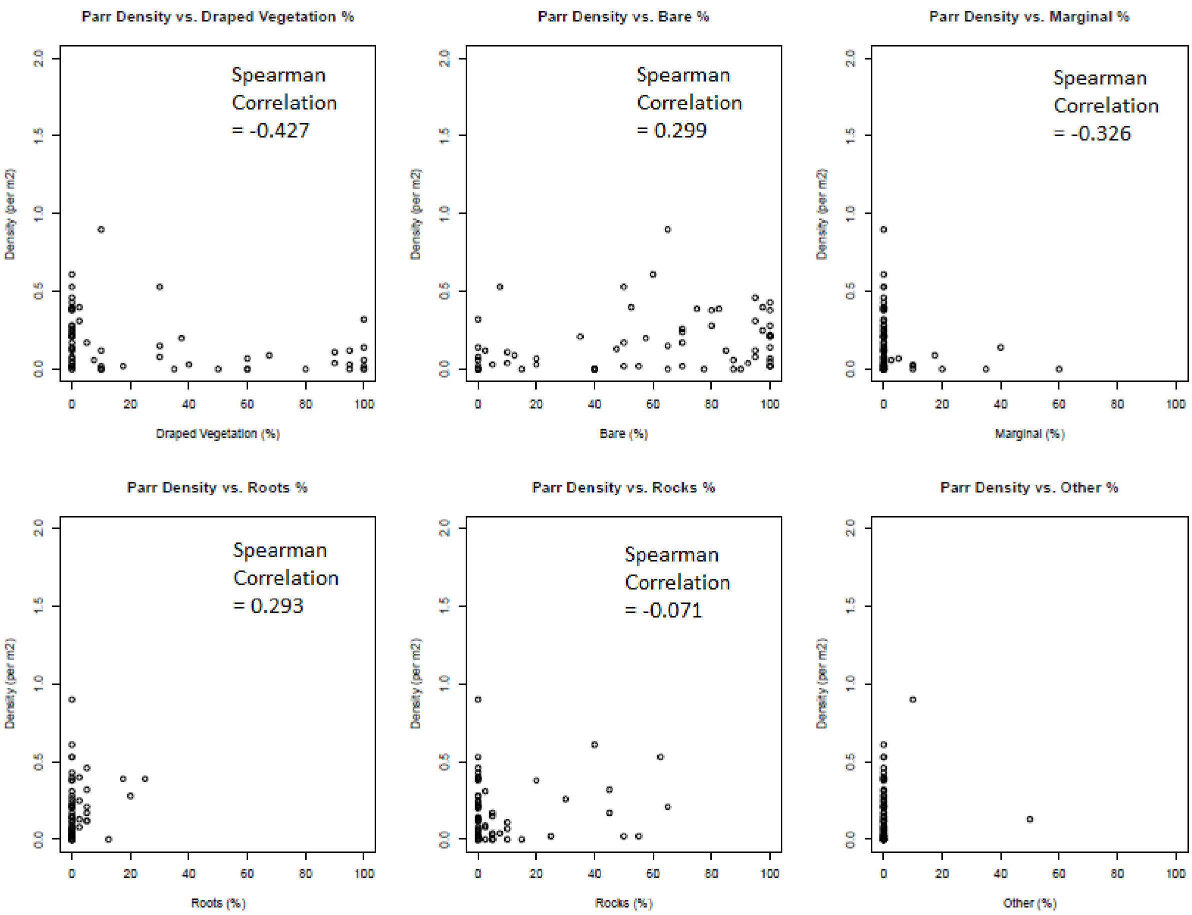

Figure 11. Parr Densities Compared to Bankside Cover Composition

The comparisons between fry density and bankside cover composition indicate positive relationships between fry density and roots and rocks (0.100 and 0.109) and a very slight positive correlation between densities and bare (0.041). Roots provide cover but also stabilise the bank as they hold the soil together and therefore a positive relationship was expected. Rocks provide cover and also occasionally fall into the river providing new substrate material and therefore a positive relationship was also expected (Gard, 2000, Armstrong *et al*., 2003. However bare banks offer no advantages to the salmon, they provide no cover or bank stability and greatly lessen the likelihood of insects falling into the water due to the lack of overhanging vegetation (Moir *et al*., 2000). As a result it is possible that the apparent positive relationship has occurred not because bare banks offer preferred habitat but because unfortunately the majority of sites contained within the dataset had primarily bare banks. This would suggest that high densities are found at these sites despite bare banksides as opposed to because of it. Similarly the negative correlations found between fry density and draped vegetation and between fry density and marginal stand against the accepted beliefs between salmon and habitat. Draped vegetation provides shade, cover and the possibility of insects falling into the water, as does vegetation growing against the bankside as described by the "marginal" variable (Louhi *et al*., 2008). The fact that three of the five variables analysed appear to offer false results would suggest that currently there is not enough information within the dataset to confidently define the existing relationships between fry density and bankside cover composition.

When viewing the comparison between parr densities and the bankside cover composition variables the same anomalies occur as with the fry densities comparison. Fairly strong negative correlations are found between draped vegetation (-0.427) and marginal (-0.326) and a positive relationship between density and bare banks is again found (0.299). As this again stands against the relationships known to exist between density and habitat it is concluded that the dataset is again too small to reflect the relationships that exist between parr density and bankside cover composition. As no recommendations can confidently be made regarding the ideal ranges for these variables, they will not be considered when assessing the current condition of sites within the catchment during the second stage of analysis.

4.1.2.3 Density and Bankside Vegetation and Land Use

When assessing both bank face and buffer zone vegetation variables on site, four categories can be used as means of description: bare (<50% vegetation cover), uniform (predominantly one vegetation type, but lacking trees or scrub), simple (predominantly 2-3 vegetation types, including tall or short herbs) or complex (four or more vegetation types which must include scrub or trees). Spearman's correlations were included for both variables as though the values are not numeric they are linear in progression and therefore a relationship may be detectable. For primary land use a correlation was not included as there is no linear structure to the categories, each simply describing a type of land use i.e. "conifer plantations".

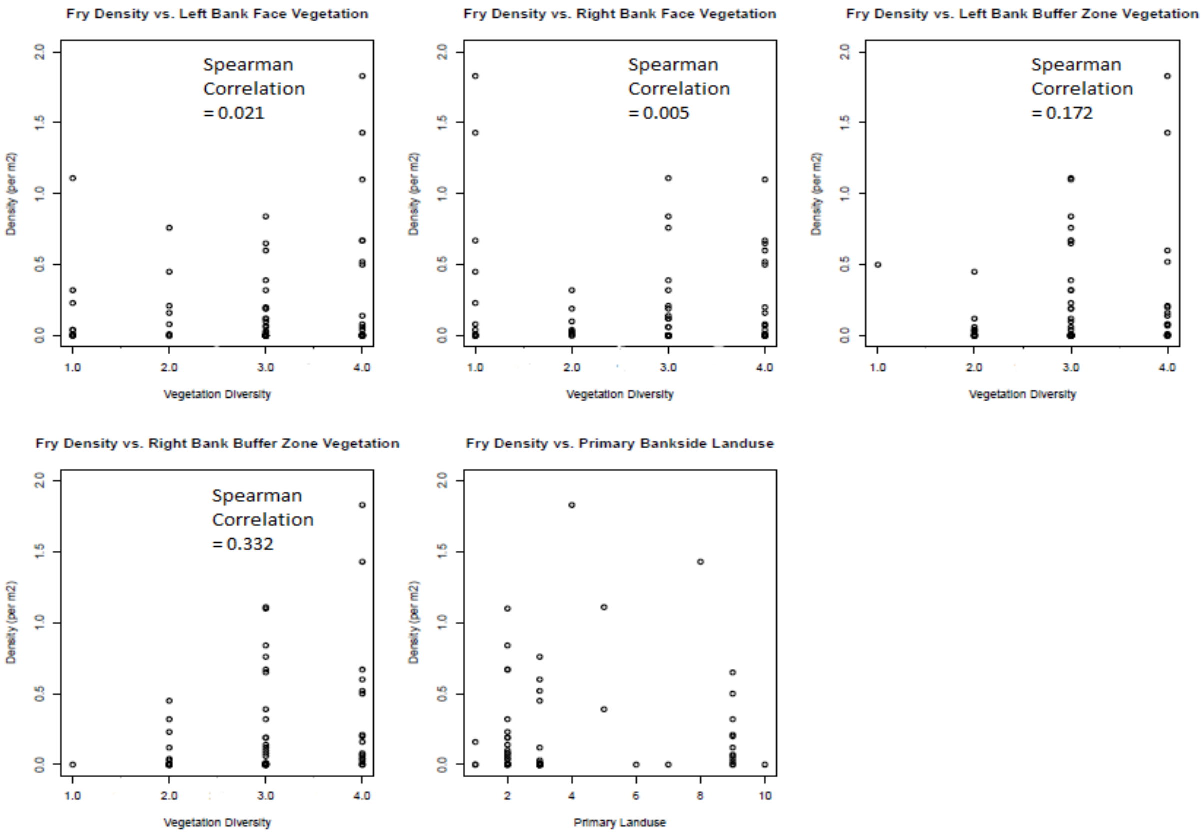

Figure 12. Fry Densities Compared to Bankside Vegetation and Land Use

Vegetation Diversity	
1	Bare
2	Uniform
3	Simple
4	Complex
Primary Land Use	
1	Arable
2	Broadleaf/Mixed Woodland
3	Conifer Plantations
4	Garden
5	Improved/semi improved grassland
6	Moorland Heath
7	Orchard
8	Road
9	Rough Pasture
10	Scrub

Key for Figures 12 and 13.

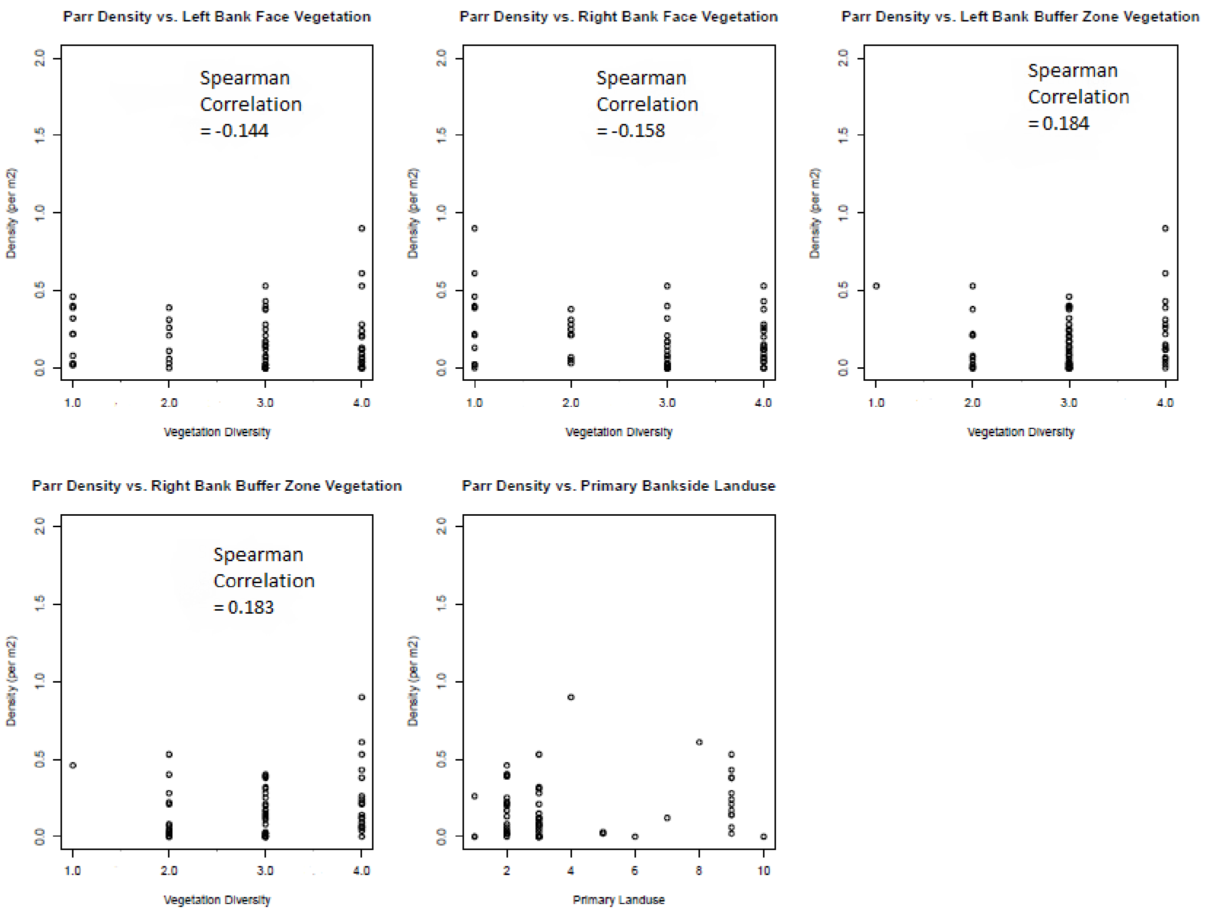

Figure 13. Parr Densities Compared to Bankside Vegetation and Land Use

A heavily vegetated bank face (i.e. simple or complex) and bank side not only provide bank stability through their roots, they also increase the biodiversity of the environment, attracting a wider range of insects and small invertebrates that may provide a food source for the salmon (Crisp, 2000). A greater amount of vegetation also results in a higher oxygen content in the area, increasing the habitat quality (Gard, 2013). When comparing density and bank face/buffer zone vegetation, it must be considered that left and right bank values could not be combined before analysis. As a result events may register a high density at a site where the left bank is bare, not because this is the preferable environment for the fish but because the right bank has complex vegetation, thereby lessening the negative impacts of a bare left bank.

Viewing the scatterplot displaying fry density vs left bank face vegetation a single high density of slightly over 1.0 can be seen in the bare column, however it's corresponding value in the scatterplot displaying fry density vs right bank face vegetation falls within the simple column. Similarly high values in the right bank face scatterplot bare column have corresponding values in the complex column in the left bank face scatterplot. This anomaly could explain the lack of correlation exhibited by Spearman's calculation. Similarly when viewing parr vs left/right bank face vegetation, a negative relationship is found for both, suggesting a decline in density as vegetation increases, the opposite suggestion to the findings on fry. This however could also be caused by the lack of high parr densities anywhere within the analysed dataset, resulting in low densities being recorded at sites with favourable conditions. A visual appraisal of the parr vs left/right bank face scatterplots shows a very slightly higher peak on densities within the simple and complex columns but also a fairly even distribution of densities across all ranges of vegetation, suggesting that the parr are less reliant on diverse bank face vegetation than fry. Therefore it would appear that ideal conditions for both fry and parr would include at least one bank face holding simple or complex vegetation, although it would be preferable for both to hold at least simple.

The buffer zone around a river refers to the first five metres stretching away from the river in either direction from the top of the banks. Similar to bank face vegetation it provides bank stability and increases habitat quality when present in greater quantities and varieties encouraging biodiversity and insect life (Bardonnet and Bagliniere, 2000). Diverse populations of plant life within the riparian habitat zone also cut down the amount of soil run off during rainfall, when run off occurs it increases the amount of silt and sediment in the river, decreasing substrate quality. Positive Spearman correlations were detected for both life stages on both banks, with fry reading 0.172 and 0.332 and par reading 0.184 and 0.183 (left and right banks respectively). Scatterplots for both fry and parr vs buffer zone on the left and right banks confirm this relationship, a steady linear progression can be seen with densities increasing as buffer zone vegetation becomes more diverse. Therefore it can confidently be concluded within the confines of this project that the preferred range for buffer zone vegetation diversity is complex, though significant densities can also be found in areas of simple vegetation diversity.

Primary land use refers to the predominate form of land use within a 50 metre radius of the electrofishing site and as explained earlier no correlation calculation can be fitted to this relationship. The vast majority of events occurred at sites whose primary land use was one of broadleaf/mixed woodland, conifer plantations or rough pasture. The scatterplots display a similar image for all three categories and both fry and parr scatterplots are also similar. Accordingly no material conclusions can be drawn from this analysis. As no definitive patterns could be drawn between land use and density, land use will not be considered when suggesting ideal conditions within the catchment. It will also be removed as land use decisions come under the jurisdiction of the land owner, therefore it may not be within the remit of RAT to make changes at sites regarding this variable.

4.1.3 Summary of Suggestions of Ideal Site Conditions

Following the first stage of analysis, several potential patterns have been identified between habitat variables and salmon densities. As the results between fry and parr showed distinct similarities throughout the analysis, one overall proposal of suggested ideal site conditions has been created to encompass both life stages. Though three main anthropogenic driven variables were removed from the initial analysis stage (site accessibility, presence of siltation, presence of pollution). They have been reintroduced for the second stage as they are known have a negative impact on fish density and are therefore relevant when assessing the health of a site or sub-catchment. All variables to be considered when assessing catchment health and their suggested ideal ranges or values are displayed below (Table 1).

Anthropogenic Drivers	Suggested Ideal Range	Flow	Suggested Ideal Range
Accessible	Regularly/Occasionally	Still/Marginal	< 10%
Silted	No	Deep Pool	< 10%
Pollution	No	Shallow Pool	< 20%
General Instream Quality	Suggested Ideal Range	Deep Glide	<20%
Instream Cover	Good/Excellent	Shallow Glide	10 - 30%
Stable Substrate	Stable	Run	30 - 50%
Compacted Substrate	Uncompacted	Riffle	10 - 30%
Substrate Composition	Suggested Ideal Range	Torrent	< 5%
Silt	< 5%	Bankside Cover	Suggested Ideal Range
Sand	< 5%	Canopy Cover	> 50%
Gravel	10 - 30 %	Fish Cover	30 - 80%
Pebbles	20 - 40%	Undercut Banks	10 - 50%
Cobbles	30 - 50%	Overhanging Boughs	> 50%
Boulders	10 - 30%	Bankside Vegetation	Suggested Ideal Range
Bedrock	< 5%	Bank Face Vegetation	Simple/Complex
		Buffer Zone Vegetation	Simple/Complex

Table 1. Results of First Stage Analysis (Suggested Ideal Ranges).

4.2 An Assessment of Sub-catchment Health

4.2.1 Sub-catchment Rankings

In order to assess the health of each sub-catchment it was necessary first to determine what percentage of sites within each sub-catchment fell within the suggested ideal ranges for each variable. This then allowed the calculation of an overall "within suggested ideal ranges" percentage for each sub-catchment. Using these it was then possible to rank each sub-catchment relative to one another, the results of which are displayed in order in Table 2.

Sub-Catchment	Wamphray Water	Water of Ae	Annan Water	Dryfe Water	Evan Water	Moffat Water	Mein Water	Kinnel Water	Water of Milk
Number of Sites Surveyed in 2017	11	13	14	13	16	17	5	15	22
Salmon Accessible									
Regularly/ Occasionally	54.55%	84.62%	92.86%	100%	75%	100%	80%	80%	86.36%
Silted									
No	90.91%	92.31%	78.57%	100%	87.50%	94.18%	100%	80%	81.82%
Pollution									
No	100%	92.31%	92.86%	100%	81.25%	100%	100%	100%	95.45%
Instream Cover									
Excellent/Good	90.91%	100%	71%	77%	81%	82.35%	100%	87.66%	68.18%
Stable Substrate									
Stable	100%	92.31%	78.57%	100%	100%	52.94%	100%	100%	81.82%
Compacted Substrate									
Uncompacted	90.91%	100%	78.57%	92.31%	93.75%	94.12%	80%	100%	81.82%
Substrate Composition									
Silt	100%	100%	100%	100%	87.50%	100%	100%	100%	100%
Sand	100%	84.62%	92.85%	92.31%	87.50%	100%	100%	86.67%	90.91%
Gravel	90.91%	84.62%	64.28%	76.92%	75%	88.24%	100%	80%	86.36%
Pebbles	100%	84.62%	57.14%	69.23%	81.25%	64.71%	80%	80%	45.46%
Cobbles	81.82%	84.62%	64.29%	69.23%	68.75%	76.47%	80%	60%	54.55%
Boulders	90.91%	84.62%	64.29%	76.92%	75%	41.18%	100%	80%	31.82%
Bedrock	81.82%	100%	92.85%	100%	93.75%	100%	80%	66.67%	95.45%
River Flow									
Still/Marginal	100%	100%	85.71%	100%	93.75%	100%	100%	66.67%	77.27%
Deep Pool	100%	100%	85.71%	100%	100%	100%	100%	60%	81.82%
Shallow Pool	100%	100%	78.57%	100%	100%	100%	80%	73.33%	86.36%
Deep Glide	81.82%	84.62%	92.86%	100%	81.25%	88.24%	100%	87%	86.36%
Shallow Glide	90.91%	84.62%	64.29%	61.54%	68.75%	76.47%	60%	66.67%	72.73%
Run	81.82%	61.54%	50%	61.54%	50%	58.82%	60%	20%	54.55%
Riffle	81.82%	76.92%	71.43%	84.62%	81.25%	76.47%	80%	86.67%	63.64%
Torrent	100%	92.31%	78.57%	100%	100%	100%	100%	93.33%	100%
Bankside Cover									
Canopy Cover	27.27%	7.69%	14.29%	7.69%	6.25%	23.53%	20%	53.33%	18.18%
Fish Cover	36.36%	7.69%	50%	23.08%	31.25%	5.88%	0%	33.33%	45.45%
Undercut Banks	45.45%	0%	57.14%	23.08%	50%	35.29%	0%	26.67%	40.91%
Overhanging Boughs	0%	0%	0%	0%	0%	11.76%	0%	26.67%	13.64%
Bank Face Vegetation									
Simple/Complex	40.91%	3.85%	25%	41.48%	34.38%	26.47%	10%	20%	15.91%
Buffer Zone Vegetation									
Simple/Complex	72.73%	42.31%	42.86%	39.28%	59.38%	41.18%	10%	60%	29.55%
Average % Within Ideal Range	82.66%	79.20%	75.52%	73.94%	71.98%	71.79%	71.11%	69.43%	66.16%

Table 2. Sub-catchment Rankings

4.2.2 Discussion of Sub-catchment Rankings

As visible in Table 2, the sub-catchment's rankings were as follows, in descending order: the Wamphray (82.66%), the Ae (79.20%), the Annan (water) (75.52%), the Dryfe (73.94%), the Evan (71.98%), the Moffat (71.79%), the Mein (71.11%), the Kinnel (69.43%) and the Milk (66.16%).

The most apparent observation from across all of the sub-catchments is the lack of cover and a lack of riparian habitat (bankside vegetation). Only two sub-catchments were found to have over 50% of sites within suggested ideal ranges for any type of bankside cover, the Kinnel had 53.33% of sites within suggested canopy cover range and the Annan water had 57.14% of sites within suggested range for undercut banks. No sub-catchment was found to have over 42% of sites displaying simple/complex bank face vegetation, and only two were found to have over 60% of sites displaying simple/complex buffer zone vegetation (the Wamphray and the Kinnel). As explained during the first stage of analysis, bankside cover and vegetation play key roles in maintaining suitable salmonid habitat, they offer fish protection, bank stability, increase the oxygen content of the area and assist in preventing surface run off reducing siltation and sedimentation of the substrate (Armstrong *et al*., 2003, Louhi *et al*., 2008). The distinct lack of cover and vegetation diversity throughout the catchment poses definite potential threats to available salmonid habitat. As a result it is found that bankside habitat variables throughout all sub-catchments are in need of restoration or remedial works.

Viewing the percentages of sites within range of suggested instream habitat quality variables, it can be seen that across all sub-catchments siltation and pollution do not appear to be present in meaningful quantities. Only the Milk and the Kinnel showed a concerning amount of siltation, with around 20% of sites in each displaying siltation above the recommended range. This could be due to the severe lack of vegetation resulting in an increase in run-off (Eggilshaw *et al*., 1986). Similarly the Evan showed around 20% of sites were suffering from pollution. The only sub-catchment that showed problems with substrate stability was the Moffat, only 52.94% of the 17 sites were found to have a stable substrate, this could potentially result in the changing of substrate composition across the sub-catchment in the event of excessive heavy rain fall resulting in increased flow rates possibly dislodging the substrate (Gard, 2013).

Substrate composition was found to be furthest from the suggested ranges within the Milk, only 45.46% of sites had the suggested range of pebbles, 54.55% of cobbles and 31.82% of boulders. Similarly the Kinnel had 40% of sites outside the suggested range for cobbles, and around 30% of sites had more bedrock presence than suggested. As pebbles, cobbles and boulders are all essential components in suitable young salmonid habitat, this poses a significant threat to the suitability of sites within these sub-catchments. The Moffat, Evan, Dryfe and Annan waters were all found to have the majority of sites showing substrate composition within acceptable ranges, and no significant problems were found within substrate composition at a sub-catchment level within the Mein, Ae and Wamphray.

Flow was found to be within acceptable ranges throughout the Wamphray sub-catchment, however all other sub-catchments showed a low percentage of sites within the suggested range for runs, and all but Ae and Wamphray also showed, to a lesser degree, a lack of sites within the suggested range for shallow glides. The Kinnel in particular, showed only 20% of sites within the suggested range for runs and only 66.67% of sites in range for shallow glides. Both the Evan and the Annan showed only 50% of sites within the suggested ranges for runs. As runs and riffles are both known to provide several advantages to fry and par, providing oxygen, cover and food, this poses a potential threat towards the suitability of the habitat within the sub-catchments.

4.3 Project Recommendations

Throughout this project, the author has attempted to explain the results that the analyses have produced and where reasonable to do so draw conclusions from them. However it must be recognised that the eventual volume of data that could be analysed was low and this often resulted in inconclusive results and sometimes displayed findings that are contrary to known positions. Consequently it is important to state that the author suggests the recommendations made in this report be treated with some caution and should be the subject of further investigation and verification before implementation is considered.

4.3.1 Recommendations for Restoration/Remedial Works

The Milk, Kinnel and Mein have been highlighted as the sub-catchments that are most in need of restoration/remedial works within the Annan catchment. Therefore the recommendations of this paper will focus on methods of improvement aimed specifically at the three sub-catchments.

The habitat variables in most need of attention within the Milk are flow, substrate composition and bank face vegetation diversity. The problems with flow within the Milk are primarily found in the lack of runs and riffles which are key features for juvenile salmon (runs) and spawning (riffles) (Jonsson, 2016). These problems within flow dynamics are likely to be linked to the problems within substrate composition, larger substrate material such as cobbles or boulders cause breaks in the water flow, causing the water to speed up as it is narrowed and diverted creating runs. Similarly pebbles and cobbles can create areas of turbulence in the water creating riffles. Less than 55% of sites within the sub-catchment were reported to have pebble, cobble and boulder presence in their substrate within the suggested ranges. As these play a vital role in young salmonid habitat, providing shelter and also microenvironments for food sources for the salmon, it would be the initial suggestion that work should be undertaken to rebuild the substrate, and in doing so possibly solve the problems within flow dynamics. However the recreation of substrate composition is in itself a very difficult task that can, if poorly managed, lower habitat quality (Moir *et al.*, 2000). Substrate must be correctly positioned and dispersed within the water system so as to provide substrate stability while also not being compacted. The incorrect placement of new substrate material can in some cases cause upsets to flow and increased erosion, or in some cases if not properly positioned/secured it can simply be swept downstream (Gard, 2013). If this should occur then it can result in habitat degradation further downstream or in extreme cases can create a build-up, resulting in a shallow portion of the river that may become a barrier to migration (Lacroix and McCurdey, 1996, Gard, 2013). As a result it is the recommendation of this project that more research be undertaken into the successful restoration of substrate, and that any attempts to restore substrate conditions within any of the sub-catchments be done following sue diligence.

The Kinnel similar to the Milk also shows a distinct lack of runs across the catchment with only 20% of sites found to be within the suggested range. This could be in part responsible for the water quality problems also seen, 20% of sites reported the presence of either pollution, siltation or both. Runs not only provide oxygen, cover and food for the salmon, they also remove excess silt or sediment from water ways and substrates, carrying it downstream and depositing it more evenly throughout the river (Gard, 2013). The Kinnel is also noted to have 33% of sites reporting an excess of still/marginal points of river flow, this too will result in silt and sediment accumulation as these areas of little to no flow are unable to carry debris downstream. One possible method of increasing flow within the Kinnel would be to narrow the channel upstream of sites suffering from siltation and low flow speeds, this increased flow would carry some of the sediment downstream and may distribute it more evenly lessening its impacts. Channel narrowing could be achieved with the introduction of wooden deflectors or submerged weirs (Gard, 2013, Bardonnet and Bagliniere, 2000). Following this the introduction or repositioning of boulders within the waterway could break this now faster flowing water creating runs and riffles for the fry and parr (Crisp, 2000, Gard, 2013).

Though ranked last amongst the sub-catchments the Milk and Kinnel were found to offer the best collective cover of all sub-catchments, the Kinnel in particular showed around 50% of sites within acceptable range for canopy cover, 23% higher than the Wamphray which has the second best canopy cover of all sub-catchments and was ranked first overall. The Mein however displayed the worst collective results for cover and of vegetation diversity of all sub-catchments, only 20% of sites were within range for canopy cover, and 0% of sites were found to be in range for any other form of cover. This combined with the very low vegetation percentages (10%) shows that the Mein is in need of large scale riparian habitat zone restoration. The best method for improving sites within the Mein would be the planting of trees and shrubs along the banksides and in the buffer zone, though this will take time to take effect, however once grown they will create a more diverse environment around the river (Armstrong *et al*, 2003). A faster solution could be to introduce wooden debris within the waterway such as large fallen branches, these provide instream fish cover and also microenvironments increasing food supplies (Rimmer *et al*., 1983). Due to the problems found with vegetation diversity and the lack of cover across all sub-catchments these restoration techniques could be applied at most sites within any sub-catchment.

4.3.2 Recommendations for Future Monitoring of Catchment Health

An important factor when considering what items of data to collect in surveys is to recognise that the more variables (e.g. Flow) that are collected and the more outcomes that can be selected within each variable (e.g. Still/Marginal, Deep Pool, etc) this will result in the data being held at a very granular level. Consequently the dataset compiled for analysis requires to be very large in order to derive meaningful results from analysis particularly when searching for relationships at outcome level.

Until a sufficiently large volume of events has been compiled at granular level it is suggested that consideration is given to introducing in future surveys, where reasonable to do so, an additional "higher level aggregation" of outcomes to be used where there are many outcome values possible for a variable. For example, for the variable "Cover", the data collected in each survey would continue to break this down into its constituent granular level outcomes but introduce an additional aggregation level outcome which summarises the overall cover present at the site as a percentage (for example: 0, 1-30, 31-60, 61-90, 91-100). This "higher level aggregation" approach if widely applicable would in the short to medium term enable relevant analysis to be performed on the dataset until it has grown sufficiently in size to enable analysis at granular level. In the long term these values could be used when looking for high level inter-relationships between variables before focusing further investigation into the granular outcomes within the variables.

Where practical to do so the sites selected for survey should be chosen with a view to providing a more even distribution across all outcomes within each variable; when analysing the relative merits of each outcome within a variable this will provide a balanced assessment. Additionally when choosing sites for surveys, consideration should be given to including locations that would not normally be viewed as preferred habitat for salmon. This would serve as a control group and also may be a useful way to help achieve a more even distribution over the outcome values within variables. As a by-product this control group may possibly reveal something that was previously unproven or unknown about salmon behaviour.

Finally, in order to aid in the future monitoring of catchment health, steps should be taken to enable RAT to determine their own accurate density estimates based on electrofishing results. This would allow the use of a larger dataset than that based on SEPA provided density estimates. There is a method of generating density estimates, known as "zippin" estimates, however it requires at least three runs at each electrofishing site, with detailed accounts of how many fish are caught on each (Imre *et al*., 2005). As a result it is suggested that electrofishing survey protocol be expanded to allow the generation of "zippin" estimates for use in future studies.

5. Conclusion

Following the initial analysis stage of this project, several suggested patterns were found between instream and bankside habitat variables and juvenile salmonid density, as presented and discussed in section 4. This allowed the creation of suggested ideal ranges for 27 unique variables, all influencing habitat quality, tailored to the Annan catchment area. Using these ranges it was then possible to assess and rank the habitat quality of each sub-catchment relative to its potential for salmonid production. The results of this ranking showed the Milk, the Kinnel and the Mein to be the three main tributaries or "sub-catchments" most in need of restoration and remedial works. It also showed that across the Annan catchment area all main tributaries have sites that could be improved, particularly with regards to bankside cover and bank face and buffer zone vegetation. Several possible management methods were suggested as to how to improve habitat quality within the Milk, the Kinnel and the Mein, and as to how to improve vegetation and cover throughout the catchment. These included the reconstruction of substrate within the Milk, the introduction of weirs and boulders to improve flow within the Kinnel and the replanting of riparian habitat within the Mein. With the suggestion that riparian replanting could also be implemented at sites across the catchment in all main tributaries.

Suggestions have also been made to assist in future studies of this kind and in the future assessment of the Annan catchment's overall habitat quality. Expanding current electrofishing protocol to include multiple runs would allow the creation of estimated salmon densities for every site surveyed using the "zippin" method. The introduction of less granular variables such as an overall estimation of substrate condition or an overall estimation of flow condition with four or five possible outcomes i.e. excellent/good/moderate/poor. Introducing new variables at a level above the granular variables would allow future research to establish stronger patterns between variables such as substrate or flow condition and salmonid density, which could then be investigated further at the granular level i.e. silt/sand/gravel to determine the individual influence of each. This would allow the creation of more precisely defined ideal ranges for each variable, allowing a more in-depth analysis of habitat conditions within each tributary and the catchment as a whole.

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7. Appendices

Appendix 1. Electrofishing Results (RAT)

Appendix 2. Habitat Surveys (RAT)

Appendix 3. RAT Master Spreadsheet (RAT)

Appendix 4. SEPA Density Estimates (SEPA)

Appendix 5. Final Dataset

Appendix 6. Pattern Analysis Dataset

Appendix 7. Habitat Analysis Dataset

Do to the size of the data sets they are have been stored in a dropbox account.

url: www.dropbox.com

email: acsgillan@yahoo.co.uk

password: ACSGillan