CHAPTER 6: LINKING ATLANTIC SALMON W

6.1 SALMON ABUNDANCE DATA

The previous two chapters (4&5) have highlighted the large degre
variability both spatially and temporally in the UK, and indicated th
consistency with patterns between the different regions. The anal
suggested natural flow variability was lost when generalising at th
local scale, and therefore individual river analyses was essential i
understanding flow variability and how this might impact the rivers

These chapters have also started to allude to some potential impl
could have for Atlantic salmon, including 1) the potential importan
diversity of spring flows which could impact the juvenile life stage
salmon; where low spring flows may restrict access to feeding ha
high flows may wash the juveniles downstream, and 2) the import
autumn flows in initiating and maintaining adult migration from tra
waters into freshwater, where low flows could prevent migration,
the question as to whether high flows in autumn are always bene
timing is important.

In order to develop this further and effectively explore relationship
Atlantic salmon and flow, long-term salmon abundance data is re
UK a number of different methods for obtaining information on sa
abundance are available, including rod and net catch data, fish c
adult and smolt traps and redd counts (Table 6.1: Eatherley *et al.*
However, despite this range of methods for estimating Atlantic sa
abundance, national long-term (in excess in 30 years data) abun
only exists from angler's rod catch data, which is not without its o

Table 6.1: Different monitoring/survey techniques for collecting Atlantic salmon data in the UK.

Type of salmon data	**Details of abundance method**
Rod catch data	The Salmon Fishery Act, 1865, first introduced the requirement for every person wishing to fish for salmon or sea trout in England and Wales, commercially or by rod and line, to obtain a license. This resulted in some historical data on fishing effort, but it was not until the Salmon and Freshwater Fisheries Act, 1923, that a provision was made for regional fisheries authorities to make a byelaw requiring persons to complete a catch return. Initially this was collected locally to differing degrees of success. A step change occurred when the Salmon and Freshwater Water Fisheries Act, 1975, extended powers and required compulsory catch returns (including the requirement to submit nil returns if no fish were caught).
Fish counters	These provide an absolute count of adult salmon from the tributary to catchment level, depending on the location. The equipment is expensive to buy and install, and requires regular monitoring to ensure data collection is accurate, as data can become compromised by missed, false, multiple or by-passed counts (Stephen, 1999, 2003).
Net catch	All coastal and estuarine net fisheries are legally required to record the number of salmon caught in their nets (Eatherley *et al*., 2005). Research has shown when correlating in-river salmon abundances the influence of nets cannot be ignored (Youngson *et al*., 2002). In England and Wales, generally fisheries are a public right and cannot be bought or sold. This means agreements are required with the fishermen, who hold the licenses of agreement, compensating them not to fish (in Scotland, this is different; fishing rights are private and transferable). In 1999, netsman were banned from killing, and in most cases fishing for salmon before the 1st June, however there are derogations that allow fishing in some areas where netting is predominately for sea trout, under the assumption any salmon caught will be returned alive.
Adult traps	Like counters these traps count the number of migrating adult salmon from the tributary to catchment level. As each fish is verified the data collection method does not suffer the same limitations as the counter method with missed, false, multiple or by-passed counts. The traps are expensive and require monitoring and may alter fish behaviour.
Smolt traps	These can be fixed or mobile traps, which catch smolt migrating downstream from the tributary to catchment level. Again, the traps are expensive, require monitoring and may alter fish behaviour.
Redd counts	This is an estimation of the number of female adults in the section of river from counting the number of spawning redds. However, this method is limited in that some females can lay eggs in multiple redds, or multiple females can lay eggs in the same red (Taggart *et al*., 2001). In addition redds can be eggless.

6.1.1. Rod catch data and its limitations

The Salmon and Freshwater Fisheries Act, 1975, requires all rod fisheries to annually report the total number of salmon caught in their rivers. These catch statistics provide one of the primary means for formulating salmon management policies at local, national and international levels. However, there are significant limitations in using the data, such as there is no estimate of fisheries effort (Thorley *et al*., 2005). But in the absence of long-term data from other direct measures, they typically represent the only available information to assess the state of the stock, and when compiled over a number of years in a consistent manner, fish catch data may be indicative of long-term stock abundance trends (Russell *et al*., 1995).

In any fishery, the number of fish caught will depend on the number of fish available (stock abundance), the susceptibility of those fish to capture (catchability), and the duration, intensity and effectiveness of fishing activity (fishing effort) (Gulland, 1983). In order to use fish catch data, the limitations must be recognised. Harris (1986) concluded that the limitations effectively fall into two categories: 1) problems of incomplete/inaccurate data and 2) difficulties of relating catch to actual stock size (Table 6.2).

Table 6.2: Limitations of rod catch data

Types of data limitations	**Details on limitations**
Incomplete/inaccurate data limitations	
Variable reporting procedures	Most data is extracted from catch returns, but some data has historically been derived from bailiff records and other sources. Mandatory returns were also not required throughout the time period used in this thesis.
Variable reporting rates	It is suggested the introduction of catch and release salmon fishing, typically for spring salmon, increased awareness of the perceived drop in numbers amongst anglers and may have changed the precision of recording (Youngson *et al*., 2002). Also, catch return reminders over time have been issued in some areas and not others.
Inaccurate returns	Under reporting, both real and/or perceived.
Illegal fishing/ poaching	Recognised as a major problem in many areas and not reflected in the records. In 2009, a national byelaw banned the sale of rod-caught fish: designed to reduce the sale of illegally caught fish and hence poaching.
Inaccurate identification	Some misclassification is likely, e.g. fisherman may have misidentified salmon for sea trout, etc.
Difficulties of relating catch to stock size	
Changes in effort	Anglers are typically constrained on where and when they can fish; therefore effort can vary greatly seasonally (Smith *et al*., 1993) and environmental conditions, such as rainfall, will also affect effort. Currently there is a total absence of effort data apart from license numbers, which do not provide a direct measure.
Efficiency	The skill of individual anglers can reduce the efficiency.
Catchability	Changes in the responsiveness of fish to fishing lures.
Other exploitation	Exploitation by commercial fisheries, such as coastal nets.

Incomplete/inaccurate data limitations will apply to varying degrees in different areas, although the reliability of these is thought to have improved through time

(Russell *et al*., 1995). Even if you assume the angler rod catch data is accurate, there are difficulties of relating catch to actual stock size, as the correlation between exploitation rate and stock size can be very complex.

It is believed all these limitations are also affected by river flow (Menzies, 1938; Mills *et al*., 1986; Milner, 1990; Clarke *et al*., 1991; Laughton, 1991). Research from British rivers indicates anglers' catches of salmon can be strongly influenced by river flow (Brayshaw, 1967; Millichamp and Lambert, 1967; Alabaster, 1970; Gee, 1980; Clarke *et al*., 1991). The catchability of a fish is impacted by weather conditions resulting in changes to water depth, turbidity and wind. Low rainfall periods, resulting in low flows, also typically impact fishability, with catches depressed typically because of less fish migrating into freshwater during this time and often less fishing effort.

Catch and release rod fishing is now an integral component of fisheries management in many countries. Data from studies spanning over 30 years assessing the biological response of Atlantic salmon to catch and release show survival rates, when the correct code of practice is followed and in favourable environmental conditions, are very high and can be 100% (Appendix G1). However, catch and release can result in reduced spawning success and could, therefore, give an unrepresentative picture of the Atlantic salmon abundance.

Effective catch and release can be jeopardised by extended playtime, hooking location, the use of live bait and air exposure (Casselman, 2005). Studies have also shown that several environmental factors, such as water temperatures above 22°C and very soft water, can reduce the survival rate of angled salmon by having a profound effect on their recovery. Angled salmon that have recently entered freshwater are also more vulnerable to stress due to the significant osmoregulatory pressure recently endured (Tufts *et al*., 1997). Mäkinen *et al*., (2000) investigated the effects of gill-net entanglement and catch and release on the behaviour of 23 grilse and one 2 sea-winter radio-tagged Atlantic salmon in the River Ohcejohka, Finland. They found gill-net caught fish exhibited more extensive downstream running, than rod-caught salmon. This suggests gillnetting impedes upward migration more than catch and release practises.

This chapter assembles and uses 850 station-years of catch data, assembled for 17 sites over the time period between 1959-2010, to explore flow/fish relationships. Because, despite the well documented limitations of rod catch statistics, the advantages of record length and spatial coverage justify the investigation of these data in this study.

6.1.2. Current UK salmon population monitoring

The EA have a duty in England and Wales to ‘maintain, improve and develop fisheries’ and, therefore, they use a range of techniques to assess the status of our fish populations. As of 2004, the EA’s monitoring approach has consisted of four tiers:

1. Index sites; sites intensively monitored in order to understand fish population dynamics and the impacts of different stressors. This includes measuring fish abundance and analysing age and sex structures. The EA currently has four index monitoring programmes on salmon rivers: the Tyne (northeast England), Tamar (southwest England), Dee (Wales) and Lune (northwest England).
2. Temporal sites; sites surveyed annually to a lower level of detail in order to gauge long-term population trends. This monitoring occurs in 545 salmonid sites.
3. Spatial sites; sites surveyed once every five years, to detect differences in fish populations between different locations. There are 4010 salmonid sites surveyed.
4. Sentinel sites; sites surveyed once every five years, to provide data on the distribution of fish species. This includes 575 salmonid sites.

Each year the International Council for the Exploration of the Seas (ICES) makes an assessment on the status of salmon stocks in the northern hemisphere, including the north east Atlantic area, in order to provide an overview of the changes in salmon stocks over time. This report provides advice to the North Atlantic Salmon Conservation Organisation (NASCO), whose objectives are to contribute to the ‘conservation, restoration, enhancement and rational management of salmon stocks’. The ICES model first estimates the salmon returning into freshwater in each region, and then uses this to extrapolate how many fish would be required at sea to produce these returns. This model uses available catch and effort data in order to calculate pre-fishery abundance; therefore, trends may not reflect every individual river. For England and Wales, the outcome of the model suggests that overall the pre-fishery abundance of salmon has declined by over 65% from the early 1970s to 2009 (Cefas and EA, 2010). However, the total declared salmon rod catch in 2010 increased by 60% (24,826 rod caught salmon) compared with 2009. This was also a 24% increase when compared with the 5-year mean of 19,997 fish (Cefas and EA, 2011). In 2012, 18,450 salmon were caught, a 20% decrease on 2011 (EA, 2013c).

The catches of grilse and multi-sea winter (MSW) salmon were also above the previous 5-year average. This was in despite of the fact that river flows in 2010 were below average for most of the year, particularly in May, June and December. However, the flows between July and November were at average levels, and these are the main fishing months. The declared salmon catch by nets and fixed engines in 2010 (22,634 salmon) was almost double the average of the last five years (Cefas and EA, 2011). However, there has been a marked decline in net catches over the past 15 years as a result of the phasing out of mixed stock fisheries and increased regulatory controls, such as the ban of the killing of spring salmon before 1 June, which was introduced in 1999. Since 1993, there has been a policy to phase out mixed stock salmon fisheries. This has resulted in the phasing out of eight small coastal mixed stock fisheries (Appendix G2). Since February 1973, there has been a prohibition on fishing for salmon in waters off England and Wales beyond the six-mile limit. Inside this limit it also became an offense for anyone to fish for salmon without a fishing licence.

The current EA salmon and sea trout rod licence system dates back to 1994 (EA, 2004). Since this time, the numbers of short-term licenses, which are one day and eight-day licences, have remained reasonably consistent, at approximately 10,000 issued per year. However, the number of annual licences decreased dramatically from approximately 26,000 in 1994 to 15,000 in 2001. It is hypothesised that this was due to declining salmon stocks and the restrictions placed on angling, such as the protection of early MSW fish. However, since

2001 the annual licences have begun to increase again. In 2009 and 2010 the annual licence sales were at 26,000-27,000, which is the highest since the current system was introduced in 1994. Despite the recent increase in annual licences, the actual number of days fished by anglers has declined over the same time period, from approximately 300,000 days in 1994 to under 200,000 days in 2010 (Cefas and EA, 2011).

The salmon stock levels on 64 individual rivers are assessed by the EA against conservation limits (CL), which are the minimum number of spawning adults needed to ensure the conservation of salmon stocks. In order to calculate this, thresholds are set below which the number of spawning fish should not fall below. Compliance is assessed using all available data. In 2008, it was estimated that 41 rivers of the 64 rivers (66%) were deemed to be above the CL. However, in 2009 this declined sharply to 22 rivers (34%). In 2010, this number was back up to 59% of rivers. Numbers of spawners can vary significantly from year to year due to environmental conditions, and hence so can compliance with CL. Due to this, the EA also sets a longer term goal that rivers should meet their CL in 4 years out of 5.

The EA classifies salmon rivers into four categories, according to the likelihood that they will comply with the CL. According to this, the results for 2013 and predicted forecasts for 2018 are:

- Not at Risk (rivers with more than a 95% probability of meeting the CL): In 2013, 6 rivers (14%) in England and 1 rivers (5%) in Wales were in this category, which is forecast to decrease to 3 rivers (7%) in England and 0 rivers (0%) in Wales by 2014.
- Probably not at risk (rivers with a probability of between 50% and 95% of meeting the CL). In 2013, 7 rivers (17%) in England and 2 rivers (9%) in Wales were in this category, which is forecast to decrease to 6 rivers (14%) in England and remain at 2 rivers (9%) in Wales by 2014.
- Probably at risk (rivers with a probability of between 5% and 50% of meeting the CL). In 2013, 13 rivers (31%) in England and 4 rivers (18%) in Wales were in this category, which is forecast to increase to 25 rivers (60%) in England and 7 rivers (32%) in Wales by 2014.

- At risk (rivers with less than a 5% probability of meeting the CL). In 2013, 16 rivers (38%) in England and 15 rivers (68%) in Wales were in this category, which is forecast to decrease to 8 rivers (19%) in England and 13 rivers (59%) in Wales by 2014.

6.2 NATIONAL ANALYSES OF SALMON ROD CATCH DATA

The 850 station-years of Atlantic salmon rod catch data used in this study (Figure 6.1) show a stable pattern over the 1959-2010 period, with average values of about 700 fish per year. The suggested linear trends reflect i) the relatively high values at the start of the period and ii) the strong recovery of the salmon population in one river, the River Tyne (see section 6.3.3) since the mid 1990s.

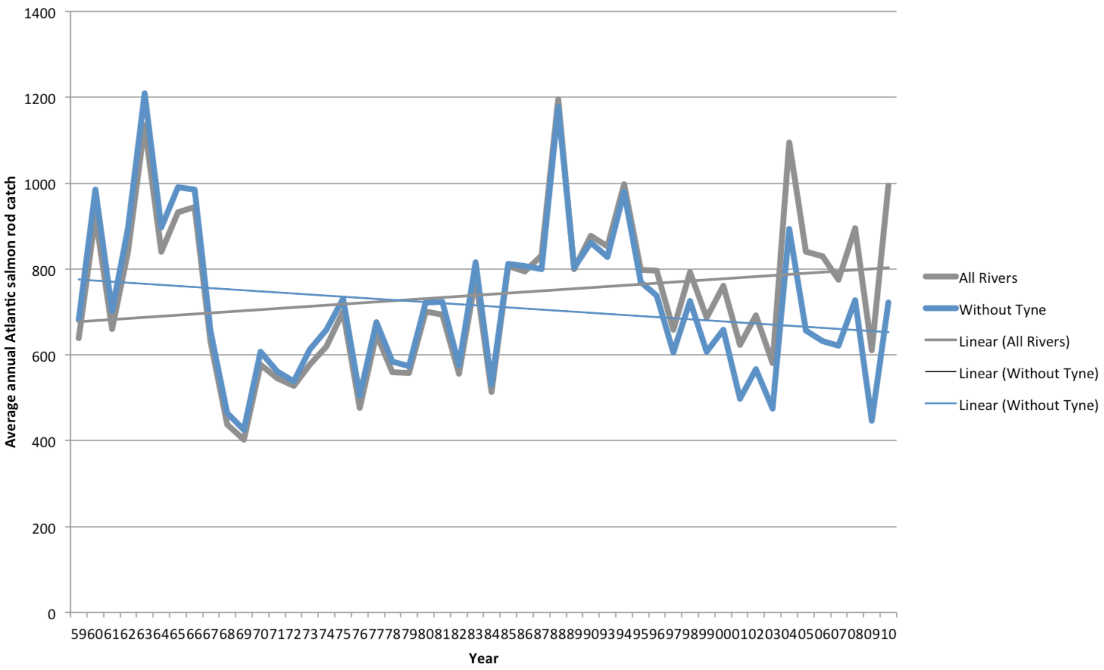

Figure 6.1. Average annual Atlantic salmon rod catches from the 17 selected rivers used in this study and the 16 rivers excluding the River Tyne.

If, however, the rod catch figures for the River Tyne were excluded from the analysis (Figure 6.1), the trend changed to an overall decline over the same time period. The recovery of the River Tyne, particularly from the mid 1990s, masked the declining rod catch figures found in the other rivers.

6.3 REGIONAL ANALYSES OF SALMON ROD CATCH DATA

In England and Wales prior to 1983, there was a plethora of organisations responsible for collecting and collating annual rod catch statistics, which has resulted in the publication of differing sets of statistics. From 1951-1973 the Association of River Authorities (formerly River Boards) published the data in Annual Reports. Following the reorganisation of the Water Industry in 1974, a similar annual summary was published by the Department of the Environment in its ‘Water Data’ series and subsequently in its ‘Digest of Environmental Pollution and Water Statistics’. For one year, in 1981, the Fisheries Advisory Committee of the National Water Council (NWC) compiled the data, until the NWC was disbanded into the Ministry of Agriculture, Fisheries and Food (MAFF). The Directorate of Fisheries Research (DFR), which took over catch data collation from 1983 until 1989 (publishing the data in its Fisheries Research Data Report Series). In 1989, the National Rivers Authority (NRA) was established and published the data in its reports (Russell *et al*., 1995). This continued until 1996, when the NRA was disbanded into the EA. The EA continues to co-publish the catch data in the annual publication of salmon and migratory trout catch statistics along with the Centre for Environment, Fisheries and Aquaculture (CEFAS). In 1995, Russell *et al.,* collated the best available data from these sources available from 1951-1990[6]. Although salmon catch data exists prior to 1951, this year was used as the start date in the present thesis because it was the year the regional River Boards were first formed and for the first time the data was collected and reported on a relatively regular and consistent basis between regions.

In assembling the dataset of rod catch statistics for the southwest, Wales, and the English northern river, the Russell *et al.,* (1995) report was used for records between 1951-1990. From 2000, annual Fisheries Statistics reports are

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[6] *Russell et al., (1995) concluded in their review that one factor which affected stocks and catch data throughout England and Wales was the disease ulcerative dermal necrosis (UDN). The presence of the disease was first recorded in England in 1965 in the northwest of England. However, by the late 1960s it was widespread across the country and persisted for approximately 10 years. The impact of UDN of catch records during this time has not and cannot be quantified, but should be noted.*

available on the Environment Agency website; these reports have summary tables which record salmon catch records from 1990 until the present time. Pre 2000, the data is only available as an annual average. After 2000, monthly rod catch figures are available. The River Tweed rod catch data was obtained, via email, in one complete set from Marine Scotland Science. These records were then analysed to assess temporal patterns within and between rivers before combining with flow indices selected from Chapters 4 and 5 to describe flow-fish catch relationships.

6.3.1. Southwest region introduction

In the southwest region, salmon support a number of important rod fisheries. Although the long-term angling effort has not been collated during the analysis period (starting 1951), it is believed to have increased over time, particularly from the earlier years. In 1959, reminders to submit catch returns were issued to all anglers in the Cornwall area after persistently low rates of reporting catches. The reminder system was extended to the whole southwest region in 1974, but was later discontinued (exact timings of this are not known). Reporting procedures have varied over this review period and some years had very low proportions of anglers submitting catch returns (Russell *et al*., 1995).

Another factor affecting the angling effort in the southwest over this period was changes in fishing seasons for particular rivers, which allowed fishing for previously unexploited early or late running salmon. The first change of this manner, applicable to this study, was approved for the River Camel in 1964, where the fishing season was deferred until 1st April, but the close was extended to 15th December. Similar changes were also implemented on the River Dart in the 1970s.

In the 1950s, stocking programmes were implemented by both the Cornwall and Devon River Boards in a number of catchments in the southwest using both Scottish and local wild broodstock. The River Authorities continued these programmes, but the majority were discontinued with the formation of South West Water Authority in 1974. There is little evidence to indicate if these stocking programmes impacted on local stocks (Russell *et al*., 1995).

Many of the rivers in the southwest have supported net fisheries, predominately seine nets and a drift net fishery in the Camel estuary. The fishing methods in the region are largely unchanged; however, a byelaw in 1976 banned the use of monofilament nets in the southwest region. In 1962, a Net Limitation Order (NLO) came into force, restricting the numbers of seine nets permitted in the Tamar District (affecting the Tamar, where 15 were permitted; and Lynher, where 5 were permitted). In 1977, an NLO was imposed on the River Camel, restricting the number of drift nets to 7. Buy-out arrangements are now operating in some of rivers used in this study (Appendix G2). Illegal and under-reported net catches are thought to be substantial in many of the years sampled. In 1989, a byelaw to prevent drift netting for sea fish in the Tamar estuary is believed to have helped reduce illegal catch in the area. In 1956, the fishing right for one of the Poole harbour seine nets, which impacts the River Frome, was purchased by Avon and Dorset River Board. This net operated until 1978. A byelaw was introduced in 1957 to increase the annual close season for the commercial fisheries by one month to reduce exploitation of spring fish. Buy-out arrangements are now operating on the other nets that impact on the River Frome.

The River Frome is a chalk stream in the Wessex region. Between 1950 and 1965 there was a significant increase in salmon angling effort in Wessex region, particularly on the River Frome. This was due to increased fishable water caused by weed cutting, installation of fish passes and an extension in the angling season. In the Wessex region, the accuracy of catch reporting is higher than the southwest, with over 95% of licenses reporting their catches between 1951-1990, with the aid of postal reminders (Wessex Water, 1986).

6.3.2. Southwest regional analysis

Overall, of the 6 southwest region rivers analysed, 5 had declining salmon rod catches over the time period from 1951-2010 (Appendixes G5-G10 and Figure 6.3).

The peak year for rod caught salmon on the River Dart was 1966 with 475 salmon caught, followed by 1986 with 455 salmon caught. All of the years with fewer salmon catches on the River Dart were in the 2000s apart from 1976, in which, as described earlier, there was a widespread national drought. The 1970s and early 1980s were particularly low for salmon rod catches, this then increased in the late 1980s and early 1990s. However, rod catches from the late 1990s and 2000s have returned to low levels (Appendix G3).

The River Tamar has also shown a decline in salmon rod catches, although this is less pronounced than the other southwest region rivers. The Tamar had a high peak in rod catches in 1958 (1495 salmon caught) and 1957 (1395 salmon caught). In the late 1990s and 2000s, the rod catches dramatically reduced, with four out of the five worse years for salmon caught occurring during this time (2003, 2001, 2005 and 2002; Appendix G4).

On the River Axe, the number of rod caught salmon declined to zero between 1985 and 1990. The numbers then increased in the late 1990s and 2000s, but remained lower than previous trends in the 1950s and early 1960s. The year with the highest number of rod catches was 1959 with 59 salmon caught (Appendix G5).

The River Lynher had a small decline in salmon catches over the time period. The peak in rod catches occurred in the early 1970s, with the highest rod catch of 260 salmon in 1974. For this river, the salmon rod catches were very variable between years; however, there was a more pronounced decline in catches from the late 1990s. Rod catches did however increase again in 2010 (Appendix G6).

The River Camel was the only river surveyed in the southwest where rod caught salmon numbers were shown to generally increase during the time period, with the second highest year for rod caught salmon occurring in 2010, with 546 salmon caught. This is compared to the early fifties, where only 10 salmon were caught in 1952, 36 in 1955 and 61 in 1953 (Table 6.3). There were also low catch years in 1978 (74 salmon) and 1968 (75 salmon). The highest year for rod caught salmon was 1988 with 556 salmon caught (Appendix G7).

The River Frome showed a clear decline in salmon rod catch numbers over the analysis period, peaking in the 1950s and early 1960s, with the highest catch of 692 salmon caught in 1963. Following this period, between 1965 and 1989 the catches remained relatively consistent. However, from the early 1990s continuing to 2010, rod catches underwent a further decline. The lowest number of rod caught salmon was in 2009 with just 35 fish caught (Appendix G8).

Table 6.3: Top five high and low years for numbers of rod caught salmon on the rivers Dart, Camel, Tamar, Axe, Lynher and Frome between 1951-2010.

Rivers	**High years (# of rod caught salmon)**					**Low years (# of rod caught salmon)**				
Dart	1966 (475)	1986 (455)	1951 (401)	1988 (394)	1954 (374)	2002 (34)	2003 (37)	1976 (47)	2006 (49)	2001 (50)
Camel	1988 (556)	2010 (546)	1974 (476)	1963 (408)	1994 (408)	1952 (10)	1955 (36)	1953 (61)	1978 (74)	1968 (75)
Tamar	1958 (1495)	1957 (1395)	1980 (1169)	1981 (1109)	1975 (1092)	2003 (114)	2001 (114)	2005 (131)	2002 (143)	1961 (163)
Axe	1959 (71)	1954 (1967)	1956 (63)	1960 (53)	1958 (50)	1989 (0)	1990 (0)	1985 (0)	1987 (0)	1988 (0)
Lynher	1974 (260)	1972 (245)	1975 (177)	1986 (160)	1973 (158)	1989 (15)	1995 (19)	1996 (22)	1961 (27)	2003 (28)
Frome	1963 (692)	1954 (571)	1955 (499)	1962 (470)	1959 (464)	2009 (35)	2010 (43)	2008 (46)	2003 (57)	2006 (57)

6.3.3. North region introduction

The rivers analysed in the northern region include those from the EA Northumbria region and northwest region and SEPA South Scotland region.

Historically, Northumbria has supported some of the country's finest salmonid rivers; however, several of the rivers lost their stocks early this century due to gross industrial pollution, particularly the River Tyne. Smaller rivers, such as the Coquet in the northern part of this area, supported salmon runs throughout the analysis period. Angling effort is believed to have increased following the recovery of local stocks. In the northwest region, salmon were widespread, although many rivers are short and spatey. Angling within this region is also believed to have increased over time (Russell *et al*., 1995). Catch returns have been variable and generally low for all northern regions. In many of the early years of analysis, the reported catch was supplemented by catches arising from water bailiff's reports.

Salmon stocking programmes in the northwest region started in 1952 and continued for most of the timeframe. In Northumbria, salmon stocking was initiated in 1955 and continued for about 10 years. However, no significant increase in catches was observed during this time. More recently, in 1978, since the building of Kielder reservoir, a large number of salmon parr were stocked into the region's rivers, especially the Tyne, to mitigate for the loss of spawning area from the reservoir. This stocking programme coincided with improving water quality and catches in many rivers increased (Russell *et al*., 1995).

In the northeast coastal fishery, drift and T-nets have been licensed since the analysis period started in 1951. By 2009, 15 licenses remained in the northeast coast fishery, which is down by 89%. However, catches taken by the drift net and T & J net fisheries in the northeast region still account for over 50% of the total catch taken by nets in England and Wales. Haaf nets are hand-held nets unique to the northwest area and have been used in a number of estuaries, including the Lune. Dip nets have been used in the River Kent, in varying numbers, throughout the early analysis period. Drift nets have also operated in the vicinity of the rivers Ribble and Lune (Russell *et al*., 1995).

6.3.4. North regional analysis

Overall, of the 6 rivers analysed, 82% (5 out of the 6) had increasing salmon rod catches over time, from 1951-2010 (Appendices G9-G15 and Figure 6.4).

The River Ribble's lowest rod catches were in the early 1950s up until the early 1970s. The lowest number of salmon caught in the river was in 1959 with only 38 fish. From the early 1970s to the end of the 1990s, catches increased from earlier norms. In 2004, the number of rod caught fish dramatically increased, with the highest number in the time record of 1442 fish. Following this peak, rod catches have remained high, with the entire top five peak years in catch occurring in the 2000s (Appendix G9).

The lowest salmon rod catches on the River Lune occurred in 2010, with only 117 fish caught. This did not follow the trend of increasing catches that started in the late 1980s. In late 1960s and 1970s there was a dip in rod catches, following previous high catch years in the early 1960s. The highest number of salmon caught was in 2004 with 1893 fish caught (Appendix G10).

Rod catches on the River Kent remained low from the beginning of records in 1955 to late 1980s. The lowest years for rod catches were 1968 and 1967, when only 4 salmon were caught in each year. From the early 1990s, rod catches dramatically increased on the Kent, with the highest number of salmon (786 fish) caught in 1998, followed by the second highest catch of 657 salmon in 2010 (Appendix G11).

The River Coquet had the lowest rod catch in the 1970s, and in particular 1974, when only 78 salmon were caught. The 2000s saw increased salmon rod catches with the highest number occurring in 2004, where 1177 salmon were caught (Appendix G12).

Table 6.4: Top five high and low years for numbers of rod caught salmon on the rivers Coquet, Kent, Lune, Ribble, Tweed and Tyne between 1951-2010.

Rivers	**High years (# of rod caught salmon)**					**Low years (# of rod caught salmon)**				
Coquet	2004 (1177)	2005 (1108)	2010 (978)	2008 (842)	1967 (832)	1974 (78)	1976 (91)	1982 (117)	1973 (124)	1969 (125)
Kent	1998 (786)	2010 (657)	1994 (616)	2004 (582)	2000 (576)	1968 (4)	1967 (4)	1969 (19)	1959 (29)	1960 (32)
Lune	2004 (1893)	1994 (1854)	1988 (1487)	2005 (1481)	1998 (1451)	2010 (117)	1969 (196)	1983 (235)	1968 (143)	1951 (286)
Ribble	2004 (1442)	2008 (1372)	2005 (1094)	2010 (1085)	2007 (1062)	1959 (38)	1969 (47)	1951 (48)	1955 (51)	1956 (82)
Tweed	1963 (12,497)	1991 (11,421)	1957 (11,087)	1960 (10,760)	1988 (9,907)	1974 (3,864)	1969 (3,866)	2009 (3,883)	1972 (4,469)	1952 (4,469)
Tyne	2010 (5,075)	2004 (4,122)	2006 (3,795)	2005 (3,595)	2008 (3,389)	1959 (0)	1958 (2)	1955 (3)	1960 (3)	1953 (4)

The River Tyne has seen a steady continual growth in rod catches, from 0 salmon in 1959, to a peak in 2010 of 5,075 fish. The 2000s were particularly high for rod catches on the Tyne; with the entire top five catch years occurring during this decade (Appendix G13).

The River Tweed was the only one of the northern rivers to show an average trend of slightly declining rod caught salmon over the analysis period, according to the trend-line; however, the records are very variable. The highest numbers of salmon were caught in 1963 (12,497 fish), but following these high catch years, numbers began to decrease in the late 1960s. In the early 1980s and 1990s, numbers started to increase again. However, the 2000s saw further declines in rod caught salmon numbers, with the third lowest number of salmon caught during the analysis period occurring in 2009, with 3,883 (Appendix G14 and G15).

6.3.5. Welsh region introduction

The Welsh region supports many migratory salmonid runs, and normally accounts for approximately half of the declared annual rod catch of salmon and sea trout in England and Wales. Atlantic salmon is widespread through the region, apart from some rivers of the industrialised southeast region. Stocking programmes were initiated in most of the Welsh fishery districts from the 1950s; however, it is not clear what effects these have had on the stocks (Russell *et al.*, 1995).

Anglers catch returns from the Glamorgan and southwest Wales regions were supplemented with bailiff's reports in the early part of the review period, due to infrequent reporting. Various regional changes in rod licenses occurred from 1951, in particular there was a restructuring in 1976. The impact of these changes on the accuracy of data is not known. From 1976, reminders were issued and the region's catches were based almost entirely on angler's return reports, with the exception of the River Wye, which continued to supplement with owner's returns (Russell *et al.*, 1995).

A variety of fishing techniques have been employed for taking salmon in the Welsh region. Seine nets were the most widely used, particularly in southwest Wales and Gwynedd areas between 1965-1973. Coracle nets, which are short trammels operated by coracles (a technique unique to Wales), were used on the rivers, including the River Teifi. Stop nets were also used in the estuary of the River East and West Cleddau. Fixed traps were used on the River Conwy. The use of monofilament and monoplied nets was banned throughout Wales in 1983; however, on rivers where it was extensively used, such as the River Dyfi, a phasing down period until 1987 was allowed (Russell *et al*., 1995).

6.3.6. Welsh regional analysis

Overall, of the 5 rivers analysed, 80% (4 out of the 5) had decreasing salmon rod catches over time, from 1951-2010 (Appendixes' G16-G20 and Figure 6.5).

Rod catches on the River Dysynni were highest in the mid/late 1960s and early 1970s. The highest number of rod caught salmon was in 1966 with 101 fish caught. After this peak, the number of salmon catches have declined to just a few fish per year in the late 1990s and 2000s, with the lowest year within this record occurring in 2003, with just one fish. Before the peak in the 1950s, the number of fish caught per year averaged approximately 20 fish (Appendix G16).

The River Cleddau (rod catches are combined for the western and eastern Cleddau) has also shown a decline in salmon rod catches. The Cleddau had a high peak in rod catches in 1975 (353 salmon caught) and 1966 (307 salmon caught). After 1975 the catches reduced, with the lowest year for salmon rod catches in 1990, with just 17 fish caught (Appendix G17).

The River Teifi was the only one of the Welsh rivers to show an average trend of increasing rod catch salmon over the analysis period. The highest numbers of rod caught salmon were in 1988 with 1,889 fish caught, followed by high rod catches in 2004 (1,962 fish) and 2010 (922 fish). In contrast to the other Welsh rivers, the lowest salmon catch year was 1969 with only 116 fish caught (Appendix G18).

The River Dyfi had an overall decline in salmon catches over the time period. The peak in rod catches occurred in the late 1950s, with the highest rod catch of 1,110 salmon in 1958. The salmon rod catches were very variable between the years; however, there was a more pronounced decline in catches from the late 1990s continuing into the 2000s. All five of the lowest salmon catch years occurred during this period; the lowest salmon catch year was in 2003 with only 46 fish caught (Appendix G19).

The River Conwy showed a clear decline in salmon rod catch numbers over the analysis period, peaking in the mid 1950s, with the highest catch of 1,302 salmon caught in 1958. Following this period, there was a gradual more variable decline, until the early 1990s when the decline became more pronounced. The lowest number of rod caught salmon was in 1992 with just 81 fish caught (Appendix G20).

Table 6.5. Top five high and low years for numbers of rod caught salmon on the rivers Dysynni, Western Cleddau, Teifi, Dyfi and Conwy between 1951-2010.

Rivers	**High years (# of rod caught salmon)**					**Low years (# of rod caught salmon)**				
Dysynni	1966 (101)	1965 (97)	1964 (74)	1970 (47)	1974 (44)	2003 (1)	1995 (2)	1999 (2)	2001 (2)	2005* (2)
Western Cleddau	1975 (353)	1966 (307)	1964 (234)	1967 (223)	1956 (213)	1990 (17)	1969 (23)	1996 (29)	1992 (31)	2006 (32)
Teifi	1988 (1889)	2004 (1062)	1987 (934)	2010 (922)	1963 (1896)	1969 (116)	1959 (128)	1968 (131)	1992 (133)	1957 (159)
Dyfi	1958 (1110)	1970 (785)	1965 (751)	1971 (740)	1974 (705)	2003 (46)	2002 (49)	2009 (84)	1999 (106)	2005 (114)
Conwy	1958 (1302)	1957 (1171)	1956 (1159)	1964 (1047)	1965 (997)	1992 (81)	1999 (89)	2002 (110)	1997 (118)	1998 (134)

* = 2006 and 2007 also only had rod catches of 2 salmon.

6.3.7. Comparison between the regions

The salmon rod catches in the southwest and Wales have, on average, declined from the 1950s, whereas the northern rivers have tended to increase. However, it is important to recognise that the start and finish date (1951-2009) of these data are artificial, and thus the trend line imposed on each of these salmon rod catch datasets may misrepresent or hide long-term cyclic trends in catches.

The salmon rod catch data for the northern region of the UK show increasing numbers of salmon caught during this time in most of the rivers, despite, according to the WFD 2012 classifications only 28% of the River Ribble, 36% of the River Kent and 62% of the River Lune being at good or above status (EA, 2013b), suggesting that freshwater pressures could still be limiting salmon populations. However, the rivers in Wales and southwest England also have low compliance with WFD, which could suggest that salmon from the northern region are migrating to and feeding at different marine locations to salmon from the southwest and Wales.

Some of the northern rivers are recovering from water quality problems from an industrial past, particularly the River Tyne, whose salmon run demise was mainly attributed to poor estuarine water quality from the industrial and urban sewage pollution, which was at its worst in the 1950s. The reduction of the industrial activity and improvements to effluent treatment and disposal during the 1960s to 1980s improved water quality markedly. A stocking programme supported the salmon run in the late 1980s and early 1990s, following the development of Kielder reservoir (Milner *et al*., 2004). Since these improvements, dramatic increases in rod catches have been found in the River Tyne, going from no salmon caught in the 1959 to over 5,000 salmon in 2010.

The River Tweed, which is a large catchment on the east coast of the UK, with sub-catchments in both Scotland and England, was the only northern region river to show a slight decline in salmon population, using rod catch data as a proxy for abundance. However, the rod catch data for the Tweed appears cyclic over the analysis period from 1951-2009; with a previous peak in catches between the late 1950s and early 1960s, followed by a decline in the 1970s, followed by an increase in the late 1980s and early 1990s, to the current decline in the 2000s. The River Tweed is a Special Area of Conservation (SAC) under the EU Habitats Directive, with Atlantic salmon classified as an Annex 2 species. It was chosen as the ‘best example in Britain of a large river showing a strong nutrient gradient along its length, with oligotrophic conditions in its headwaters, and nutrient-rich lowland conditions just before it enters the sea at Berwick' (JNCC, 2013a, site accounts paragraph 22). It notes 'considerable work has been done by the Scottish Environment Protection Agency (and previously the Tweed River Purification Board) and the River Tweed Foundation in tackling pollution and easing the passage of salmon past artificial barriers in the river. This has reversed many of the river's historical problems with water quality and access for salmon' (JNCC, 2013a, site accounts paragraph 22). This suggests that other factors, outside of the freshwater environment, are affecting Atlantic salmon on the River Tweed.

Over the same analysis period, however, the numbers of wild grilse caught on the River Tweed have shown a steady increase (note: the River Tweed is the only river studied where catch records distinguish between grilse and multi-sea winter salmon). Other studies have shown extensive variability in the composition of stocks over the last 100 years (Martin and Mitchell, 1985; Summers, 1995; Heddell-Cowie, 2003). Aprahamian *et al*., (2008) found on the River Dee prior to the 1980s the composition was dominated by multi-sea winter salmon, after which grilse increased. This change occurred at a broadly similar time for other rivers, including the River Tweed. This suggests that there may be common factors operating in the marine phase of the salmon's lifecycle that are responsible for the change. There is, however, currently no mechanism to explain annual variability in salmon maturation (ICES, 2010). Maturation rate is thought to be influenced by stock genetics (Steward *et al*., 2002) and the environment; however, there is no mechanism to explain the comparative influence of each of these in determining annual variations in maturation (Thorpe, 1994; Friedland, 1998).

The southwest and most of Wales (part from the southern region) have had a less industrial past than the north of the UK. However, there are high levels of metals in many of Cornwall's river, including the River Camel, a legacy from the county's mining past. On the Camel, there are particular problems on the lower reaches with increased levels of copper and zinc (EA, 2013a). However, the River Camel was the only southwest river that showed increased salmon populations over the studied time period. It is also the furthest west of the 6 rivers analysed in the southwest and the only river to drain into the Atlantic

Ocean on the northern coastline of the southwest. This could suggest fewer pressures on salmon returning on this length of coastline, or the water quality is improving within the river and estuary.

The River Teifi was the only Welsh river to have increasing salmon rod catches over the time period. JNCC (2013a) believe this is likely to reflect the high quality of the catchment, with a semi-natural channel largely unaffected by poor water quality or artificial barriers to migration. This suggests freshwater pressures are still dominant in other southern rivers.

The salmon populations in the southwest and Wales, arguably in more rural rivers, now appear to be under more stress than the northern populations. The large returning population in the north may suggest the problems are not at sea, unless the populations have distinctly different feeding grounds in the marine phase. This could also suggest that the freshwater/estuarine environment in the southwest and Wales is now less favourable to salmon populations, possibly due to pressures such as; low river flow, impoundments and barriers preventing migration or declining water quality. It is also possible declines in salmon are due to climate change and increasing water temperatures in the south of the UK.

6.4. CORRELATING ANNUAL SALMON ROD CATCHES WITH FLOW

The longest dataset for rod catch figures exists only as an annual summary from 1951- to the current time. To assess if this 850 station-year data set could infer any relationships with flow, a Spearman's correlation[7] was conducted between the ranked selected IHA flow parameters[8] and the ranked annual salmon rod catch figures for the same period. A positive correlation means as

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[7] *Spearman's correlation is a nonparametric measure of statistical dependence between two variables, X (the independent variable) and Y (the dependent variable). The sign of the Spearman correlation indicates the direction of association between X and Y.*

[8] *The selection IHA parameters, as described in Chapter 3 are: January, March, May, July, September, October and November median flows, 1-day maximum and minimum flows, high flow peak, high flow time, high flow frequency, large flood time and large flood peak.*

the values of one of the variables increase, the values of the second variable also increase (likewise, as the value of one of the variables decreases, the value of the other variable also decreases), and in a negative correlation, as the values of one of the variables increase, the values of the second variable decrease (likewise, as the value of one of the variables decreases, the value of the other variable increases).

6.4.1. Correlating salmon catches with flow in the southwest

On the River Dart, the Spearman correlation analyses indicated a significant relationship between August median monthly flows and catch data, where the higher the flow the greater the fish catch or vice versa, but a stronger relationship was found with flows in April. All other months indicated no significant relationship. There was no correlation between April and August flows (r= 0.195, n= 50, p=0.175). The annual high flow frequency had a significant positive relationship with salmon rod catches, indicating more salmon were caught during years with a higher frequency of high flow events (Table 6.6).

On the River Frome, there was a significant positive relationship between salmon rod catches and June median monthly flows. There was also a significant positive relationship between salmon rod catches and high flow frequency, indicating more salmon were caught during years with more high flow events or vice versa (Table 6.6).

On the River Axe, the Spearman correlation analyses indicated a significant positive relationship between September median monthly flows and catch data. A significant positive correlation was also found between the 1-day minimum flow and catch data, indicating more salmon were caught during years with a higher 1-day minimum flow or vice versa (Table 6.6). The 1-day minimum flows were also significantly positively correlated with monthly flows in May (r= 0.528, n= 44, p< 0.001), June (r= 0.619, n= 44, p= 0.000), July (r= 0.703, n= 44, p< 0.001), August (r= 0.536, n= 44, p< 0.001) and September (r= 0.348, n= 44, p= 0.021).

On the River Tamar, the analyses indicated a significant positive relationship between December median monthly flow and August median flow (where a stronger relationship was found) and rod catches (Table 6.6). There was no correlation between December and August flows (r= 0.215, n= 52, p=0.126). The December median flows did positively correlate with the overall average annual flow (r= 0.658, n= 52, p< 0.001) and 1-day maximum flow (r= 0.371, n= 52, p=0.007). The August flows positively correlated with flows in June (r= 0.321, n= 52, p= 0.020) and July (r= 0.632, n= 52, p< 0.001), as well as 1-day minimum flows (r= 0.496, n= 52, p< 0.001) and high flow frequency (r= 0.444, n= 52, p= 0.001). The annual high flow frequency also had a significant relationship with salmon rod catches (Table 6.6).

On the River Lynher, the analyses indicated a significant positive relationship between August median monthly flows and catch data (Table 6.6). The August median flows also positively correlated with the flows in May (r= 0.327, n= 45, p= 0.028), June (r= 0.352, n= 45, p= 0.018), July (r= 0.648, n= 45, p< 0.001) and with 1-day minimum flows (r= 0.637, n= 45, p< 0.001) and high flow frequency (r= 0.394, n= 45, p= 0.007). The August median flows negatively correlated with March (r= -0.306, n= 45, p= 0.041). The annual high flow frequency had a significant positive relationship with salmon rod catches, indicating more salmon were caught during years with a higher frequency of high flow events or vice versa. High flow frequency itself was positively correlated with 9 of the other IHA variables, including monthly flows in February, April, May, June, July, August and September. The average 1-day minimum flow also had a significant positive relationship with salmon rod catches (Table 6.6).

On the River Camel there was a significant positive relationship between salmon rod catches and June median monthly flows (Table 6.6). June median flows were also positively correlated with flows in April (r= 0.389, n= 44, p= 0.009), May (r= 0.869, n= 44, p< 0.001, July (r= 0.595, n= 44, p< 0.001), as well as 1 day maximum flows (r= 0.415, n= 44, p= 0.005) and high flow frequency (r= 0.299, n= 44, p= 0.049).

Table 6.6. Significant Spearman's correlation results for selected IHA parameters against salmon rod catch numbers for the southwest region.

IHA Parameter	**Dart**	**Frome**	**Axe**	**Camel**	**Tamar**	**Lynher**
Sept			r=0.384 n=44 p=0.010			
Oct						
Nov						
Dec					r=0.340 n=52 p=0.014	
Jan						
Feb						
March						
April	r= 0.452 p= 0.001 n= 50					
May						
June		r=0.320 p=0.037 n=43		r=-0.313 p=0.039 n=44		
July						
Aug	r= 0.349 p=0.013 n= 50				r=0.401 n=52 p=0.003	r=0.405 n=45 p=0.006
Annual flow						
1 day min			r=0.302 n=44 p=0.046			r=0.319 n=45 p=0.032
1 day max						
High flow peak						
High flow freq	r=0.304 p=0.032 n=50	r=0.370 p=0.015 n=43			r=0.327 n=52 p=0.018	r=0.493 n=45 p=0.001

6.4.2. Correlating salmon catches with flow in the north

On the River Lune the Spearman correlation analyses indicated a significant positive relationship between January median monthly flows,1-day minimum flow and 1-day maximum flow and rod caught salmon (Figure 6.7). The 1-day minimum flows were positively correlated with 7 other IHA parameters, including median flows in August (r= 0.422, n= 39, p= 0.007), June (r= 0.617, n= 39, p< 0.001), July (r= 0.525, n= 39, p= 0.001), and high flow frequency flow (r= 0.535, n= 39, p< 0.001). The 1-day maximum flows were positively correlated with the annual flow (r= 0.404, n= 39, p= 0.011) and the March flow (r= 0.326, n= 39, p= 0.043).

The River Ribble analyses indicated a significant negative relationship between salmon rod catches and both May and April median monthly flows (Figure 6.7). This indicates as flow during these months goes up rod catches go down or vice-versa. The April flows were not correlated with any of the other IHA parameter, however, May flows were positively correlated with June flow (r= 0.419, n= 48, p= 0.003) and the 1-day minimum flow (r= 0.356, n= 48, p= 0.013).

On the River Tweed, the analyses indicated a significant positive relationship between annual salmon rod catch and April median flows (Figure 6.7). The April flows were negatively correlated with February flow (r= -0.355, n= 49, p= 0.012) and positively correlated with 1-day minimum flow(r= 0.296, n= 49, p= 0.039). The salmon rod catches were also positively correlated with annual flow (r= 0.387, n= 49, p= 0.015), which in turn was positively correlated with 5 other IHA parameters: March flow (r= 0.524, n= 49, p< 0.001), June flow (r= 0.437, n= 49, p= 0.046), July flow (r= 0.287, n= 49, p= 0.046), December flow (r= 0.658, n= 49, p< 0.001) and 1-day minimum flow (r= 0.578, n= 49, p< 0.001). On the River Tweed, the records also exist for number of salmon grilse caught. The analysis for correlations with grilse number indicated two different IHA parameters were important: July flows (r= 0.316, n= 49, p= 0.015) and 1-day maximum flows (r= 0.322, n= 49, p= 0.024). Consideration should be given as to why July flow may be more important for grilse on the Tweed and April flows for multi-sea wintering salmon.

Table 6.7. Significant Spearman's correlation results for selected IHA parameters against salmon rod catch numbers for the northwest region.

IHA Parameter	**Lune**	**Ribble**	**Coquet**	**Kent**	**Tweed**	**Tyne**
Sept						
Oct						
Nov						
Dec						
Jan	r=0.471 n=39 p=0.002					
Feb						r=0.30 n=52 p=0.029
March						r=0.275 n=52 p=0.048
April		r=-0.376 n=48 p=0.008			r=0.387 n=49 p=0.006	
May		r=-0.376 n=48 p=0.033				
June						r=0.370 n=52 p=0.007
July						
Aug						
Annual flow					r=0.387 n=49 p=0.015	r=0.521 n=52 p=0.000
1 day min	r=0.334 n=39 p=0.038					r=0.457 n=52 p=0.001
1 day max	r=0.368 n=39 p=0.021			r=0.473 n=40 p=0.002		
High flow peak						
High flow freq						

The River Tyne had the highest number of significant relationships between salmon catches and IHA parameters. Three median monthly flows positively correlated with salmon rod catches: February, March and June (Figure 6.7).

The February flows were not correlated with any other IHA parameters, March flows were positively correlated with annual flow (*r*= 0.346, *n*= 52, *p*= 0.012) and 1-day minimum (*r*= 0.317, *n*= 52, *p*= 0.022), and the June flows were positively correlated with annual flow (*r*= 0.367, *n*= 52, *p*= 0.007), May (*r*= 0.445, *n*= 52, *p*= 0.001), 1-day minimum (*r*= 0.628, *n*= 52, *p*< 0.001) and high flow frequency (*r*= 0.365, *n*= 52, *p*= 0.008). A positive correlation between salmon rod catches on the River Tyne was also found with 1-day minimum flows and total annual flow (Figure 6.7).

The River Coquet catch data had no significant correlations with any of the selected IHA parameters. On the River Kent the only significant positive relationship found with annual salmon rod catches was with 1-day maximum flows, and this parameter did not correlate with any other IHA parameters (Figure 6.7).

6.4.3. Correlating salmon catches with flow in Wales

On the River Dysynni, the Spearman correlation analyses indicated a significant positive relationship between January and June median flows and rod caught salmon (Figure 6.8). The January flow was negatively correlated with 1-day maximum flow (*r*= -0.313, *n*= 44, *p*= 0.039), and the June flows positively correlated with high flow frequency (*r*= 0.497, *n*= 44, *p*= 0.001). The salmon rod catches on the River Dysynni were also negatively correlated with 1-day maximum flow, which in turn was negatively correlated with January median flows (*r*= -0.313, *n*= 44, *p*= 0.039).

On the River Conwy analyses indicated a significant negative relationship between annual salmon rod catches and median October flows and 1-day maximum flows (Figure 6.8). The October median flows were also negatively correlated with September flow (*r*= -0.328, *n*= 46, *p*= 0.026), February flows (*r*= -0.294, *n*= 46, *p*= 0.048), 1-day maximum (*r*= -0.357, *n*= 46, *p*= 0.015) and positively correlated with high flow frequency(*r*= 0.457, *n*= 46, *p*= 0.001). The 1-day maximum flows were negatively correlated with December flow (*r*= -0.374, *n*= 46, *p*= 0.01), March flow (*r*= -0.528, *n*= 46, *p*= 0.005) and 1-day minimum (*r*= -0.391, *n*= 46, *p*= 0.007), and positively correlated January flows (*r*= 0.407, *n*= 46, *p*= 0.005).

Table 6.8. Spearman's correlation results for selected IHA parameters against salmon rod catch numbers for the Welsh region.

IHA Parameter	Dysynni	Cleddau	Teifi	Dyfi	Conwy
Sept					
Oct				r=-0.326 n=43 p=0.033	r=-0.32 n=46 p=0.03
Nov					
Dec					
Jan	r=0.298 n=44 p=0.049				
Feb					
March					
April					
May					
June	r=0.379 n=44 p=0.011				
July					
Aug					
Annual flow					
1 day min		r=-0.307 n=43 p=0.045			
1 day max	r=-0.408 n=44 p=0.006				r=-0.454 n=46 p=0.002
High flow peak					
High flow freq		r=-0.406 n=43 p=0.007			

On the River Western Cleddau, analyses indicated a significant negative relationship between salmon numbers and 1-day minimum flow and high flow frequency.

Catch data from the River Teifi had no significant correlations with any of the selected IHA parameters, and catch data from the River Dyfi only had a significant negative relationship between annual salmon rod catches and median October flows (Figure 6.8). The October flows were negatively correlated with high flow peak (*r*= -0.326, *n*= 43, *p*= 0.038) and positively correlated high flow frequency (*r*= 0.314, *n*= 43, *p*= 0.04).

6.4.4. Comparison in correlating flow with salmon catches between regions

Overall, the relationship between annual salmon rod catches and flow, described using IHA parameters, was the least pronounced in the Welsh region (8 significant correlations), followed by the north region (13 significant correlations. However, 5 of these correlations occurred on the River Tyne), and then the southwest region (14 significant correlations). As a general rule, populations of salmon tend to be increasing in the north and decreasing in the southwest and Wales. The correlational analyses above do not suggest any systematic differences in the relationships between salmon rod catches and IHA describers of flow according to declining or increasing salmon populations.

In the southwest, the IHA variable that correlated the most to annual salmon rod catches was the frequency of high flows, which was positively significant in 4 out of 6 of the rivers. The frequency of high flow events were, however, not significant with rod catch data on any of the northern region's rivers and only one river in the Welsh region (which strangely was a negative correlation and therefore maybe an artefact of the data rather than true correlation). The high flow peak was not significantly related with rod catches in any of the regions, suggesting the magnitude of the high flows was less important to fish migration than the frequency of the high flows. This could have management implications, particularly in the southwest, suggesting it might be possible to utilise a proportion of this high flow for water resources, as long as the frequency e.g. the variability in the flow cycle, is maintained. However, this analysis does not establish if a trigger or minimum flow was required during these high flows to initiate migration and, if so, what magnitude it might be.

There was not a single prevailing IHA variable that correlated most frequently with annual salmon rod catches in the northern and Welsh regions. In the northern rivers April flows, total annual flow, 1-day minimum and 1-day maximum were all significantly correlated for two out of the 6 rivers. In the Welsh rivers, only October and the 1-day maximum were significantly correlated for two out of the 5 rivers. Alarmingly, most of the significant correlations in Wales were negative relationships, indicating has the flow increased, salmon rod catches declined or vice versa. These could be artefacts of the data or due to angler effort; where the greater the flow the less fish are caught, rather than present.

The second most common IHA variable correlated to salmon rod catches in the southwest rivers was August median flows occurring on half of the rivers (the Dart, Tamar and Lynher), where the greater the August flow, the greater the annual number of salmon caught in the systems. However, August median flows were not significantly correlated with catch data on any of the northern or Welsh rivers. As the flows are being compared against salmon migrating upstream, which are caught on rod and line, it suggests that the salmon could be waiting in the estuary for stimulation flows in August to instigate migration into freshwater, and therefore if the median flows in August are low, the number of salmon moving into the rivers is lower.

October median monthly flows were the most common monthly flows correlated to salmon rod catches in the Welsh rivers, occurring on 2 out of the 5 rivers (the Dyfi and Conwy). However, October median flows were not significantly correlated with catch data on any of the northern or southwest rivers.

Some of the IHA parameters had a high degree of significant inter-correlation with the other parameters; for example, the 1-day minimum flows on the River

Axe was significantly positively correlated with flows in May, June, July, August and September. The 1-day minimum flow, therefore, functions as proxy for lower flows in these months, and consequently indicates lower flows between May and September resulted in reduced salmon rod catches, or vice versa, on the River Axe. This suggests the toolbox of relevant flow parameters could be further reduced.

On the River Tweed, the distinction between grilse and salmon rod catches indicated that higher July flows correlated significantly a higher number of rod caught grilse, whereas April flows were more significant for multi-sea wintering salmon. The reason for this is not clear, and would require further investigation.

6.4.5. Correlating monthly salmon rod catches with monthly flow data

From 2000, the EA started reporting rod catches as monthly figures, instead of annual averages, and so therefore monthly data is available between 2000 and 2008. Although this is a limited dataset, the River Dart was used as a case study to correlate this higher-resolution data with the IHA flow parameters to see if this would provide more clarity (Table 6.9).

Despite only eight years of data, the results indicated a positive correlation between August flows and salmon rod catch figures in September, where the higher the August flows, the greater the number of Atlantic salmon were caught in September or vice versa (Table 6.9). Adult salmon moving into the rivers after high flow pulses in the late summer is well evidenced in the scientific literature. This illustrates as the database grows in years, this higher resolution data could provide better insight into the relationship between salmon and flow.

Table 6.9. Spearman's correlation results for selected IHA parameters against monthly salmon rod catch numbers for the River Dart, 2000-2008.

		Salmon May	**Salmon June**	**Salmon July**	**Salmon Aug**	**Salmon Sept**
Sept	r=	0.035	0.34	-0.155	0.108	0.042
	p=	0.934	0.41	0.713	0.799	0.922
Oct	r=	0.554	0.505	-0.323	-0.59	-0.432
	p=	0.154	0.202	0.436	0.124	0.285
Nov	r=	-0.071	-0.046	0.035	-0.508	-0.444
	p=	0.868	0.913	0.935	0.198	0.27
Dec	r=	-0.324	-0.166	0.289	-0.051	0.406
	p=	0.433	0.694	0.488	0.905	0.318
Jan	r=	-0.416	0.374	0.573	0.264	0.508
	p=	0.305	0.362	0.137	0.527	0.199
Feb	r=	0.057	-0.096	-0.047	-0.407	-0.041
	p=	0.894	0.822	0.911	0.317	0.923
March	r=	0.025	-0.692	-0.357	-0.09	0.498
	p=	0.954	0.057	0.386	0.833	0.209
April	r=	-0.058	-0.563	-0.47	0.028	0.627
	p=	0.892	0.146	0.24	0.947	0.096
May	r=	-0.025	-0.633	-0.498	-0.248	0.41
	p=	0.954	0.092	0.209	0.554	0.313
June	r=	-0.02	-0.547	-0.434	-0.241	0.435
	p=	0.963	0.161	0.283	0.566	0.282
July	r=	-0.1	-0.267	-0.077	-0.069	0.525
	p=	0.813	0.523	0.856	0.871	0.182
Aug	r=	-0.227	-0.347	0.056	0.298	**0.714**
	p=	0.589	0.4	0.895	0.473	**0.047**
AnnualFlow	r=	-0.125	-0.331	-0.118	-0.182	0.458
	p=	0.769	0.423	0.781	0.666	0.254
OneDayMin	r=	-0.03	0.245	0.183	0.378	0.232
	p=	0.943	0.558	0.664	0.356	0.58
OneDayMax	r=	0.208	-0.336	-0.097	-0.225	0.134
	p=	0.621	0.417	0.82	0.593	0.751
HighFlowPeak	r=	0.477	0.151	0.164	0.113	-0.126
	p=	0.232	0.721	0.699	0.79	0.766
HighFlowFreq	r=	-0.421	0.542	0.489	0.442	-0.063
	p=	0.299	0.165	0.219	0.273	0.882

6.4.6. Comparison of wet and dry years and salmon rod catches.

As the IHA parameters failed to show any clear patterns between flow and salmon rod catches, a simple comparison between wet/dry years and salmon rod catches was conducted. The Met Office UK average annual rainfall figures were used to derive wet and dry years between 1951-2010 (Appendix G.21), where the 25th lowest and highest percentiles were used to determine the wettest and driest years. This data was then compared with the top five highest and lowest years for Atlantic salmon rod catches for each river to establish the percentage of overlap.

The results indicated no clear patterns across the regions (Table 6.10). The strongest relationship was found between wet years and peak salmon catch years in the northern region (where 53% of the wettest years overlapped with the years with the highest salmon rod catches); however, this relationship was not repeated across the Welsh and southwest regions. The second strongest relationship was between wet years and the worse salmon catch years in the Welsh region (44%). This could indicate despite wet years increasing the number of salmon returning to the rivers, the increased rain may reduce angler’s effort and the increased flow may reduce catchability in some regions. The relationship between dry years and reduced salmon rod catches was strongest in the northern region (43%).

Table 6.10. Comparison of wet and dry rainfall years with peak and worst Atlantic salmon rod catch years, across the Welsh, northern and southwest regions.

	Dry years		**Wet years**	
	Peak salmon years	Worst salmon years	Peak salmon years	Worst salmon years
Welsh region	28%	24%	4%	44%
Northern region	20%	43%	53%	17%
Southwest region	33%	30%	30%	20%

Further analysis into why peak salmon years occurred during dry years did not demonstrate any notable shared patterns. For example, the peak salmon years did not all follow previous wet winters or have a significant proportion of early high autumn flows to allow initial migration. This could indicate these years with peak salmon numbers were more likely to be due to favourable marine conditions, rather than the impact of freshwater flows.

Dry years are likely not only to have an impact on returning salmon that year, but also consequent years as reduced access to spawning grounds could result in reduced juvenile production, and thus a consequent reduction in returning adults. To test this relationship, the lowest salmon rod catch years were compared against plus 3,4 and 5 years from the dry year events. The results indicated no clear patterns across the regions. The strongest relationship was between dry + 5 years in the northern region, where 40% of these years overlapped with the worst salmon rod catch years (Table 6.11).

Table 6.11. Comparison of dry rainfall years plus 2, 3, 4 and 5 years for worst Atlantic salmon rod catch years across the Welsh, northern and southwest regions.

	Worst Atlantic rod catch years			
	Dry year + 2	Dry year + 3	Dry year + 4	Dry year + 5
Welsh region	16%	16%	16%	16%
Northern region	27%	23%	27%	40%
Southwest region	3%	13%	13%	17%

6.5. SALMON AND FLOW SUMMARY

The IHA parameters have known ecosystem influences; for example the high pulses provide migration and spawning cues for fish and the small floods provide nursery habitat for juvenile fish. However, in linking these parameters with ecology, the resolution and quality of the ecological data is often the limiting factor. In this study, Atlantic salmon rod-catch data was compiled from 1951-2009 to correlate with the selected IHA parameters, considered to be the most relevant to salmon. However, only an annual figure of salmon caught on rod and line was available between 1951-1999. This allowed only very coarse, high-level correlations to be conducted, which provided only a few significant relationships, which were inconsistent across rivers and regions. Unfortunately, this indicates the longest available proxy for salmon numbers in England and Wales (rod catch figures) provides no meaningful insight into the relationship between salmon and flow, using the toolbox of IHA parameters. The increased resolution of rod catch to monthly figures (from 2000), could provide additional insight, because despite only 8 years of data currently being available, one significant correlation was found on the River Dart between August flows and salmon rod catches in September. Further increasing the resolution of angling records may improve this, although the cost of processing this data and its value should then be compared alongside other approaches, such as installing fish counters.

The intricate freshwater life cycle of the Atlantic salmon has evolved to utilise the natural variations in water flow (Enders *et al*., 2009). The role of flow discharge in the entry of adult salmon from the sea to their spawning river is one of the best documented (Potter, 1988; Potter *et al*., 1992; Smith *et al*., 1994; Solomon *et al*., 1999, Solomon and Sambrook, 2004). However, the issue is a complex one and not fully understood. The timing and duration of pre-spawning migration varies between rivers, as a function of distance from the sea to spawning area and the interaction between stream temperatures, flow regimes and river geomorphology (Tetzlaff *et al*., 2008). This is further complicated by variations in the timings of migration due to the age class of the salmon. All of this makes finding generic, overarching parameters to describe the impact of flow on salmon very challenging.

One of the biggest limitations of the IHA model is that it does not elucidate temporal dynamics that may be influential in the Atlantic salmon life cycle. For example, the IHA measures ‘high pulse count’ and ‘high pulse duration’ but independently of each other, which can have very different impacts on salmon; a river with 20 high pulse counts each of 2 days interspersed with periods of low flow, could have very different impacts on salmon migration than to 20 high pulse counts of 2 days interspersed with average flows. The timing and sequence of these different flow events throughout the year/seasons cannot be analysed using the IHA model. Therefore, a more sophisticated flow toolbox integrating temporal dynamics important to Atlantic salmon could provide greater insight.

CHAPTER 7: DISCUSSION

This chapter will aim to answer the main objectives of the study: to investigate if the hydrologic approach was successful in characterising the inter-annual and intra-annual flow variability at local, regional and national scales to allow comparisons with long-term Atlantic salmon rod-catch data. And, to assess if there is evidence that hydrological change is a main driver to changing Atlantic salmon populations across the UK, and if so how, given increasing pressures on water resources and climate change, we can best manage river flows for Atlantic salmon.

7.1 FLOW VARIABILITY IN SPACE AND TIME

The importance of a river's flow regime for sustaining ecological function and biodiversity is well recognized (Poff *et al*., 1997; Bunn & Arthington, 2002). Flow affects practically every function of aquatic ecosystems in rivers, estuaries and even coastal zones, from structure of channels and habitat availability, to species diversity, movements and abundance. However, it is fundamental to understand the natural temporal and spatial heterogeneity of the flow regime in order to make meaningful correlations with ecology. Species naturally experience 'poor', 'average' and 'good' years, depending on a range of varying conditions, including river flow. However, there are few detailed analyses of the temporal variability of flow conditions, in relation to species/ecosystem needs, with which to benchmark managed or regulated flow regimes to help advance the delivery of Water Framework Directive objectives. This study has attempted to develop this.

Objective 1: To characterise inter-annual and intra-annual flow variability at local, regional and national scales.

Classifying rivers and their catchments by similarities in hydrologic properties has a number of applications; to quantify flow alteration and its effect on ecology (Poff *et al*., 2010; Arthington *et al*., 2006, Harris *et al*., 2000), understanding catchment function and process (Sawicz *et al*., 2011) and prediction of flow in un-gauged catchments.

The results from chapters 2, 3 and 4 highlighted a high degree of local, regional and national flow heterogeneity, both within and between years. At the national level, analyses of the 17 rivers analysed across England, Wales and Scotland, indicated that the timing and magnitude of flow did vary from the ‘typical’ (or most common) river regime between years. The most commonly occurring regime type was characterised by a single high magnitude peak in January, followed by spring flow recession. This typical type of flow regime, which we expect to see in the temperate UK, with wet winters and dry summers, only occurred approximately 1 in every 2.5 years.

The remaining years in this national analysis consisted of a further 6 different regime types, varying from wet autumn but dry winter regime types, to complete wet years including high summer flows. The IHA parameters highlighted that between these regime types, the timing and frequency of key environment flows, such as high flows and flood events, also varied, as did the timing and duration of minimum flows. For some individual years, such as 2008, the weather events, and corresponding river flows, were sufficiently different from other years to result in a unique regime type for this year only. This supports research by Bower & Hannah (2002), who found that, despite regional variability in flow regime, a single regime type could dominate the whole UK in years with strong synoptic (large) scale climatological forcing.

At the regional level, the PCA and CA analyses indicated that Wales had 5 typical regime types, the southwest had 4 and the north had 3 regime types. The reasons for less diversity in flow regimes in the north are not fully understood. The length of flow records in the north was generally less than in the southwest, which could explain some of the reduced variability. However, the Welsh region also had reduced records and still more varied flow regimes.

The magnitude analyses indicated across the regions that there was greater similarity in the timing of low flow than high flow parameters. This was predicted, as extreme high flow events tend to be more localised storm/rain events, whereas extreme low flows tend to be more typically the result of regional/national drought events.

At the local level, although rivers within the same region tended to have the same number of regime types, the actual flow attributes of these regimes varied. The PCA/CA method of analysing the flow regimes clusters the years based on similarities and, therefore, the method removes a proportion of the extreme variability (or outliers) within the dataset. This means the remaining variability between the rivers are ‘key’ differences in the functioning of the system, and important attributes to manage and maintain. The lack of conformity in the flow regimes between the national, regional and local scales indicates how important individual catchment characteristics are on river flow variability. Even during periods of national extreme low or high flow conditions, local catchment variability resulted in varying flow regimes that could provide potential refugia for species, particularly a regional population.

This study indicated that the only chalk stream in the analyses functioned differently to the other rivers. Despite the local analyses indicating the River Frome also had 4 dominant regime types (the same as the other southwest rivers), in the national level PCA/CA the river was dominated by one regime type. The differences in regime type at the local level were subtler and less diverse than the other rivers. Bower & Hannah (2002) also found catchments with large aquifers had greater regime stability than those without. This shows that chalk streams are fundamentally different in terms of their flow regime stability, due to the buffering from the high base flow and therefore should be managed separately from a water resources perceptive, something which does not happen under current water policy. The importance of more tailored water resource management of chalk stream habitats in the UK is highlighted by the fact that England has approximately 85% of the global resource of chalk streams and, therefore, should have an obligation to protect and maintain this unique aquatic environment.

7.1.1 Hydrological succession

The timing of the peak, most dominant median flows can to used to characterise national regime variations in discharge. This analysis indicates that most of the peak median flows for the southwest region occurred in January, with secondary magnitude peaks in February. The River Frome, the most south-eastern river, was the outlier, with its median monthly peak typically occurring in February. The northern rivers also predominately had median monthly peaks in January, although the secondary peaks were typically earlier than in the southwest, occurring between October and December. The Welsh region was more variable, with peaks occurring predominately in December and January. The River Dyfi was a notable exception, with the highest median flows occurring in February, although the lesser magnitude peak occurred earlier in November (Table 7.1).

Table 7.1: Timing of peak median flows for each studied river, where the month in brackets indicates the month of additional peaks.

Region	**River**	**Month of highest median flows**
Southwest	Dart	Jan (Feb)
	Lynher	Jan (Feb)
	Tamar	Jan
	Axe	Jan
	Camel	Jan (Feb)
	Frome	Feb
Northern	Lune	Jan (Dec)
	Ribble	Nov
	Kent	Jan (Oct)
	Coquet	Jan (Dec, Feb)
	Tweed	Jan
	Tyne	Jan
Wales	Conwy	Dec
	Teifi	Jan
	Dyfi	Feb (Nov)
	Cleddau	Jan
	Dysynni	Dec

Ward (1968) noted similar regional timing variations in a study looking at mean maximum flows in 59 rivers across the UK. The study found that the mean monthly maximum flow in Scotland, northwest England and the western areas of Wales, typically occurred in December, with maximum monthly flows becoming later (February or March) towards the south and east of the UK. These patterns are thought to result from the effects of hydrogeology and other catchment characteristics, along with increasing evapotranspiration to the south and east (Lewin *et al*, 1981). However, despite these broad similarities at the monthly flow scale, river flow variations at the finer scale (such as daily data) did vary extensively. This suggests that individual river flow analyses are required to obtain a true measure of between and within year flow variability, as each river, even within the same region, can behave differently, and the impact these more subtle differences have on rivers ecology is not understood.

7.1.2 Deviation from dominant regime - wet or dry years

The flow regime analyses did show at the monthly scale that there was typically a ‘dominant’ flow that the different regime types clustered around (similar to that illustrated in 3.3.1 for the River Dart), and often a single outlier (wetter or drier) flow alternative. To illustrate this concept, the Rivers Dart, Dysynni and Lune (arguably the most ‘natural’ rivers from each region) were used. The percentages of years classified under each regime were added together if the regimes were clustered together to determine if the outlier flows (less common) were wetter or drier than the average.

On the River Lune, the most variation from the dominant regime occurred in December, where 1 in 2 years the flow was drier than the normal and January, where 1 in 2 years the flow was wetter than the normal. Overall, one third of the months had similar flows, one third were wetter and one third were drier than typical dominant regime type (Table 7.2).

Table 7.2: Percentage of dominant regime occurrence and variability from dominant regime, wet or dry, on the River Lune

Month	Dominant regime (%)	Variability from average flow regime (wet or dry)	Occurrence (to nearest whole number)
Sept	100.00%	-	-
Oct	78.80%	Dry	1:5
Nov	78.80%	Dry	1:5
Dec	51.10%	Dry	1:2
Jan	51.10%	Wet	1:2
Feb	78.80%	Wet	1:5
March	78.80%	Wet	1:5
April	78.80%	Dry	1:5
May	78.80%	Wet	1:5
June	100.00%	-	-
July	100.00%	-	-
Aug	100.00%	-	-

On the River Dart the most variation from the dominant regime occurred in February, where 1 in 2 years the flow was drier than the normal flow and June, where 1 in 2 years the flow was wetter than normal. December and May were also wetter on average 1 in 3 years. The least variable month was August, when all regimes had similar flows. In July and November, 1 in 12 years the flows were wetter than the dominant flow. On the River Dart, the late spring, between April-June, was also highly variable from the dominant flow. Overall, the flow variability from the dominant regime type was wetter than the average flow conditions in 8 out of the 12 months (Table 7.3).

Table 7.3: Percentage of dominant regime occurrence and variability from dominant regime, wet or dry, on the River Dart

Month	Dominant regime (%)	Variability from average flow regime (wet or dry)	Occurrence (to nearest whole number)
Sept	87.20%	Wet	1:8
Oct	78.70%	Wet	1:5
Nov	91.50%	Wet	1:12
Dec	61.70%	Wet	1:3
Jan	87.20%	Dry	1:8
Feb	53.20%	Dry	1:2
March	87.20%	Wet	1:8
April	78.70%	Dry	1:5
May	61.70%	Wet	1:3
June	53.20%	Wet	1:2
July	91.50%	Wet	1:12
Aug	100.00%	-	-

On the River Dysynni the most variation from the dominant regime occurred in December and January, where 1 in 4 years, the flow was drier. December and May were also wetter on average 1 in 3 years. The months of September to November were relatively stable on the River Dysynni, with a wetter year occurring on average 1 in 10 years in September and October, and a drier year 1 in 10 years in November. Overall, the flow variability from the dominant regime type was wetter than the average flow conditions 8 out of the 12 months (Table 7.4).

Table 7.4: Percentage of dominant regime occurrence and variability from dominant regime, wet or dry, on the River Dysynni

Month	Dominant regime (%)	Variability from average flow regime (wet or dry)	Occurrence (to nearest whole number)
Sept	90.00%	Wet	1:10
Oct	90.00%	Wet	1:10
Nov	90.00%	Dry	1:10
Dec	72.50%	Dry	1:4
Jan	72.50%	Dry	1:4
Feb	82.50%	Wet	1:6
March	90.00%	Wet	1:10
April	80.00%	Wet	1:5
May	100.00%	-	-
June	80.00%	Wet	1:5
July	80.00%	Wet	1:5
Aug	80.00%	Wet	1:5

This method indicates that, despite variations in river flow each month, there is typically a dominant flow. This could be used to develop a more sophisticated flow regime management routine for modified/impounded rivers using past flow records to derive between-year variability, both frequency and magnitude, from the dominant flow regime. This provides an interesting concept because in some years this would result in giving the river/aquatic environment less water than normal in order to truly mimic natural variation. This method, however, also illustrates that the variation away from the dominant regime type is highly inconstant between rivers, and therefore using this type of analysis to inform flow management would also need to be conducted on an individual river basis. Using previous historic flow records would also limit future variability, and not take account of our changing climate. The only method of truly enabling flow variability on managed rivers is to ensure all impoundments and/ or abstractions have 'real time' flow monitoring to allow a proportion of the flow is used relative to the flow in the river, so that the river maintains the natural pattern of variability at any given time.

7.1.3 Regime Occurrence

The variability of the UK's weather has become evermore apparent in recent years, with the prolonged droughts in 2010-2012, followed by subsequent flooding in summer 2012, and the unprecedented widespread floods seen in 2013/2014. The method used in this study of classifying each year for each river as a regime type makes it possible to plot the occurrence of these regimes types through time.

For the rivers of the southwest, the regime occurrence through time indicates increased variability in the distribution of regime type in the last 20 years, with the most common regime (e.g. the typical wet winter, spring recession to a dry summer regime) becoming less dominant. This pattern was less pronounced in the other regions, particularly the northern region. This could be because the UK's weather systems are dominated by maritime tropical air masses (Figure 7.1) from the southwest, and therefore the southwest and Wales are more exposed and responsive to these air masses, which bring warm moist air to the UK. Whereas, typically, the north east of England and Scotland are more susceptible to continental polar air masses that bring in cold dry air, and typically less rain. However, research has shown that in the UK a shift in spatial and temporal rainfall patterns has resulted in a trend towards wetter winters and drier summers, with increasing rainfall totals, principally in the north and west (Marsh, 1996).

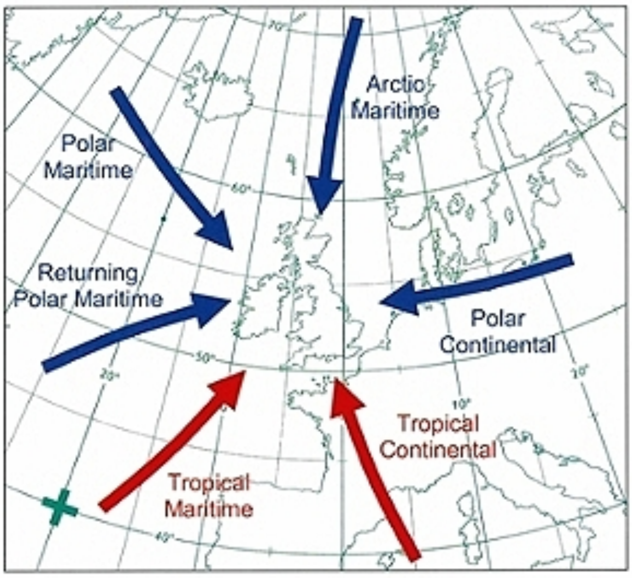

Figure 7.1. Air masses affecting Britain (taken from Met Office website)

The shift in regime distribution, particularly during the 2000s, could be due to climatic changes linked to changes in North Atlantic sea temperatures. The North Atlantic Oscillation (NAO) is a major regional system controlling atmospheric circulation that influences climate in Europe, northern Africa, and

Greenland, as well as in North America and much of northern Asia (Hurrell, 1995; Hurrell and van Loon, 1997; Wilby *et al*, 1997). The NAO has significant inter-seasonal and inter-annual variability, and prolonged periods of both positive and negative phases of the pattern are common. The wintertime NAO also exhibits significant multi-decadal variability (Hurrell, 1995). Research shows that European river flows are strongly correlated on a spatial scale with the NAO. The influence of the NAO on meteorological conditions is especially strong in winter (Shorthouse and Arnell, 1997). When the North Atlantic Oscillation Index (NAOI) is high (or in its positive phase; i.e., the pressure gradient is greatest), low-pressure anomalies over the Icelandic region combine with high-pressure anomalies across the subtropical Atlantic. This produces powerful westerly winds across mid-latitudes, resulting in further penetration into Europe and causing warmer and wetter winters in Northern Europe. When the NAOI is low, the westerlies are weaker, resulting in the winter temperatures being influenced more by the cold high pressure located over Eurasia. This results in cold weather in northern Europe (Shorthouse and Arnell, 1997). By extrapolating (from Figure 7.2) the occurrence of positive and negative NAOI for each year, a comparison could be made against the national regime occurrence between 1977-2009.

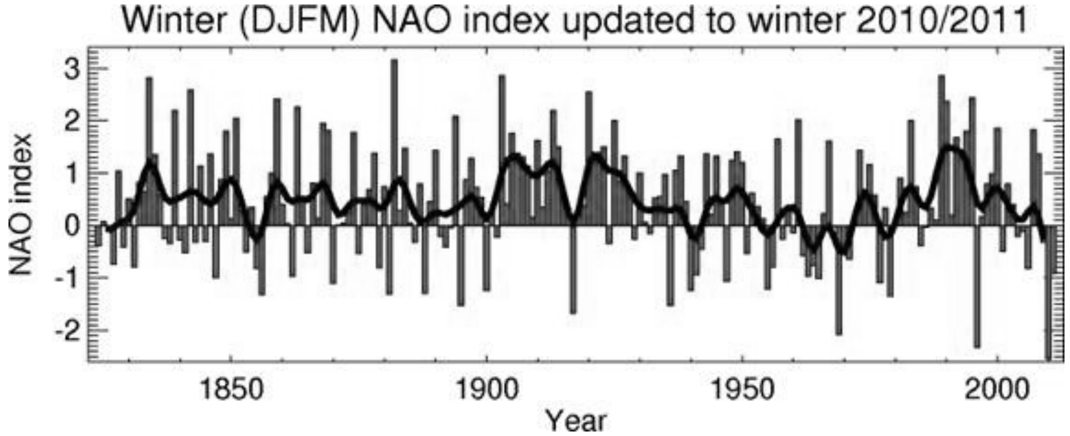

Figure 7.2: Time series of the winter average (December to March) NAO index, taken from Jones et al. (1997).

This analysis indicated that the different national flow regimes do not correlate exactly with changes in the NAOI (Table 7.5). Of the 6 annual negative NAOI present during the timeframe investigated, 3 of these events occurred during the national regime type 2. National regime 2 was characterised by a high magnitude peak in median flow between November and January. Two of the negative years were found during national regime type 1, which had a single high magnitude peak in median flow in January and the lowest median monthly flows of all the different regimes in October. There was also no relationship between which regime proceeded the negative NAOI year.

Research by Wilby *et al*., (1997) and Kettlewell *et al*., (2003) has shown that in the British Isles, if the winter NAOI is higher than usual, the summer tends to be dry, and after winters dominated by low NAOI, the river runoff in autumn is predictability very low (Wilby, 2001: Wedgbrow *et al*., 2002). Regime 3 had the lowest median monthly flows of all the different regimes between July and September and this was only found in the years with positive NAOI.

Table 7.5: National regime classification compared against NAOI.

Year	**National regime classification**	**NAOI (pos/neg)**	**Year**	**National regime classification**	**NAOI (pos/neg)**
1977	1	Neg	1991	3	Pos
1978	1	Pos	1993	1	Pos
1979	1	Neg	1994	1	Pos
1981	3	Pos	1995	1	Pos
1982	3	Pos	1996	2	Neg
1983	1	Pos	1998	2	Pos
1984	2	Pos	1999	1	Pos
1985	6	Neg	2001	4	Pos
1986	2	Pos	2004	4	Pos
1987	5	Neg	2005	2	Neg
1988	4	Pos	2007	1	Pos
1989	3	Pos	2008	7	Pos
1990	1	Pos	2009	2	Neg

Analysis of the 25th percentile highest and lowest national rod caught salmon years indicated no overlap between negative NAOI and the number of salmon. One of the negative NAOI years, 1979, occurred in the lowest 25th percentile of rod catches and one year occurred in the highest 25th percentile of rod catches, 2005 (from previous chapter, Figure 6.1). This is likely to be the result of overall declines in Atlantic salmon numbers over the studied time period rather than linked to NAOI. However, it is important to remember that within climate cycles, the ~40 years of flow analyses within this study is a very short and isolated time frame.

7.2. SALMON AND FLOW RELATIONSHIPS USING ROD CATCH DATA

The flow requirements of different life stages of Atlantic salmon are generic and imprecise, despite the species being comparatively well studied. A major constrain in developing this understanding is the limited availability of sufficient long-term hydrological and ecological datasets, coupled with the complexity of multiple stressors and interrelationships between environmental parameters.

Objective 2: To compile long-term Atlantic salmon rod-catch data and to examine patterns of variation at different temporal and spatial scales, and to assess the validity of using long-term rod catch data to improve understanding of Atlantic salmon's relationships with river flow.
Long-term Atlantic salmon rod-catch data was compiled from 1951-2009 for 17 different rivers within 3 different regions of the UK. The resolution of the long-term rod-catch data available (between 1951- to the current time) only allowed annual correlations to be conducted with river flow data. Notwithstanding the inherent problems with rod catch data, the size of the database gave optimism that patterns might emerge. However, the analysis resulted in limited statistically significant correlations, and those that were found were sporadic between regions (see previous chapters Table 6.4, 6.5 and 6.6). Unfortunately, this provided little meaningful national insight into the relationship between Atlantic salmon numbers and flow. Nevertheless, other research has recognised that the relationships between hydrological regime and the selection of life history strategy and migration patterns vary from river to river (Beechie *et al.*, 2006).

Atlantic salmon rod catch data are anglers' records from fish caught on rod and line. These fish are typically migrating upstream to spawn when caught, hence a large proportion of statistically significant results between rod catch figures and flow occurred during the migration months in August, September and

October. The frequencies of high flow events, the pulses in flow that help initiate and enable migration, were also positively correlated with rod catch numbers, particularly in the southwest region. It is documented that the initiation of salmon migration occurs in conjunction with other cues, such as tides, onshore winds and cooler weather (Mills, 1991), which could explain the local differences in timing between the rivers, but both flow and water temperature have a key role to play in this behaviour.

The southwest region had the highest number of significant correlations between rod catches and flow. This could infer that the southwest salmon populations, which continue to decline, are reacting more to variations in river flows because of ‘survival of the fittest’, than the increasing (possibly less ‘fit’) populations in northern region. On the other hand, the fact the UK salmon populations are already stressed might mean the species as a whole is less likely to react to environmental cues, such as flow, in the normal way because only the fittest remain and would complete their lifecycle regardless. The concept of interactions with environmental triggers/cues differing between declining/stressed and increasing populations is an interesting one, although no insightful research could be found.

It is recognised that extreme events, such as flood and drought flows, can put selective pressure on salmon populations, and more subtle variations can influence the relative success of individuals (Resh *et al.*, 1988). The large degree of flow regime heterogeneity between rivers and regions, due to different catchment characteristics and weather events, suggests that the differing regimes could provide refuge for discreet salmon populations in some rivers, whilst extreme flow conditions maybe occurring in a nearby river. This means species responses within different rivers may vary, as some rivers will be less impacted by extreme weather events than others. If Atlantic salmon populations act as regional or national units, in some areas populations may survive whilst others are impacted, because despite salmon being known to return to their native rivers, they also have sufficient roaming instincts to exploit more favourable conditions/opportunities in surrounding rivers, should the opportunity arise.

7.3 CRITIQUE OF METHODS USED

7.3.1. Hydrologic model: PCA/CA and IHA

The PCA and CA does successfully characterise inter and intra annual variability in the flow regime. However, the approach by its very nature eliminates the extreme flow variability by grouping flow years according to similarities. The CA groups data by minimising within group variance whilst maximising between group variance (Wilks, 1995). This, however, is not necessarily a limitation because the method characterises the recurring flow variability, which therefore provides a manageable and practical tool for flow management, providing it is understood that further flow extremes exist. However, a recurrent limitation of the approach is that, if a hydrologic year exhibits shared variation between different regime types, this method has difficultly in assigning which it should be incorporated within (Yarnal, 1993). The PCA is also very focussed on the shape of flow regime rather than the magnitude, which could mask important differences in threshold flows, which might be more important to salmon than the timing of that flow.

The IHA parameters also have limitations because they are based around the human artefact timing of a ‘month’, with the hydrologic cycle forced to conform to 12 months. Analyses of the results in this study demonstrate that both the timing of the start of the hydrological year and its length change between years and rivers. The IHA model does allow the start of the annual hydrologic year to be changed[9], however it does not allow this to changed between years within the same dataset. The method also does not allow any flexibility in the length of hydrological cycle. This illustrates a fundamental problem with current flow management tools (with this method being no different), where management tools standardise the hydrologic cycle so that a flow year starts on a homocentric date and runs for a fixed 12 month cycle, which does not accurately represent many hydrological years. This study showed a range of hydrological ‘years’ varying from start dates in July to October/November, resulting in hydrological years longer and shorter than the ’12 month’ imposed

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[9] *However, within this study, to enable comparisons across regions, the start of the hydrological year was standardised as September.*

timeframe. This was, however, unpredictability variable, which makes forward-assigning any fixed parameters impossible, and retrospectively accounting for differences complex and problematic. In the future, developing flow models that incorporate this variation could allow greater opportunities to link relationships between flow with ecology, although managing the complexities may prove too challenging for practical implementation.

Objective 3: To establish a toolbox of biologically relevant flow parameters for managing Atlantic salmon in rivers.

The relationships linking Atlantic salmon with flow are multifaceted, and complicated further by the salmon's complex lifecycle, in particular the variance in years they spend within the river and at sea. Fundamentally the IHA model was designed to describe changes in flow parameters pre and post a hydrological alteration. It is not designed, nor were the descriptors of the flow regime designed, to link with Atlantic salmon. Therefore, as a series of monthly/annual flow magnitude parameters, whilst valuable for describing the differences in flow regimes, they are not the most suitable parameters to link salmon with flow. The IHA parameters fail to elucidate the temporal dynamics that may be influential in providing ecological cues that influence the Atlantic salmon lifecycle. For example, instead of the median monthly flows, the months could be divided and analysed based on a series of 'key flow timings'. These could provide more biologically relevant flow parameters linked with Atlantic salmon, and could be used to assess if there are threshold or ideal flows required during key timings.

Flow variability during the four seasons might best be described as: winter (catchment stores full) and summer (catchment stores emptying), therefore discharge (magnitude) is the most important variable, but during autumn and spring the flow timing may be more important. In the autumn this is the timing of migration flows to allow adult salmon entry into freshwater, and in the spring, flows ensuring food and habitat availability for emerging fry. To illustrate this (as an example only) the four different seasons could be used as different 'eco-windows' for Atlantic salmon (Figure 7.3): i) autumn flows; important for upstream migration, ii) winter flows; influential in spawning success, where high floods can result in redd wash-out or extreme low flows in redds drying out iii) spring flows; important for juvenile access to rearing habitat and iv) summer flows; important for downstream migration. These eco-windows could then be used to assess the potential impact on salmon of each regime type qualitatively (as illustrated in Table 7.6). And, the IHA model could be tailored to report/summarise flow parameters corresponding to the different ‘eco-windows’ or, in this case, seasons. So, instead of annual or monthly averages, it would report spring and autumn averages, e.g. the duration of high flows during the autumn window.

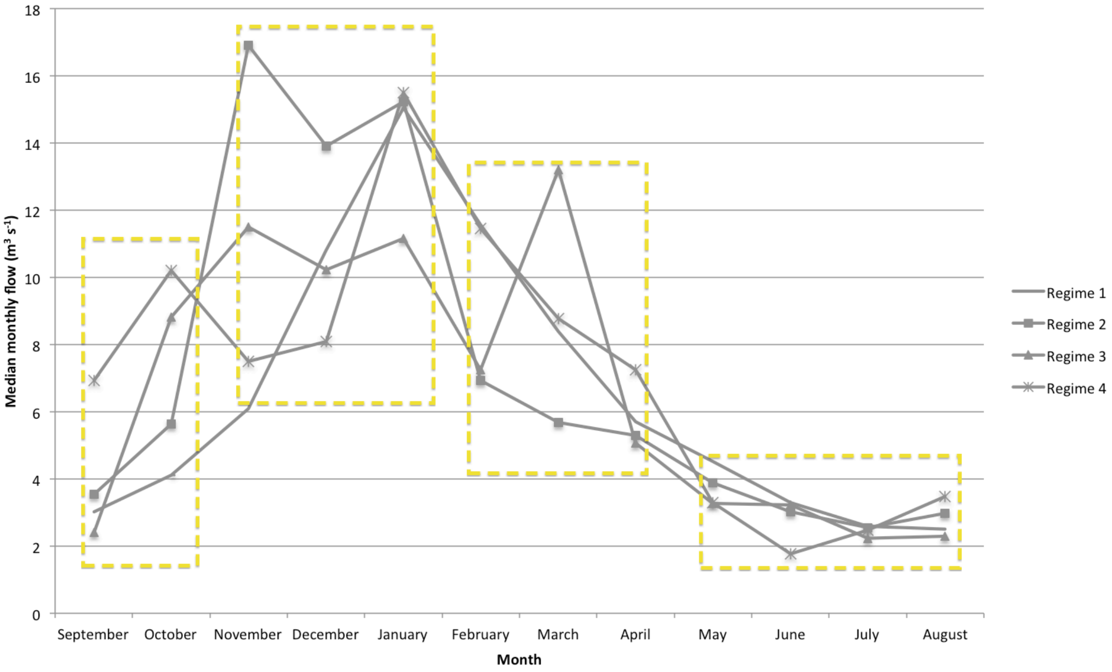

Figure 7.3: Example of potential eco-windows, using national regime summary graph

Further to this, an additional hypothesis is that the sequence of hydrological events could be more important to Atlantic salmon than the magnitude or timing of individual events alone. For example, after *X* days of low flow in the autumn, the timing of the first flood, followed by a succession of further high flow events, might be more important than the magnitude of the first high flow alone. Similarly, during migration, a series of enhanced flows between high flow pulses may be more beneficial to salmon than high flow pulses interspersed with baseline flows, because they ensure access to adequate habitat and cover from predators whilst adult salmon migrate up river. To develop or incorporate this type of sequential flow analysis into the IHA would require the ability for the user to program different ‘time-line’ flow events and combinations for investigation.

Table 7.6: Eco-windows for Atlantic salmon analysed against regime type.

	Regime			
	1	**2**	**3**	**4**
Timing of peak	January	November and January	March	October and January
Occurrence	1 in 2.6 years	1 in 4.4 years	1 in 6.5 years	1 in 8.2 years
	Potential impact on Atlantic salmon during eco-window			
Autumn	Low October flows could reduce initial migration into freshwater	Low October flows could reduce initial migration into freshwater	Low September flows could prevent initial migration into freshwater	High autumn flows should provide good access into freshwater and flushing flows to clean spawning gravels.
Winter	Steady increase in median flows may optimise access to prime spawning gravels in headwaters	High winter may result in redd wash-out	Low flow winter may limit access to prime spawning gravels	Lower Nov and Dec flows may limit access to prime spawning gravels
Spring	Typical spring recession; should provide adequate access to riparian habitat	Low flow spring may result in inadequate access to juvenile habitat	High March flows may result in juvenile displacement	Typical spring recession; should provide adequate access to riparian habitat
Summer	Stable summer flows	Stable summer flows	Stable summer flows	Low June flows may impact downstream migration and access to juvenile rearing habitat

7.3.2. Salmon rod catch data

Since 2000, the EA has started to report monthly rod-catch data, which is a vast improvement on the long-term annual total used from 1951. In the future, this should improve the validity of using rod-catch data to correlate with flows, but further steps could be taken to maximise opportunities. The day and month of catch should also be nationally reported, in order to provide greater resolution for studies such as this. This would allow more accurate comparisons with actual flow events and other methods of recording salmon, such as counter data. Anglers should be encouraged to routinely fill out a simple online form every time they fish, possibly using an on-line app, which should include the period fished (to allow an estimate of fishing effort or catch per unit effort to be calculated) and the river beat (instead of just river name) to allow more accurate correlations with nearby flow gauging stations. In an era of Government budget cuts, every opportunity should be taken to maximise low-cost information gathering opportunities such as this.

7.4 PRESSURES ON SALMON POPULATIONS

The Atlantic salmon is a protected species, yet despite this, their abundance at sea is estimated to have declined from approximately 10 million fish in the early 1970s to approximately 3.5 million in recent years (ICES, 2011). Since the late 1980s, the abundance of Atlantic salmon in each of the three stocks assessed by ICES (northern America, northern Europe and southern Europe) have declined (ICES, 2011), with the largest declines seen in multi-sea winter salmon in the southern parts of the species range (ICES, 2011).

The lack of understanding of the exact factors responsible for this decline (Hansen *et al*., 2012) has made management difficult. Recognised factors affecting salmon survival include:

- Alternations to flow regimes and water quantity
- Water pollution from chemicals, including endocrine disrupting chemicals (EDCs) and organic wastes
- Habitat loss and degradation, including destruction of spawning gravels, intertidal habitats and floodplain/riparian habitats
- Physical barriers to migration
- Overexploitation at sea, in transitional and freshwaters (by-catch, netting and angling),
- Soil erosion, causing silting up of spawning gravels
- Eutrophication from excess nutrients, particularly phosphorus
- Parasites and disease
- Introduction of non-native invasive species and non-native salmon stocks, which threaten genetic integrity

- Predation
- Climate change

This extensive list of pressures on Atlantic salmon populations, coupled with the unknown impact of each in isolation or cumulatively, makes independently attributing the impact of varying river flows on salmon very challenging.

Objective 4: To evaluate the evidence for hydrological change as a driver to changing Atlantic salmon populations across the UK

Atlantic salmon have a diverse range of different life histories, exhibiting variability both within and amongst populations, such as in habitat use, length of freshwater residence and age of maturity (Klemetsen *et al*., 2003). The development of a salmon's life strategy is genetic, but influenced by the environment, where it is believed they depend on the abiotic environment for initiation and the biotic environment for completion of the life cycle (Thorpe, 1990). As stated previously, it is widely recognised that hydrological variability within rivers is one of the primary factors influencing aquatic flora and fauna. However, when this is discussed, the focus tends to be on a species short-term behavioural response to parameters, such as flow, rather than long-term evolutionary responses.

River flow is considered to be especially important to salmon during migration, the timing of which varies greatly across the salmons' geographical range, as well as within stocks and over time (ICES, 2010). In the UK, 1 sea winter (SW) salmon typically enter rivers between June and September, 2SW fish tend to enter rivers throughout the year and 3SW tend to enter early in the year, normally before May (ICES, 2010). The run timing is believed to be a genetic characteristic. For example, an experiment (Steward *et al*., 2002) took juveniles from spring salmon parents from the River Tilt and from late summer grilse parents from the River Almond, tagged them and stocked them into the River Braan. The results showed that the emigrating smolts from the River Tilt still returned in spring, whereas the River Almond fish still returned in late summer, despite both being reared in the same environment (Steward *et al*., 2002). This raises the question of why these two dominant runs are present in the UK? If we go back to the fundamental principle that migratory salmonids have evolved in response to the natural flow regime, it infers two possible options for the two runs over a post-glacial (15,000 years) time-scale:

- *Option 1) Initially one single run.* Salmon historically could run anytime between spring and autumn, but the development of the temperate flow regime with low summer flows resulted in the water being too low in most years, so the salmon adapted not to run in mid-summer. In this case, the stress imposed by summer low flows would have been the driver in determining a split in runs.
- *Option 2) Never a single run, but spring run was previously driven by snowmelt runoff.* The spring high flows associated with snowmelt provided a trigger for fish to run.

If option 2 is correct, the recently documented declines in spring runs could be a behavioural adaptation to the decline in snow and consequent snow melt in the UK. The spring run could have evolved from the Little Ice Age (in Europe between 1560-1850) and now, over generations, the subsequent decline in snowmelt has resulted in a behavioural response and the gradual elimination (and evolutionary response) of the spring run. However, in Norway there is predominately only one yearly salmon run (NASCO, 2007), suggesting this might not be the case and that the run is more likely to be driven by option 1.

Appreciating the lag-time in an evolutionary change in Atlantic salmon populations in response to flow, as well as the behavioural response to the real-time flow pressures, may go some way to describing why there are limited linear relationships between flow and salmon, or indeed any pressure. Adaptation does not mean that there is a constant population from year to year, but that the population will be able to strengthen itself following periods of adverse conditions, such as changes in flow. Variability in the short term results in tactical changes, which need to be assessed alongside evolutionary responses, which can take many years/generations to actually become apparent through empirical studies. So, what we are actually looking at today is the superstition of short-term impacts influencing tactical behaviour of fish and consequent rod catch data. We might not yet be in a position to understand and evidence the long-term adaptation over evolutionary timescales (Figure 7.4).

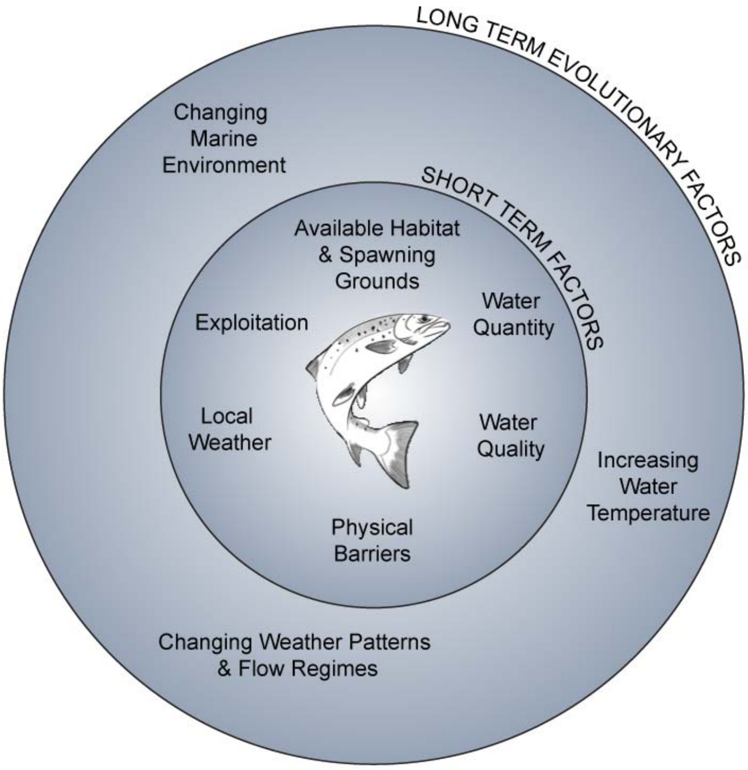

Figure 7.4: Conceptual model of factors influencing rod catch data, as a proxy for salmon populations, on long term and short-term time frames

7.4.1 The impact of temperature on salmon

Water temperature is closely linked to flow and is an important variable that can confound the influence of flow on fish (Milner *et al*., 2010). The global average surface temperature during the twentieth century has increased by 0.6°C, and this is likely to have increased water temperature of rivers and lakes (EA, 2007). Water temperature is influenced by changes in air and ground temperatures, and alterations to the hydrological regime. Changes in water temperature are also linked to changes in water quality, because temperature influences gas solubility (such as dissolved oxygen) and chemical reaction rates (Webb, 1996). At the source of a stream, water temperature is generally close to that of groundwater. The mean daily water temperature increases with distance downstream, or with increasing stream order (EA, 2007). Water temperature also varies on a daily cycle, with maximum temperatures occurring in the late afternoon/early evening, and with a sinusoidal annual cycle from spring to autumn (Caissie *et al*., 1998).

Anthropogenic activities can result in changes to the thermal river regime, for example:

- *Abstraction*: the impact is dependent on the channel shape and surface area. If the surface area remains similar but flow is reduced, the water temperature will increase during hot weather (Solomon, 2005).
- *Flow regulation*: dams and reservoir releases can directly impact water temperature downstream, which can result in increases or decreases depending on the depth at which the water is taken from the reservoir (the deeper, the colder). Augmentation of flow by groundwater can also reduce river water temperature.
- *Land-use changes*: vegetation cover, land drainage and soil erosion can all impact hydrology, water quality and thus water temperature.
- *Forestry*: removal of riparian trees increases river water temperature. Bartholow (2000) modelled a 4°C temperature increase in river temperature from clear-cutting.
- *Heated effluents*: the electrical power industry returns significant volumes of heated effluent to rivers every year (Webb, 1996), which can have a great effect of river temperature when river discharge is low (Solomon, 2005).

Temperature impacts aquatic organisms, including Atlantic salmon, in terms of growth rate, metabolism, reproduction, distribution behaviour and tolerance to parasites, diseases and pollution (Alabaster and Lloyd, 1980; Crisp, 1996; Webb, 1996; Caissie, 2006). Predicted future temperature increases paint a bleak picture for Atlantic salmon as they are likely to result in significant impacts on growth rates (Davidson & Hazlewood, 2005) and the higher river temperatures will be detrimental to the habitat requirements of this cold water species (Webb and Walsh, 2004).

Salmon eggs incubation time is expressed as 440 degree days. Therefore, the river flow and resultant water temperature during the incubation period will impact the timing of juvenile salmon emergence out of the gravels, which could be an important factor influencing subsequent survival in relation to river flows.

Average temperature data from the River Exe[10] in the southwest of England between 1974-1983 were used to investigate the timing of juvenile emergence based on egg deposition in November, December, January and February (Figure 7.5).

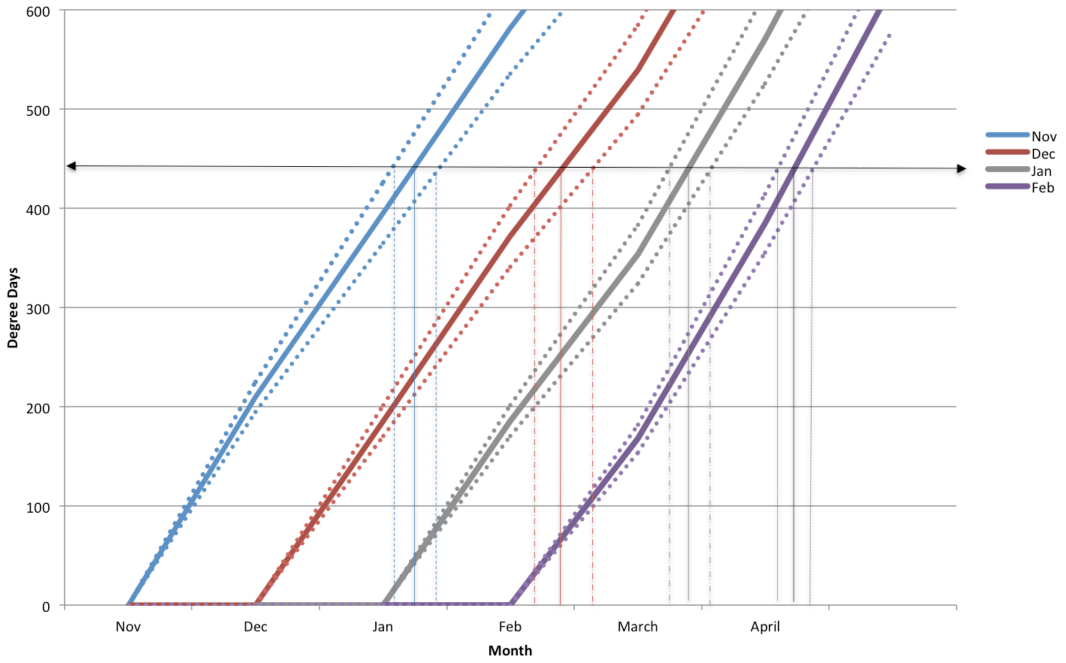

Figure 7.5: Emergence of salmon fry based on degree days starting in Nov, Dec, Jan and Feb, where dotted lines around each parameters represent a 0.5°C increase and decrease from the average temperature.

Overall, the hatching time on the River Exe was approximately 8 weeks, although as the river became slightly warmer, e.g. in February, this reduced. The dotted and dashed lines around each of the months data on Figure 7.5 represent a 0.5°C increase and decrease from the average temperature, which could represent climate change or varying winter river flows. The results indicate little difference in the timing of emergence due to this small, +/- 0.5°C, variance in river temperature. For example, if eggs were laid on the 1st November, based on river temperature data for the River Exe (Figure 7.5) and 440 degree days, under normal conditions they would hatch on the 8th January, while with a 0.5°C temperature increase it would be the 3rd January, and with a -0.5°C temperature decrease it would be 15th January. However, the exact

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[10] *No comparable resolution temperature data could be found for any of the rivers used in this study.*

impacts of these changes would depend on actual flow conditions in the river during and after emergence. Typically, ‘average’ flows favour the greatest survival of juveniles, when sufficient refuge habitat is available. During periods of high flows, water velocity can wash juveniles away from available habitat and during low flow periods, access to marginal habitats is limited.

A greater impact on emergence times could result from delays due to insufficient flows to stimulate adult migration into rivers. Later migrations would typically coincide with warmer river temperatures and therefore quicker emergence times. However, research indicates that delays entering freshwater correlated with low freshwater flow can result in a failure of the fish to reach the river at all (Solomon & Sambrook, 2004).

The flow regime analyses (in Chapters 3 and 5) indicated that the key timeframe for incubation and emergence, between November and February, also correlated with the highest degree of flow variability between years. This could be a significant factor on why egg to smolt survival is so low. Greater flow certainty during this period could improve survival. However, as well as increased water temperatures, projected climatic modelling has shown seasonal flow regimes could also significantly alter, by more than 10%, by the 2050s on 90% of the global land area (excluding Greenland and Antarctica: Döll and Zhang, 2010). Atmospheric rivers (narrow bands of intense moisture in the lower troposphere) are also projected to intensify under climate change across Britain, which would result in larger, more frequent flood episodes (Lavers *et al*., 2013). With flow conditions set to change dramatically in the UK over the coming years, establishing high-resolution ecological datasets to couple with flow and water temperature data should be a top priority in order to understand and manage environmental flows in the future.

7.4.2. Impact of changing marine conditions

Marine survival of Atlantic salmon has collapsed from nearly 30% in the 1960s to now less than 10%, meaning now only one salmon returns for every ten smolts that goes to sea (ICES, 2013). From the late 1980s, the North Atlantic has undergone changes including; rising sea temperatures (Hughes *et al*., 2010), changes in circulation (Hátún, *et al*., 2009), changes in the distribution, species composition and abundance of plankton (Beaugrand *et al*., 2009) and changes in the distribution of fish (Brander, 2010). Studies have found significant correlations between declines in salmon since the late 1980s and sea surface temperatures (SST) and northern hemisphere temperature (NHT; Beaugrand and Reid, 2003). These attributed the decline in Atlantic salmon to changes in the carrying capacity of the North Atlantic ecosystems due the increased sea surface temperature, which is nearly a degree warmer (linked to climate change). The increased SST is believed to result in alterations to the planktonic food of salmon and its prey (Beaugrand and Reid, 2003). Beaugrand and Reid (2003) found biological variables exhibited a pronounced change that started in 1982, when euphausiids (small shrimp like crustaceans) started to decline. Then, 1984 saw the total abundance of copepods increase, and 1986 saw an increase in the number of plankton taxonomic groups and decrease in *Calanus finmarchius*[11]. By 1988 a decrease in salmon catches was found (Beaugrand and Reid, 2003). These biological events coincided with a shift in large-scale hydro-climatic variables (NHT in 1987 and NAO in 1988) and SST. This regime shift was attributed, at the time, to enhanced oceanic inflow generated from regional changes in the climate of northwest Europe (Reid *et al*., 2001). A further study by Beaugrand *et al*. (2008) also observed similar changes and attributed them to a northward movement of a critical thermal boundary, indicated by the annual 9-10 °C isotherms, which separates temperate from subarctic ecosystems. Studies have also show that salmon abundance in the northwest Atlantic had an inverse correlation with the Atlantic Multi-decadal Oscillation (AMO: Beaugrand *et al*., 2008; Condron *et al*., 2005).

Ocean climatic variables, which influence salmon growth and survival through direct temperature effect (Friedland, 1998; Todd *et al*., 2008) or resultant changes in species abundance, distribution and composition (Beaugrand and Reid, 2003), are spatially heterogeneous. Thus, it makes identifying the feeding locations of populations and age cohort’s important in order to understand more effectively how one affects the other (MacKenize *et al*., 2012). Atlantic salmon are believed to be highly migratory in the ocean, where they undertake feeding

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[11] *A zooplankton species, an important component of the food web, which used to be found in enormous quantities in the northern Atlantic Ocean.*

migrations to aggregate in a range of different geographical areas; the best-known are in the Norwegian Sea and the waters off Southwest Greenland and the Faroe Islands (Hansen and Jacobsen, 2003: ICES, 2008). Salmon that remain at sea for more than one winter undertake the longest migrations, whilst grilse (which only spend one winter at sea) tend not to travel beyond the Faroe Islands and the southern Norwegian Sea. Research is underway to attribute genetically identifiable stocks to their region/river of origin on both sides of the Atlantic. This could provide a break-through in understanding exactly where the UK salmon populations are migrating to and feeding, and if this differs between southern and northern UK populations, which may help explain the differences seen in this study between regions. Further resource is needed to investigate migration routes of salmon, as well as the composition and location of plankton and prey species, in order to begin to understand these pressures at sea and if anything can be done to reduce them.

An additional pressure in the marine environment is from exploitation and by-catch. ICES have identified pelagic trawlers as a possible risk to post-smolt migrations. Political will and international co-operation is required to minimise this risk.

7.4.3. Freshwater pressures

River improvements in the past have focused predominately on creating clean spawning grounds for Atlantic salmon and deep pools as refuge for adults, with most of the work focused on tributaries. In the main channel, the focus has been on removing barriers to migration, with less focus on available habitat for adults or juveniles. As a result of centuries of human modifications to rivers and their floodplains, in particular straightening and canalisation, most UK rivers suffer from a lack of secondary channels and marginal habitat. They tend to be treated as a roadway to deliver, or in flood defence terms, remove, water as quickly as possible to the sea, rather than as valuable habitats.

Mortality from birth to maturity is high for most fish species, including Atlantic salmon, but does vary at critical periods within the life cycle (Elliott, 1995). The dietary and habitat requirements of salmon change during their lifecycle.

‘Bottlenecks’ in the availability of these resources will, therefore, impact the life stage dependent on them. These bottlenecks typically occur early or late in the lifecycle (Sinclair, 1989), however little quantitative information exists. This raises the question: how important are main river channels to Atlantic salmon? Is there a habitat bottleneck in main channels, particularly for juveniles?

Evidence suggests that stable flows are important in the late spring and early summer to maximise the marginal habitat zone available to fry (McKinney *et al*., 2001). These marginal habitats are highly productive environments, providing high accessibility to food and reduced density of competitors and predators. Research indicates that fish that are denied access to marginal habitats and floodplains, through obstructions or drought, succeed less well than species with access (Halls *et al*., 1999; Welcomme and Halls, 2001; Horak *et al*., 2004). Frenette *et al*., (1984) also found that wild parr growth and survival rates during the summer were positively correlated with flow rates, with low flows limiting parr growth and survival by reducing habitat availability and food delivery. Therefore, modified flows from abstraction and hydromorphological changes to rivers could have reduced the carrying capacity of our rivers for juvenile development. However, it could also be that a loss of habitat ‘engineering’ for these juvenile life stages is more important than flow.

Sufficient river flows are needed to maximise the effectiveness of marginal habitat and reconnect our rivers with their flood plains. Suitable habitat for juvenile life stages is fundamental; however, creating diverse habitats along channel margins alone will not improve salmon populations until the quantity of water is available to allow access to these habitats. Similarity, diffuse and point source pollution (including pesticides, endocrine disrupting chemicals and organic waste) to water bodies must also be addressed before habitat improvements can have a real impact on ecology. This was highlighted by anglers’ anecdotal evidence which suggests aquatic flylife is down by as much as 70% on some rivers (Salmon &Trout Association, 2001), which is likely to be the result of problems with river water quality and quantify. These aquatic invertebrates are a key element of the aquatic food web, including providing food for juvenile fish.

Logic suggests a more diverse riparian habitat would lead to increased feeding and habitat opportunities and therefore larger parr and sequent smolts, resulting in the potential for improved marine survival. However, this may not be the case. The smoltification process is based on salmon reaching a critical size (McCormick *et al*., 1998), and, therefore, environmental factors, such as water temperature and the availability of food, impact the smoltification age and can result in fast-growing populations smoltifying younger (Swansburg *et al*., 2002). The size of the smolts that migrate to sea varies, but is in the range of between 10 to 20 cm fork length (Klemetsen *et al*., 2003: O'Connell *et al*., 2006). Over recent decades, research across Europe has shown that juvenile salmon have grown faster and migrated to sea younger, so therefore have typically been actually smaller than previous smolts which were slower-growing (Økland *et al*., 1993; Baglinière *et al*., 2004; Davidson and Hazlewood, 2005; Jonsson *et al*., 2005; Aprahamian *et al*., 2008; ICES, 2009, 2010). It is thought the increased early growth rate could relate to increasing freshwater temperatures (Metcalfe and Thorpe, 1990; Jonsson *et al*., 2005), as well as density-dependent processes (Gibson, 1993; Jenkins *et al*., 1999; Imre *et al*., 2005; Bal *et al*., 2011) and/or increased freshwater production (Aprahamian *et al*., 2008). Conversely, this phenomenon could be having implications on salmon marine survival. An increase in smolt size is shown to increase mean survival in hatchery released Atlantic salmon (Virtanen *et al*., 1991; Lundqvist *et al*., 1994; Farmer, 1994). It is thought that larger smolts (18-20cm) have fewer predators than smaller (<14-15cm) smolts (Hansen and Jonsson, 1989; Virtanen *et al*., 1991; Salminen *et al*., 1995). Skilbrei *et al*. (1994) studied the stomach content of gillnetted predators and found small smolts but no larger juveniles. This raises a number of questions; 1) if the process is temperature driven and the optimum temperature is breached with climate change (optimum temperature for parr growth is ~16°C (Elliott and Hurley, 1997)) what impact will this have on salmon production? 2) Are productive freshwater habitats a bad thing, resulting in reduced marine fitness due to smaller smolts going to sea? 3) Or is a different life strategy at play, where other factors are limiting or causing unfavourable conditions in freshwater, resulting in early juvenile salmon migration?

Several populations of Atlantic salmon, in both the UK and North America, have been shown to demonstrate early downward migration during the autumn (Buck & Youngson, 1982; Youngson *et al*., 1983; Cunjak *et al*., 1989, Riley *et a*l., 2002, Pinder *et al*., 2006; Riley, 2007; Ibbotson *et al*., 2012). Unlike the spring migrants, who migrate directly into salt water, the autumn migrants are not physiologically adapted to do so (Riley *et al*., 2008). The size of parr is thought to have no effect on whether an individual migrates in the spring or autumn, although data from the River Frome indicated a higher proportion of salmon tagged in the main river channel became autumn migrates, compared to salmon tagged in smaller flood relief channels and carriers (Ibbotson *et al*., 2012). This could suggest that a lack of habitat and food availability in the main river channel encourages/forces some parr to migrate downstream early to seek better conditions. Both autumn and spring migrants have been detected returning as sea-run adults, so it is not yet clear which is the most successful strategy (Riley *et al*., 2009), or what the implications to the population could be. Further research is needed to better understand what implications this could be having on salmon populations.

It should, however, be recognised that this could be complicated further by the role of density-dependent processes, in particular in regard to varying habitat conditions. Work on brown trout (*Salmo trutta*) populations (Elliott, 1987, 1988, 1989a,b) has lead to the hypothesis that; high-density populations living in favourable habitats are governed by density-dependent processes in the juvenile life-stage and are, therefore, predominately stable, whereas low-density populations living in unfavourable conditions show limited density-dependent regulation and therefore, the populations vary in their densities. This is broadly supported by analyses of commercial and rod catch sea-trout data from 67 rivers in England and Wales, where rivers with high catches had little variation in catches between years (Elliott, 1992). This hypothesis could help to explain the large between-year variation and low rod catches in Atlantic salmon seen in this study, in particular those in south-west England and Wales. This could suggest the freshwater habitat conditions in these rivers are unfavourable and contributing to the ‘boom or bust’ variation between years because the populations are not limited by density-dependence.

The distribution and abundance of salmon is strongly influenced by riverine habitats, and the strongest effects of these habitats is thought it be during population bottlenecks, when the carrying capacity of the river is reached (Armstrong *et al*., 2003). Yet, so little is known, in particular about juvenile habitat requirements when in the river. Section 2.4.1 illustrates we can broadly define wide ranges of acceptable conditions for different life-stages of salmon, however these are exactly that, wide ranges. The science is currently lacking on understanding within populations preferences and tolerances, and the interactions between different biotic and abiotic factors impacting habitat selection and preference (Armstrong *et al*., 2003).

The lack of quantitative understanding of the specific habitat requirements for fish, including Atlantic salmon, is a major weakness in current fisheries management. The current 'close season'[12] management does recognise that different stages of the salmons life cycle are more vulnerable than others, but better understanding of these bottlenecks, the critical periods associated with them and the impact of density-dependence would help develop salmon management in the future, particularly in light of climate change.

As we look towards an uncertain climatic future, the diversity of marginal habitats/refuges may become even more important for cool-water salmon and in particular their sensitive juvenile life stages. Future policy must emphasise

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[12] *Closed seasons are time periods when you are not permitted to fish. These are set out in the Rod fishing Byelaws as a measure to protect fish stocks. A closed season exists for salmon in all water in England and Wales, although the dates may vary between regions. National Byelaws for salmon include:*

- *Any person who removes any live or dead salmon taken by rod and line from any waters or banks without the previous written authority of the Agency before the 16th day of June in any calendar year shall be guilty of an offence. This byelaw shall not apply to any person who lawfully takes a salmon and returns it immediately to the water with the least possible injury. (National Salmon Byelaw 5; applies throughout England and Wales).*
- *Any person who fishes for, takes or attempts to take any salmon with rod and line by any means other than an artificial fly or artificial lure before the 16th day of June in any calendar year shall be guilty of an offence. (National Salmon Byelaw 6; applies throughout England and Wales).*

the importance of allocating space for rivers to evolve these diverse marginal habitats.

7.4.4. Estuarine and coastal pressures

Coastal waters and, in particular, intertidal habitats are often the forgotten environments in the salmon lifecycle. These are, however, continuations of river habitats, affected by both the quality and quantity of fresh and marine water they receive. Unfortunately, it is estimated that 85% of British estuaries have lost individually up to 80% of their intertidal area through anthropogenic land claim, for reasons such as agriculture, port developments, harbours, industry, dredging and housing (Atrill *et al*., 1999; McLusky and Elliott, 2004) and coastal squeeze. The importance of these areas for fish is strongly linked to their mixture of many distinct habitat types, high food availability and low predation pressure (Miller *et al*., 1985; Pihl *et al*., 2002). Intertidal habitats are key sites for Atlantic salmon to undergo smoltification, yet we know little about their utilisation of these habitats. Evidence from the River Frome has shown that early autumn movements into tidal habitats account for approximately 19.1% of the total 0+ parr year class (Pinder, *et al*., 2006). This sizeable proportion of parr relocating downstream highlights the importance of the estuary as an over-wintering habitat and not just a transient location, and how important research is to assess the pressures salmon face during this period of their lifecycle. This raises the question as to whether the reduction in intertidal habitat across the UK could be resulting in a bottleneck for successful juvenile salmon growth and smoltification and, therefore, if significant mortality of juvenile salmon is occurring in our estuaries before the fish even reach the sea? Also, does the timing of smolt migration from freshwater (which is impacted by freshwater flow) affect initial survival of post-smolts? Is there an ‘optimum window’ related to estuarine water temperatures and oxygen levels which, if missed, is detrimental? And if there is a pollution legacy in our estuaries derived from freshwater, which during low flow conditions (high water temperatures and low oxygen), creates a water quality barrier to migration and/or a toxic cocktail to juvenile salmon during smoltification? This area needs further research, such as a tagging study to investigate fish utilisation of intertidal habitat; to provide evidence of how salmonids are using intertidal habitat; the timing of when this occurs and differences in utilisation between spring/autumn migrants.

Atlantic salmon also depend on estuaries on their journeys from the sea back into rivers to spawn. One known pressure on returning adult salmon in the coastal zone is mixed stock fisheries (MSFs), which are those capable of intercepting fish from more than one river system, making the management of individual river stocks very difficult. This has led to MSFs being considered as bad management practice by the North Atlantic Salmon Conservation Organisation (NASCO), to which all the Northern Hemisphere countries with runs of wild Atlantic salmon are members (with the exception of Iceland, which dropped out due to economic reasons in 2009). Nevertheless, coastal fisheries still operate off the English and Scottish coasts, which continue to kill significant numbers of salmon each year. However, research suggests that the daily loss of salmon in estuaries, even without legal or illegal fisheries, can account for a large proportion of the stock (Solomon & Sambrook, 2004). Recent, currently unpublished modeling research on the River Wye suggests that, although climate has a main impact on stocks, the proportion of extra fish lost due to low flows from abstraction can still be large in relation to the number of fish which do actually enter the river (G. Mawle, pers.comm). There is also some analysis on the River Usk smolt run that indicates a delay to migration since abstraction has started on the river (G. Mawle, pers.comm). Both these examples highlight the importance of sufficient flows to initiate and enable migration. Again, further research is required to investigate pressures/upholds in the estuary and the impacts of low flows in order to fully understand if this is a significant threat to current salmon populations.

7.5. WATER POLICY- CURRENT MANAGEMENT

On the 27th June 2013, a new Water Bill was presented to Parliament for its first reading, approximately 10 years since the last Water Bill, and became the new Water Act in May 2014. The recent years of extreme flood and drought have highlighted the problems with the current abstraction regime for people and the environment, and the importance of sustainable water management. Yet, the focus of the Water Act is predominately on opening up competition in the water industry and it failed to create a framework to give Government powers to reform the abstraction regime, according to the principles set out in the 2012 Government Water White Paper. This is seen by many as a missed opportunity, as the promise of an additional Water Bill soon after this one to cover abstraction reform is certainty not the norm and will have to contend with changing governments. The proposal to open up competition in the water industry without the safeguard of abstraction reform could cause more damage to the environment, as it is unsure if there will be nothing to prevent sleeper licenses[13] being re-activated, or treated sewage effluent diverted from catchments where it maintains summer river flow. The Environment Agency estimates that nearly 40% of licensed water company abstraction volume is unused (EA and Ofwat, 2012), which means we could see a considerable increase in unsustainable flows if every licence were used to its full extent, which could in turn impact salmon populations.

This study has shown that limited information still exists to understand the relationship between salmon and river flows and the multiple other stressors impacting upon the populations. So, with the UK Governments deferring the delivery of good ecological status under the WFD until the latest opportunity in 2027, and implementation of the Habitat Directive still failing to improve conservation targets for salmon on many protected rivers, what does this all mean for salmon conservation?

7.5.1. Current Atlantic Salmon management

Restoration and rehabilitation schemes to enhance Atlantic salmon populations are not new, for as long as we have impacted salmon populations, we have been trying to improve them, with examples of primitive restoration programmes dating back at least 200 years (de Groot, 1989). The current strategy for the management of salmon fisheries in England and Wales requires the production of individual Salmon Action Plans (SAP) for each principal salmon river, which are updated at regular intervals. This strategy recognises the need to maintain a national overview of salmon conservation, but a key component of this is

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[13] *These are licences, sometimes for significant quantities of water, under which there has been little or no actual abstraction for several years.*

effectively managed individual stocks. And it highlights, in order to effectively manage individual stocks, that restrictions throughout the salmon lifecycle must be identified and the possible mitigation assessed.

In order to assess the different management measures employed under SAPs, two of the rivers analysed in this study were compared; the River Tamar, which has an overall trend of declining salmon rod catches over time, and the River Tyne, which has increasing numbers of rod catches over the same timeframe. Both of the SAPs for these rivers identify habitat improvements which are required; the River Tamar plan focuses on spawning beds; both installing further gravels and using bankside fencing to reduce sediment input from cattle poaching (Table 7.7). The River Tyne plan targets juvenile habitat, linked with better riparian management. Both plans also recognise the need for longitudinal connectivity and removing barriers to aid migration, and the importance of managing exploitation on the stock. The main difference in the plans comes with the hatchery-stocking programme in the River Tyne, which is the result of the development of the Kielder reservoir and more recently the Tyne Crossing Scheme. The Kielder Reservoir resulted in the loss of 8% of the catchments' juvenile rearing habitat, and therefore as legal mitigation, a stocking programme was required providing 160,000 juvenile salmon per year. However, in practice the EA has recognised stocking as been much higher, with approximately 600,000 juvenile salmon stocked in 1997 and 2004 (EA, 2008).

A stocking review (Milner *et al*., 2004) attributed the recovery of salmon stocks in the Tyne predominately to improved estuarine water quality in the 1970 to 1990s and subsequent natural re-colonisation. Although it was recognised that stocking had contributed to the recovery, the contribution became less significant due to improved natural recruitment. The stocking programme is thought to be contributing between 2-8% of the annual run (EA, 2008). The net limitation orders (NLOs), Spring Byelaws and drift net buyout in the north east coast salmon fishery were also believed to have measureable benefits by increasing numbers of fish returning to the river (EA, 2008).

Table 7.7: Details from the River Tamar and River Tyne Salmon Action Plans

	River Tamar (2006)	**River Tyne (1998)**
Water Resources	-Comment on CAMS consultation	-Continue to monitor and develop an understanding of the effects of the release regime on the salmon population
Habitat degradation	-Install further spawning beds within catchment -Fencing project- install 13 km	-Identify degraded zones requiring restoration -Increase juvenile production through targeted improvements -Provide best practise guidance on riparian land use -Provide training in habitat restoration techniques for riparian owners
Water quality	-Assist DEFRA catchment sensitive farming officer to target resources effectively -Prompt reporting and response to fish kill incidents	-Install secondary treatment at Howden STP -Ensure compliance with all discharge consents -Monitor water quality and operate Vitox units as required -Connect remaining crude discharges to Tyneside interceptor sewer
Obstructions	-Assess migratory obstructions within the catchment -Carry out improvements to obstructions where appropriate	-Identify, prioritise, cost and remove obstructions to fish passage
Exploitation	-Continue high levels of catch and release -Maintain high levels of fisheries enforcement and vigilance to salmon poaching -Promote use of circle hook when appropriate -Work effectively with enforcement partner organisations	-Protect salmon through fisheries enforcement activities -Continue implementation of the 1992 Net Order Limitation -Reduce exploitation of spring run (national byelaw) - Adopt voluntary catch and release, and code of practise
Stocking	N/A	-Reappraise stocking needs through assessment of impacts on stocks and management aims -Monitor contribution of hatchery to stocks through tagging -Operate Kielder Burn smolt trap to evaluate in-river survival
Research	-Continue Tamar salmonid stock assessment programme -Continue Tamar salmon smolt tagging programme -River Tamar salmon genetics research study	-Monitor and assess estuary salmon mortalities -Continue Kielder release study- impacts on water quality -Investigate metal budgets and trial treatment -Radio tracking study to identify areas used by spring salmon -Aerial photography to identify habitat availability

In the Tyne SAP, Kielder Reservoir releases have also been used to try and improve conditions for salmon in the upper estuary during warm, dry conditions. Evidence shows that this has resulted in increased fish movement, although less than that from similar magnitude natural flow spates (EA, 2008). The reservoir also provides a continuous compensation flow, which ensures there is a minimum flow of 1.31 cumecs throughout the year. Before the reservoir was completed, flows in the North Tyne (the site of the reservoir) were lower than this for approximately 20% of the time (EA, 2008). The compensation flow, therefore, removes the extreme low flows which result in increased water temperatures, reduced dissolved oxygen and exposed river margins, all of which are detrimental to salmon. The River Tamar does not have a stocking programme and the Roadford Reservoir in the catchment abstracts near the tidal limit, which is thought to have a limited impact. However, the impact of low flows in intertidal waters is understudied and initial work on the River Wye does suggests low flows from abstraction can impact fish movement in the estuary (G. Mawle, pers.comm).

This very crude comparison seems to infer that we have more success in managing salmon populations with greater human invention, such as stocking programmes and regulating river flows. This could provide evidence that flow is a key factor and the ability to manipulate flow via reservoir release does help improve salmon populations. This could also infer that there is a threshold to be met before mitigation begins to deliver results, e.g. on the Tyne, a combination of many different measures from source to sea finally started to deliver results.

It should be recognised that Atlantic salmon face restrictions and pressures throughout their lifecycle. With the UKs severely depleted salmon populations, little effective self-sustaining recovery is likely to take place without first tackling all potential restrictions on the population at all stages. Even just looking at the potential restrictions on the population in freshwater (Table 7.8) raises many issues about how viable full restoration can be, from the perspective of balancing the needs of humans and the environment, the funding required and the thresholds which would need to be reached. Therefore, if we are unable to remedy all of these restrictions on the Atlantic salmon’s lifecycle, does that mean stocking is the only real certainty to preserve the population?

Table 7.8: Potential restrictions on Atlantic salmon populations based on different stages of their lifecycle

Basic salmon lifecycle in freshwater	**Potential restrictions on populations**
Adult salmon return	-Quality of water in estuary? -Quality of water upstream? -Obstructions to migration? -Quantities of flow? -Interrelations of these with time to produce optimum conditions at the optimum time?
Spawning	-Does suitable spawning gravel exist? -What quantities are present? -Will there be sufficient flow over the gravels during spawning?
Nursery areas	-Is suitable nursery habitat available? -What it the reliability in terms of river flow and water quality?
Smolt migration	-Presence of potential barriers or diversions? -Is water quality downstream, e.g. in the estuary, adequate at time of migration? -Will there be sufficient flows and habitat downstream to aid migration? - Will interrelations between these produce optimum conditions at the optimum time?

The Columbia River in the USA, used to be one of the most prolific Pacific salmon-producing rivers in the world. However, since the construction of multiple dams (predominately for hydropower), there has been an 80% decline in the total run of the salmon species (Chinook, Coho, Chum, Sockeye and Pink) in the region (Reisner and Bates, 1990). Early research suggested that hatcheries were making up some of the deficit in wild stocks. However, it was also recognised that the interbreeding between wild and hatchery bred fish could lead to erosion in genetic diversity and the loss of unique gene pools. In 1990, it was predicted that only 20% of the Columbia salmon runs consisted of wild fish (Van Dyk, 1990). Further extreme human intervention to preserve the salmon stocks saw the transportation of adult and juvenile salmon up and down-stream on trucks or barges to reach habitats, where the dams restricted assess and to prevent turbine entrapment. However, this raised concerns that the high levels of handling were impacting the fish's behaviour and distribution, and were exposing them to disease, over-crowding and increased risk of predation on release. Furthermore, delays in migration due to transport were thought have been impeding the physiological development of juvenile salmon. Today, on the Columbia River, salmon species remain threatened and are listed under the federal Endangered Species Act (ESA) as a management priority. Focus on habitat improvements continues and the reliance on hatcheries remains. Hatcheries are preserving the stock, but are not addressing the issues causing the decline.

The evidence from rivers suffering salmon extinctions during the industrial revolution suggests that stocking, in conjunction with the removal of the problems causing extinction in the first place, is able to facilitate a recovery to the point at which the population becomes self-sustaining. However, continued stocking beyond this point will not be cost effective and may potentially cause negative impacts. A review for a consultation by Natural Resources Wales (NRW) on salmon stocking and hatcheries, concluded '*whilst there is evidence that stocking, in conjunction with habitat improvements, can help restore extinct populations, there is a lack of convincing evidence that mitigation or enhancement stocking of salmon is an effective way of safeguarding or maintaining wild populations or of increasing annual rod catches. Indeed in some cases, such as on the River Spey, despite a considerable investment of resources, returns of hatchery derived adult fish appear to perform little better than direct replacement for the broodstock used in the hatchery*' (NRW, 2014 pp.6). Therefore, stocking is a short-term measure, predominately for recreational benefit, and should not and cannot be seen as the answer to restoring salmon populations, especially if no additional restoration is undertaken to reduce the pressures on the population. The loss of genetic diversity is also a very real concern, as even within migratory salmonids, many form locally reproductively discrete populations/stocks, which differ phenotypically in their physiology, morphology, ecology and behaviour. These genetically distinct stocks should be identified and conserved. Therefore, stocking to supplement existing populations should always be done with indigenous populations to ensure optimum genotypes for the particular locality (Elliott, 1995). However, even when native broodstock are used genetic changes can occur due to the absence of sexual selection.

Table 7.9: Pressures impacting Atlantic salmon and possible mitigations options.

Pressures on salmon populations in freshwater	**Mitigation options**	**Evidence of benefits to salmon populations**
Modified river flows	-Restore flow variability and water quantity.	Many examples of dam removal restoring river flow and salmon runs, however direct impact on population not quantified.
Poor water quality from point sources	-secondary sewage treatment -Ensure compliance with all discharge consents -Dilute pollutant loads with increased freshwater flows	Recovery of salmon in rivers in the northeast of England, south Wales and Scotland attributed to regulation of discharges from industry and investment in water treatment, coupled with the reductions in heavy industry in these areas (Doughy and Gardiner, 2003; Mawle and Milner, 2003).
Poor water quality from diffuse sources	-Working with farmers to reduce pollution -SUDS -Dilute pollutant loads with increased freshwater flows	No direct quantified evidence could be found.
Excess fine sediments clogging spawning gravels	-Bankside fencing reducing livestock in rivers -Best practise farming methods	Vast evidence exists demonstrating the negative impact of fine sediment on redds, however no evidence of increased salmon populations as a result of reducing fine sediments could be found.
Protection of salmon stocks from over exploitation	-Catch and release -Buy out of netting/fishing practises -Protection from illegal exploitation -Stocking/hatcheries	Buy out of North East Coast Salmon Fishery nets estimated to have resulted in, under average conditions, an additional 22,000 salmon entering various northeast and Scottish rivers (EA, 2008b, 2008c). Recovery of salmon in rivers in the northeast of England, south Wales and Scotland were supplemented with stocking (Mawle and Milner, 2003). Catch and release is expected to benefit stocks (Cefas & EA, 2013).
Habitat loss	-Targeted improvements of required habitat including instream, floodplain and intertidal habitats -Best practice guidance on riparian land-use	Experts believe habitat bottlenecks if targeted will improve salmon populations, however impacts of water quality and flow regime can over-ride this, and a sufficiently large change in physical habitat must be achieved in order to see a response in biota.
Predation	-Increasing riparian cover -Increasing river flows -Removing barriers -Management of predators	No direct evidence could be found.
Obstructions to movement	-Removing barriers	Many examples of weir removal resulting in access to previously unavailable spawning habitat, and evidence of redd above the previous obstruction, however direct impact on population not quantified.
Parasites and disease	-Procedures for diseases, such as *Gyrodactylus*, established.	No direct evidence could be found.
Invasive species	-Prevent the introduction and spreading on invasive species -Remove invasive species if found	No direct evidence could be found.

In the past, water quality improvements in the UK have seen the return of salmon to now cleaner, recovering rivers, such as the River Tyne, which previously suffered from gross pollution due to industrial and urban development. This recovery has now resulted in numerically more salmon rivers in the UK than at any time in living memory. However, at the same time, salmon rod catch figures in many more rural parts of the UK have seen a continuing decline. These declines do not necessarily derive from direct point source pollution, but are likely instead to be the result of a cocktail of pressures, which further increases uncertainty. Despite understanding many of the pressures on salmon populations and developing possible mitigation options, we have little evidence on actual improvements to salmon populations (Table 7.9). The lack of post-monitoring on many river restoration projects does not help this, as changes cannot be attributed to any one mitigation measure. However, in order to see true population level improvements from individual mitigation measures, even the most sophisticated monitoring programs would struggle.

On the ground, action is happening on many catchments in the UK to improve and restore habitats, diversify marginal habitats, improve shading, protect spawning gravels and remove barriers to migration, but so far at the regional and national scale this appears to be making little difference to salmon populations. This could suggest there is a threshold that needs to be reached before significant improvements to populations will be seen, or perhaps the pressures at sea are so dire that freshwater restoration is just slowing the rate of decline. Or are there greater underlying failures in freshwater, such as with water quality and quantity, which negates other mitigation measures? Or are there additional pressures we do not even recognise or understand which are impacting salmon populations?

7.5.2. Future management opportunities to improve our rivers and salmon populations

Although we do not understand the complex relationships between abiotic factors such as flow and salmon, the restoration of natural flow regimes has been proposed as a method to conserve native fish (Stanford *et al*., 1996; Poff *et al.,* 1997), and research has provided empirical support that natural flow regimes enhance native fish recruitment (Marchetti and Moyle, 2001; Propst and Gido, 2004). Research has also shown where only partial restoration of the natural flow regime is possible, e.g. due to flood control, reservoir releases designed to mimic natural runoff can positively influence native fish recruitment (Propst and Gido, 2004). Evidence also shows that the fauna and flora in a river with exactly the same flow everyday is much more sensitive to change, compared with a river having a natural, dynamic flow regime (Petts, 1984). However, this forms the two extremes of a bell-curve, and where the majority of scenarios involve much more subtle changes in flow variability. For the majority of rivers, most of the available flow goes straight out to sea in floodwater (unless dammed or otherwise retained), so flow management is only ever dealing with a fine-scale, sensitive proportion of the flow. Therefore, should we be surprised that relationships are difficult to establish?

This study shows that, despite the correlations between flow and salmon providing little useable outcomes, we can deduce that:

- Flow is arguably the most important parameter during upstream migration, typically in the autumn.
- Quality of spawning gravels is key to successful breeding, which are achieved with the correct spate flows that clean the riverbed before spawning.
- Diverse marginal habitat provides important rearing and feeding habitats for juvenile salmon, the accessibility of which is linked to flow. However, this is currently constrained in many UK rivers due to riverine management removing riparian trees and bank habitat, and with it the shade, refugia and feeding opportunities for juvenile fish.

With climate change suggesting drier summers, wetter winters and an intensification of runoff in the autumn, does this provide more opportunity for the autumn salmon run? In terms of salmon management, is this ‘the window’ we should be focusing on to give the river as much water as we can? This is currently the time when reservoirs start to be filled. Could water resource planning delay reservoir filling for a few weeks following the first storm of the autumn to ensure successful upstream migration? Could this provide a trade-off in catchments with major aquifers; where more water is left in the rivers in the autumn instead of spring, as spring runs of salmon continue to decline and the typically high groundwater flows in the spring could be used to maintain river quality whilst allowing more abstraction? Should we be focusing more on the time when water is taken rather than how much? However, a policy to improve and retain an individual species, such as salmon, would look somewhat different from a policy to improve ecosystem functioning and biodiversity in general. Ecosystem management would require mimicking natural flow variability to ensure that the river maintains fundamental variability in the timing, frequency and duration of particular water conditions, and the rate of change in water conditions, both within and between years.

Despite all the uncertainties, we still need to manage our rivers. Conserving salmon populations is very different from restoring salmon populations. Conserving could be seen as preserving and ensuring survival by hatcheries. But to truly restore the population means creating a self-sustaining population, which requires ecosystem level management in order to increase resilience and maintain genetic diversity and, therefore, the Precautionary Principle has never been more relevant. The Precautionary Principle is one of the key elements for policy decisions concerning environmental protection and management. It is applied in circumstances where there is reasonable grounds for concern that an activity is, or could, cause harm but where there is uncertainty about the probability of the risk and the degree of harm (JNCC, 2013b). In terms of water resource management, this equates to ensuring that all modified rivers mimic natural inter- and intra-flow variability, alongside an adaptive management programme, with long-term monitoring and analysis at its core.

This study has shown that regional flow variability exists between our rivers and that this could have implications for regional salmon populations. By ensuring that individual river water resource management mimics natural flow variability, we will maintain that regional scale flow variability, the implications of which we are yet to understand.

CHAPTER 8: CONCLUSIONS

8.1. IS WATER IMPORTANT?

Today, freshwater species, in general, are considered at a higher risk of extinction than species in forests, grasslands and coastal ecosystems (WRI *et al*., 2000), and within the United Kingdom it has been calculated that no more than 15% of all rivers can be considered as having 'natural' hydrology due to extensive anthropogenic alterations, such as abstractions, dams and reservoirs (Marsh *et al*., 2000). The challenge, with increasing human populations and escalating demand on freshwater resources, is to balance the demands of humans alongside the ecological needs (Petts, 1996). The environment is a legitimate user of the water, and therefore also requires water security to ensure its sustainable development (Naiman *et al*., 2002). A basic understanding of water resource use and current ecological consequences is required to help inform future policy decisions (Postel, 1998; Rogers, 1998).

8.1.1. The scale of flow variability

This study has highlighted the inter- and intra-annual flow variability present across different spatial and temporal scales across the UK. The novel method of analysing the flow data (PCA/CA combined with IHA model) demonstrated all the rivers studied displayed different regime types through time, with each regime type being characterised predominately by variations in the timing of peak flows. The most commonly occurring regime type across the country was characterised by a single high magnitude peak in January, followed by the spring flow recession. However, the fact this typical temperate flow pattern only occurred approximately 1 in every 2.5 years demonstrated the high flow variability across the UK.

Investigating this temporal scale inter-annual variation provides an important baseline to help understand and manage future challenges to river flows linked to climate change. At present, within water resource management: flow magnitude is managed locally and flow timing is managed nationally. This is challenged by this study as it shows the timing of flow events are river specific and distinct, therefore natural flow variability is lost when managing this nationally. Between-year flow variability is also currently not represented in river flow management, which means on a national scale significant proportions of flow variability are being lost on regulated rivers every year.

The occurrence of regimes through time also requires further consideration. The rivers of the southwest indicated increased variability in the distribution of regime type in the last 20 years, with the most common regime (e.g. the typical wet winter, spring recession to a dry summer regime) becoming less dominant. Although this pattern was less pronounced in the other two regions, this could be the due to climate change and suggests flow variability is set to increase in the future.

8.1.2. Linking hydrology and ecology

The Atlantic salmon completes its lifecycle via three environments: freshwater, estuarine and marine. Pressures operating within these environments, however, do not function independently (Russell *et al*., 2012); marine conditions can affect spawning success (Todd *et al*., 2008) and conditions in freshwater can impact smolt survival (Jutila *et al*., 2006). Therefore, disentangling where or when the main pressures on salmon populations occur is very challenging, let only apportioning single dominate drivers.

The method of correlating annual Atlantic salmon rod catches, chosen because they are the longest available proxy dataset, with IHA flow parameters provided little additional insight into this relationship, apart from confirming the relationship between increasing rod catch numbers and increasing flow during migration months, in particular August, September and October. However, from a theoretical perceptive the variety of flow regimes in British rivers should impact salmon populations in a number of ways. Developing an analysis model that focussed on functional flows for salmon, such as the timing of autumn rise and duration of spring and summer sustained flows could provide greater insight. In addition, analysing the chronological order of hydrological events could also be an important factor impacting salmon population success.

However, these many pressures make determining if hydrological change is the main driver on salmon populations almost impossible to determine, especially in light of the large knowledge gaps and lack of long-term, high resolution data to link with flow. Therefore, currently there is no clear deterministic relationship between flow and Atlantic salmon. However, in reality UK rivers are relatively small and flow regimes are unpredictable, this could suggest salmon have evolved behavioural responses to cope.

8.1.3. Confounding factor

Focus in recent years has suggested the marine phase of the salmon's lifecycle maybe the greatest threat to their survival, yet questions remain on what can be done to remedy these problems. However, some now believe the influence of freshwater phase on declining populations may be more important than previously thought (Crozier and Kennedy, 2003), and that changing freshwater conditions from climate change in the future may be more important to the viability of the species than what's happening at sea (Friedland *et al*., 2009). Focus, therefore, has again reverted back to freshwater, and maximizing production within rivers in order to create fit smolts to go to sea.

Currently so little is known about juvenile habitat requirements when in the river. The lack of this quantitative understanding is a major management limitation. Without understanding of these habitats requirements and the bottlenecks associated with them, we run the risk of focusing on and manipulating the wrong habitats, which could lead to increasing populations which will when be constrained (Armstrong *et al*., 2003).

Climate change is a challenging factor that directly affects most aspects of riverine hydro-ecology, including habitat quality and availability. Although it's potential effects are still not fully understood, both the marine and freshwater life stages of Atlantic salmon will be affected. Even with the pressures on salmon populations which we do have greater understanding on, the success of individual mitigation options are difficult to determine due to the complex inter-relationships between the different pressures and the lag-time in species response. This, coupled with climate change, may require a rethink on flow management as we know it and heighten the need for new adaptation management (Wilby *et al.*, 2010).

8.2. FUNDAMENTAL PRINCIPLES

This study has highlighted a number of key principles:

- *Flow variability is key*; this includes both extreme high and low flows. There lack of conformity in the flow regimes between the national, regional and local scales at high and low flows, as the result of catchment characteristics and local weather patterns. National or regional classification/management of river flow will result in significant proportions of flow variability being lost. Maintaining this variability, between and within years, will result in some years giving the river/ aquatic environment less water than normal in order to truly mimic natural variation. It must be recognised that we should strive to minimise anthropogenic impacts on flow, but not to eliminate natural flow variability, even if it is detrimental to an individual species. This variability increases the ecological resilient to climate change.

- *The PCA/CA and IHA model has limited scope as management tool to link with rod catch data*. The PCA/CA is a valuable tool in characterising and understanding flow variability, however the IHA is limited by its inability to vary to start and length of the hydrologic cycle. Developing flow models that could incorporate this variation could allow greater opportunities to link flow with ecology. The IHA parameters also fail to expose the temporal dynamics that may be influential in providing ecological cues that influence the Atlantic salmon lifecycle. A more targeted set of temporal flow parameters may provide better insight into the relationship between salmon and flow. Current Atlantic salmon rod-catch data lacks the sufficient resolution to enable meaningful comparisons with flow data. However, long-term quantitative biological datasets are essential in order to interpret population dynamics and the impacts/influences upon them.

- The multiple pressures impacting salmon populations may make it currently impossible to determine the impact of flow. In freshwater, the impacts of water quality, temperature, habitat loss and density-dependent processes are all likely to be major pressures on Atlantic salmon populations. However, these pressures are impacted themselves by river flow, as reduced water quantity results in increased water temperatures, reduced dilatation of pollutants and limited access to riparian habitats. The pressures in marine and estuarine parts of a salmon's life cycle could dominate over freshwater conditions and may inhibit /constrain benefits of river flow restoration. However, it should be recognised that all these habitats are interlinked; impacts in freshwater may have the greatest impact on a salmon's lifecycle in intertidal areas and/or marine areas etc., for example where excessive water abstraction prevents adults moving into freshwater or sub-lethal cocktails of pollutants picked up in freshwater become lethal during smoltification in transitional waters

8.3. MANAGING SALMON POPULATIONS

The concept of 'management' could be considered one of the more arrogant human philosophies. It is recognised that the 'best management' of wild species is to minimise human interference, and therefore manage human activities and populations rather than nature (Elliott, 1995). However, this is not always possible. The World Conservation Strategy states three scenarios where management/conversation measures are considered acceptable; i) to maintain essential ecological processes and life systems, ii) to preserve genetic diversity and iii) to ensure sustainable exploitation of species and ecosystems (International Union for Conservation of Nature and Natural Resources, 1980). All of these are, of course, applicable to Atlantic salmon. However, detailed quantitative information on the ecological requirements of Atlantic salmon is still lacking despite over 50 years of effort, which makes management challenging.

Environmental flow management falls into two main categories, those which; i) limit alternations on the natural flow regime to maintain biodiversity and ecological integrity and ii) those which construct a flow regime in order to achieve specific outcomes from a species/ecosystem. The uncertainty around specific flow requirements for Atlantic salmon makes managing for the latter very challenging. However, we also need to accept changes to flow regimes are inevitable under an shifting climate and substantial regulation and we must not confine flow regimes in the future to those in history (Acreman *et al*., in press 2014).

The science supports that Atlantic salmon, like most other species, have evolved their life strategies to suit the natural flow regime, and although variations between years in this regime may not always favour Atlantic salmon, maintaining the real-time flow variability, where possible, will aid species resilience towards pressures, such as climate change, going forward. We need to manage and/or mitigate anthropogenic impacts on flows, prioritising protected areas and/or rivers with protected species, such as Atlantic salmon, to allow them to mimic natural conditions as much as possible, and the ecology to respond accordingly.

Water quantity and river flow are important to the lifecycle of Atlantic salmon, but we currently do not have the necessary length and resolution of biological datasets to help assess ‘how important’. Future focus must be to develop and where applicable, maintain investment into long-term monitoring projects of Atlantic salmon.

8.4. FURTHER RESEARCH

In-light of the projected impacts of climate change on flow regimes is it important to establish high resolution ecological databases, including for Atlantic salmon, to correlate with changes in flow in the future.

Other specific research gaps highlighted in this study include:

- Research to define the thermal threshold in the late summer that could be a thermal cue for Atlantic salmon to begin the migration. This could provide a time window, after the thermal cue has occurred, when protecting natural flows will have the greatest benefit for upstream salmon migration.

- Monitoring programme of juvenile salmon and migrating smolts, in order to better understand the changes that occur to growth and size in freshwater and what impact this has on marine survival.
- Research on what factors drive some salmon to migrate in the autumn and what are the population levels implications of such behaviour?
- Research on the utilisation of intertidal habitats by salmon. What are survival rates in the estuarine phase of a salmon's life? What are the pressures?
- Investigating how interactions with environmental triggers/cues differ between declining/stressed and increasing populations?

This thesis focuses on adult salmon catches, dominated by the returning spawners, as a proxy for salmon populations. But, maybe a better measure of salmon populations would be focusing on smolt production, which would allow an early indication of the future of salmon stocks and partitioning of mortality between freshwater and marine life-stages. However, the facilities to carry out this type of monitoring are currently limited to only a few rivers and are normally based on mechanical trapping, which involves handling the fish (which can increase mortality) and may disrupt natural migration. Current best practice for counting smolts occurs at the Game and Wildlife Conservation Trust's East Stoke laboratory; where the first 'hands-off' counting system has been designed. This involves using acoustic bubble screens to deflect smolts via a millstream and through tubes containing resistivity counters[14]. Investment into monitoring infrastructure and smolt data sets could help us better understand how flow management might benefit smolt production, and provide a measure of river condition. This could incorporate factors such as; impacts of egg, fry and parr mortality, rearing habitat availability, spring flood and summer low flows, on the freshwater production of smolts going to sea. In light of climate change and the need to protect cool-water sheltered habitats for juvenile salmon, focus is required on riverine life stages of salmon in order to increase understanding and improve populations going forward.

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[14] *Resistivity counters are used to monitor fish migration/ movements in flowing waters. The resistivity Fish Counter detects fish passage by measuring a change in the bulk resistance of the water as a fish swam across an array of electrodes that span the tube/stream. Video recordings are used to check accuracy.*

Overall, we must invest in research and monitoring to better understand the individual flow requirements of species, such as salmon, however we can no longer view species in isolation. Successful river management requires ecosystem management. Optimum flow conditions for one species maybe sub-optimum to another species, but maintaining the natural range of flow variability is essential to ensuring the ecosystem and its dependent species have the resilience to adapt and survive in the future.

APPENDICES

APPENDIX A

A1. Rivers classified as SACs primarily for Atlantic salmon and those with Atlantic salmon as a qualifying feature.

SACs classified primarily for Atlantic salmon	SACs with Atlantic salmon as a qualifying feature
Afon Gwyrfai a Llyn Cwellyn, Gwynedd	Afon Eden, Gwynedd
Afon Teifi/ River Teifi, Caerfyrddin/ Carmarthenshire; Ceredigion; Penfro/ Pembrokeshire	Dartmoor, Devon
Berriedale and Langwell, Waters Highland	Endrick Water, Stirling; West Dunbartonshire
The Berriedale and Langwell Waters on the northeast coast of Scotland.	Lough Melvin, Fermanagh
Langavat, the Western Isles / Na h-Eileanan an Iar	North Harris, Western Isles / Na h-Eileanan an Iar
Little Gruinard River, Highland	Owenkillew River, Tyrone
River Avon Dorset, Hampshire; Wiltshire	River Borgie, Highland
River Bladnoch, Dumfries and Galloway	River Camel, Cornwall
River Dee, Aberdeenshire	River Ehen, Cumbria
River Dee and Bala Lake/ Afon Dyfrdwy a Llyn Tegid, Cheshire; Ddinbych/ Denbighshire; Gwynedd; Shropshire; Sir y Fflint/ Flintshire; Wrecsam/	River Itchen, City of Southampton; Hampshire
River Derwent and Bassenthwaite Lake, Cumbria	River Moriston, Highland
River Eden, Cumbria	River Oykel, Highland
River Faughan and Tributaries	River Teith, Stirling
River Foyle and Tributaries, Tyrone	
River Naver, Highland	
River Roe and Tributaries, Londonderry	
River South Esk, Angus	
River Spey, Highland; Moray; Perthshire	
River Tay, Angus; Argyll and Bute; Perth and Kinross; Stirling	
River Thurso, Highland	
River Tweed, Northumberland; Scottish Borders	
River Usk/ Afon Wysg, Casnewydd/ Newport; Fynwy/ Monmouthshire; Powys	
River Wye/ Afon Gwy, Fynwy/ Monmouthshire; Gloucestershire; Herefordshire; Powys	

APPENDIX B

B1. River Dart Environmental Flow Component parameters, computed by the IHA divided, into six overlapping time series, 59-74, 65-80, 72-87, 79- 94, 86-01 and 93-08.

	59-74		65-80		72-87		79-87		86-01		93-08	
	Median	CoD	Median	CoD	Median	CoD	Median	CoD	Median	CoD	Median	CoD
EFC Parameters												
Extreme low peak	1.95	0.2	1.716	0.19	1.546	0.28	1.607	0.2	1.614	0.25	1.849	0.29
Extreme low duration	8	1.28	5	1.4	5	2.3	8.75	1.31	6.5	1.39	6.5	1.31
Extreme low timing	217	0.13	201.5	0.17	218.5	0.12	215.8	0.13	217	0.16	245	0.11
Extreme low freq.	4	0.75	4	1.19	3	0.92	3.5	0.57	4	0.69	4	1.25
High flow peak	25.09	0.27	25.09	0.31	22.21	0.29	23.71	0.3	28.88	0.33	25.77	0.2
High flow duration	2	0.5	2	0.5	2	0.56	2	0.5	2	0.44	1.5	0.67
High flow timing	31	0.26	4	0.18	25.5	0.17	12.25	0.19	356.8	0.21	360.8	0.2
High flow frequency	17	0.34	15	0.43	15.5	0.35	17	0.32	12	0.56	14	0.63
High flow rise rate	10	0.39	9.83	0.44	8.69	0.63	9.63	0.33	12.72	0.42	12.21	0.33
High flow fall rate	-7.09	-0.37	-6.45	-0.56	-5.74	-0.44	-6.52	-0.44	-7.76	-0.43	-6.85	-0.45
Small Flood peak	114.1	0.27	103.6	0.24	120.1	0.13	111.4	0.14	118	0.21	103.9	0.2
Small Flood duration	33.5	0.76	20.5	0.93	17	0.59	16.5	1.39	19.5	1.41	27.5	1.06
Small Flood timing	357	0.17	21.5	0.15	21	0.22	16	0.16	353	0.02	353	0.22
Small Flood freq.	0.5	2	0	0	0	0	0	0	0	0	0.5	2
Small Flood rise rate	8.7	4.37	15.85	1.91	27.87	3.08	27.99	3.02	15.91	1.21	9.291	2.1
Small Flood fall rate	-8.08	-0.68	-7.89	-0.52	-7.62	-0.36	-7.75	-1.18	-9.45	-1.5	-7.61	-1.14
Large flood peak	140.3		268		268		268		143.2		140.6	
Large flood duration	18		13		13		13		42		17	
Large flood timing	29		362		362		362		38		19	
Large flood freq.	0	0	0	0	0	0	0	0	0	0	0	0
Large flood rise rate	42.2		128.6		128.6		128.6		7.136		15.68	
Large flood fall rate	-7.89		-21.2		-21.2		-21.2		-5.06		-12.51	

B2. River Dart environmental flow component high peak (high pk), small flood (Sfld) and large flood (Lfld) parameters from the Annual Statistics Table (1959-2008)

Year	High pk	High dur	High time	High freq	High rise	High fall	Sfld pk	Sfld dur	Sfld time	Sfld freq	Sfld rise	Sfld fall	Lfld pk	Lfld dur	Lfld time	Lfld freq	Lfld rise	Lfld fall
1959	23.5	4	96.5	10	8.408	-4.283				0						0		
1960	17	3	193	17	7.519	-3.51				0						0		
1961	16.5	3	314	14	6.849	-3.632	112	36	306.5	2	18.67	-8.833	140	21	29	1	25.76	-7.471
1962	17.5	4	57	22	5.084	-3.445	115	28	21	1	6.819	-7.86				0		
1963	15	4	187	23	4.137	-2.961				0						0		
1964	15.5	3	68.5	26	5.352	-2.884				0						0		
1965	17	4	170	21	6.012	-3.456				0						0		
1966	15	2	278	17	5.048	-4.063	115.5	44.5	21.5	2	3.778	-6.713				0		
1967	18	4	58	21	5.477	-5.07				0						0		
1968	19.5	3	39.5	24	6.191	-3.068				0						0		
1969	27.5	4	29.5	24	8.625	-3.106				0						0		
1970	16	3	87	18	7.68	-3.895				0						0		
1971	23.5	3	314.5	16	8.621	-3.853	94	7	7	1	44.66	-13.99				0		
1972	17.5	2.5	77.5	26	7.51	-3.545				0						0		
1973	18	3	50	21	6.308	-4.55	120	21	341	1	15.85	-7.197				0		
1974	16.5	3	220	22	9.97	-4.115	131	49	42	1	3.156	-10.7				0		
1975	16	2.5	55.5	20	6.154	-3.939	105	26	20	1	10.87	-5.257				0		
1976	20.5	3	366	12	8.305	-6.155				0						0		
1977	18	4	73.5	16	3.451	-2.255				0						0		
1978	16	3	325	19	4.769	-3.107	120	18	54	1	27.87	-7.234				0		
1979	19	3	85	21	6.74	-3.54				0						0		
1980	16	2	314	18	5.969	-3.026				0			268	13	362	1	128.6	-21.2
1981	19.5	3.5	24	20	5.422	-3.228	106.5	13	75.5	2	60.54	-8.373				0		
1982	20.5	3.5	327.5	20	7.016	-2.73				0						0		
1983	20	3	57	19	8.393	-3.75	107	17	3	1	32.66	-6.254				0		
1984	18	3	310	12	8.341	-4.358	106	63	16	1	2.795	-3.178				0		
1985	23	5	210	15	5.024	-3.983	107	16	21	1	51.73	-6.289				0		
1986	16	2.5	181.5	22	4.904	-3.567				0						0		
1987	18	3	40	15	7.435	-3.553	122	27	323	1	9.361	-6.938				0		
1988	16	3	208.5	22	7.635	-3.248	98	31	44	1	3.826	-8.947				0		
1989	24	3	12	13	8.9	-3.584				0						0		
1990	25.5	5.5	276	8	7.088	-3.867				0			143	47	38	1	6.714	-4.688
1991	16	2	190	21	6.269	-3.293				0						0		
1992	17	3	67	23	4.574	-2.746				0						0		
1993	15	3	209	17	5.882	-3.852	99.5	17.5	364.5	2	30.96	-8.75	135	35	335	1	5.715	-8.691
1994	19	3	314	19	4.456	-3.644	92	73	353	1	5.19	-1.385				0		
1995	15	2	353	13	5.564	-3.105	112.5	15.5	353	2	22.65	-9.532				0		
1996	20	5	8	17	8.26	-2.529				0						0		
1997	12.5	3	176	16	5.646	-3.604				0						0		
1998	24.5	5	186	20	8.388	-3.922				0						0		
1999	13	2	343	21	5.594	-3.417	95	32	305	1	5.561	-4.803	140	44	19	1	3.921	-10.67
2001	15	4	80	13	7.106	-2.209				0						0		
2002	15	3	300	21	6.201	-3.948	115	48	35	1	5.76	-3.421				0		
2003	18.5	4.5	37	18	6.483	-3.334				0						0		
2004	21	3	79	23	9.973	-3.865				0						0		
2005	13.5	2.5	311.5	26	4.295	-3.125				0						0		
2006	27	5	50	11	9.423	-3.344	93	28	311	1	4.287	-8.878				0		
2007	21.5	5	202.5	18	4.632	-4.752	104	33	31.5	2	53.24	-6.275				0		
2008	19	3	33	22	6.82	-4.021	103.5	14.5	103	2	15.71	-10.11				0		
Summary										30						5		

B3. River Dart EFCs output table [large file on disc]

B4. Regime classification method protocol

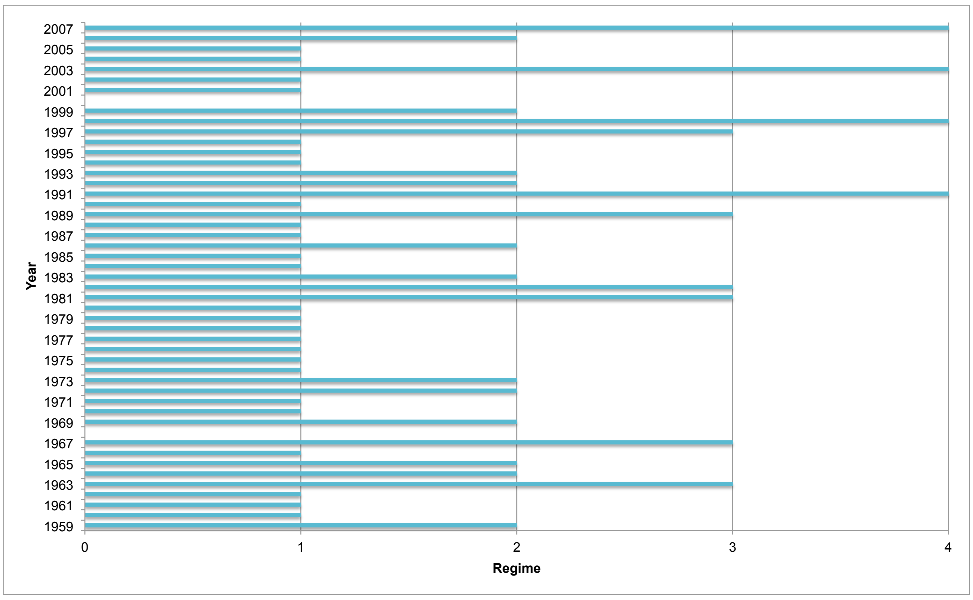
- *Daily flow data for each selected river, for the selected timeframe, was manually uploaded into SPSS PASW Statistics 12. Each column in SPSS consisted of each years daily flows averages, information obtained from the Centre for Ecology and Hydrology National River Flow Archive (http://www.ceh.ac.uk/data/nrfa/).*
- *Years with sizeable proportion's (greater than 10%) or completely missing flow records were excluded from the analysis. Otherwise, a missing data value '999999' was inputted in the gaps manually and the IHA model was used to fill the small gaps in the flow record via linear interpolation. The IHA includes a row for February 29, with the day represented by the missing data value for non-leap years (however, the IHA does not use these for interpolation).*
- *A varimax rotation principle components analysis (PCA) was when conducted on the complete daily flow data using SPSS.*
- *The resultant varimax rotation PC score summary table was then saved, transposed and inputted into a separate SPSS worksheet. An agglomerative hierarchical cluster analysis (CA) was applied to this data. The CA parameters were set to cluster the flow years into between 2-10 clusters, to find the most representative for the river. Clusters with only one year of flow data were treated as an outlier and excluded from the analysis. In this case the year was removed and the CA was run again and again until each cluster had a minimum of two years flow data.*
- *The daily flow data for the years classified in the same cluster were then amalgamated together (this involved physically changing the dates to produce an uninterrupted flow series) and inputted into the IHA model as one continuous flow series in order to obtain the IHA flow non-parametric flow parameters to describe that 'regime'.*
- *Analyses were then conducted on the resultant output.*

B5. IHA output data for River Dart regime shape 1, 2, 3 and 4; based on data between 1959-2008 (1968 and 2008 were removed as outliers).

	Regime 1		**Regime 2**		**Regime 3**		**Regime 4**	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
Parameter Group #1								
September	2.48	1.8	3.09	1.52	5.94	1.08	3.71	1.19
October	5.98	1.54	4.94	1.14	14.91	0.65	10.85	6.29
November	10.64	1.15	11.52	0.84	13.24	1.02	16.56	3.87
December	13.92	0.7	19.71	0.74	17.34	0.58	14.72	4.31
January	17.8	0.53	15.61	0.76	9.7	0.98	20.64	0.55
February	17.11	0.84	7.4	0.43	11.1	0.95	8	2.48
March	8.77	0.79	9.57	0.64	20.16	0.76	10.12	0.8
April	8.2	0.69	8.94	0.37	5.65	0.63	6.43	1.74
May	5.24	0.73	7.82	0.43	7.2	0.8	5.56	0.63
June	3.12	0.58	4.86	0.55	4.51	1.17	5.34	0.65
July	2.1	0.61	3.02	0.49	3.11	0.4	]	1.31
August	2.83	1.07	2.88	0.68	3.17	0.87	2.95	1.44
Parameter Group #2								
1-day minimum	1.18	0.43	1.39	0.48	1.19	1.04	1.71	0.33
3-day minimum	1.19	0.43	1.46	0.43	1.2	1.07	1.74	0.34
7-day minimum	1.39	0.45	1.48	0.46	1.22	1.1	1.83	0.35
30-day minimum	1.74	0.43	1.98	0.65	2.56	0.67	2.63	0.56
90-day minimum	3.59	0.44	5.21	0.62	4.23	0.59	4.9	0.55
1-day maximum	98.68	0.5	109.3	0.36	89.58	0.11	92.47	0.14
3-day maximum	57.96	0.62	73.26	0.24	55.49	0.55	76.31	0.27
7-day maximum	45.3	0.48	53.31	0.3	46.91	0.43	55.24	0.59
30-day maximum	32.18	0.28	34.77	0.31	29.57	0.23	35.88	1.28
90-day maximum	23.48	0.29	20.66	0.27	20.8	0.16	25.8	2.11
Number of zero days	0	0	0	0	0	0	0	0
Base flow index	0.12	0.46	0.13	0.32	0.11	1.01	0.14	0.69
Parameter Group #3								
Date of minimum	233	0.12	240.5	0.14	244	0.08	230.5	0.33
Date of maximum	24	0.09	359.5	0.1	355	0.22	33.5	0.33
Parameter Group #4								
Low pulse count	7	0.57	7.5	0.6	7	0.86	7	0.32
Low pulse duration	7	0.64	5	1.33	4	0.88	5.5	1.27
High pulse count	16	0.28	17.5	0.14	15	0.47	16	0.69
High pulse duration	2	0.5	2	0	2	0.25	1.5	0.67
Low Pulse Threshold	3.17		3.79		3.88		4.16	
High Pulse Threshold	14.44		13.24		16.62		18.77	
Parameter Group #5								
Rise rate	1.62	0.66	1.78	0.7	1.7	0.57	2.02	0.63
Fall rate	-0.57	-0.44	-0.49	-0.54	-0.53	-0.41	-0.55	-0.22
Number of reversals	133	0.17	127.5	0.14	132	0.2	125	0.43
EFC Low flows								
September Low Flow	3.55	0.98	4.22	0.63	6.26	0.4	4.51	0.5
October Low Flow	5.72	0.86	5.47	0.37	9.64	0.65	5.7	0.68
November Low Flow	8.03	0.68	7.47	0.49	9.53	0.48	11.09	0.72
December Low Flow	9.67	0.4	10.12	0.12	9.98	0.47	10.58	0.54
January Low Flow	10.9	0.41	9.17	0.44	8.54	0.73	11.69	0.2
February Low Flow	9.74	0.29	6.21	0.55	7.43	0.64	6.51	0.82
March Low Flow	7.32	0.7	7.2	0.52	9.9	0.68	8.29	0.35
April Low Flow	6.74	0.46	8.18	0.29	5.55	0.65	5.64	1.63
May Low Flow	4.93	0.71	6.76	0.47	5.21	0.73	5.53	0.58
June Low Flow	3.12	0.64	4.63	0.54	5.37	0.54	5.23	0.62
July Low Flow	2.53	0.41	3.21	0.25	3.46	0.47	6.5	1.02
August Low Flow	3.01	0.76	3.38	0.63	3.37	0.58	3.26	1.07
EFC Parameters								
Extreme low peak	1.45	0.28	1.68	0.22	1.89	0.36	2	0.19
Extreme low duration	7.75	1.48	11	0.73	8.5	3.59	8.5	1.24
Extreme low timing	211.3	0.14	235	0.1	225	0.12	224	0.33
Extreme low freq.	3	1.17	2	1.38	2	2	3	0.5
High flow peak	21.84	0.26	23.34	0.27	26.41	0.44	26.3	0.3
High flow duration	2	0.63	2	0	2	0.25	1.5	0.67
High flow timing	3.5	0.23	67.5	0.28	326	0.32	54	0.43
High flow frequency	16	0.34	17	0.18	14	0.5	15.5	0.68
High flow rise rate	9.49	0.4	9.41	0.46	10.09	0.64	12.49	0.38
High flow fall rate	-5.47	-0.31	-6.48	-0.33	-7.36	-0.15	-9.85	-0.46
Small Flood peak	115.4	0.12	121.5	0.13	91.95	0.11	95.39	
Small Flood duration	18	0.61	25.5	0.64	20	0.59	17	
Small Flood timing	21	0.08	347	0.06	365	0.19	305	
Small Flood freq.	0	0	0.5	2	1	1	0	0
Small Flood rise rate	13.49	1.84	9.37	3.33	14.4	2.05	6.98	
Small Flood fall rate	-8.07	-0.42	-7.67	-0.99	-8.45	-0.75	-11.05	
Large flood peak	205.6	0.61	140.6		111.4		97.2	
Large flood duration	29.5	1.12	30		9		30	
Large flood timing	17	0.11	19		81		65	
Large flood freq.	0	0	0	0	0	0	0	0
Large flood rise rate	67.67	1.8	7.02		98.45		3.39	
Large flood fall rate	-13.01	-1.26	-10.67		-10.66		-13.18	
EFC low flow threshold:								
EFC high flow threshold:		14.44		13.24		16.62		18.77
EFC extreme low flow threshold:		1.8		2.19		2.24		2.49
EFC small flood minimum peak flow:		98.68		109.3		89.58		92.47
EFC large flood minimum peak flow:		141.5		135.8		111.4		97.2

B6. Spearmans correlation for all IHA parameters using southwest England flow database, [large table on disc above]

B7. Time line of when the four different regimes on the River Dart occurred through 1959-2007 (1968 and 2008 were removed as outliers).



APPENDIX C

C1. Assessment of the flow record length and flow modifications of each salmon river within each region, to access suitability for use in this study

Name of River	Station Name (Number)	Impact	Length of flow record	Years missing	Suitable?
South West Rivers					
Avon (Hants)	East Mills (43003)	Runoff is natural to within 10% at the 95 percentile flow.	1965- 2009		Yes (chalk stream)
Piddle	Baggs Mill (44002)	Complex water meadow system 2-3km upstream can cause short-term fluctuations in river flow. Major groundwater abstractions. Runoff influenced by groundwater abstraction and/or recharge.	1964- 2009		No (sign. modified flow)
Frome	East Stoke Total (44001)	Runoff natural to within 10% at the 95 percentile flow. No direct abstractions from river, but substantial groundwater abstractions from the chalk.	1965-2009	2000, 2006	Yes (chalk stream)
Axe	Whitford (45004)	Flows affected by moderate surface and groundwater abstractions, effluent returns and groundwater recharge.	1965-2009		Yes
Exe	Thorverton (45001)	Low flows significantly affected by Wimbleball Reservoir. Runoff reduced by public water supply abstraction, and influenced by groundwater, industrial and agricultural abstraction and recharge, and effluent returns.	1956-2009		No (sign. modified flow)
Teign	Preston (46002)	Four reservoirs and water reclamation works have a minor affect on low flow. Runoff reduced by public water supply abstraction and increased by effluent returns.	1956-2005		
Dart	Austins Bridge (46003)	Regulation of surface water and groundwater. Venford Reservoir operation and exports via the Devonport Leat effect low flows.	1959-2009	2000	Yes
Avon (Devon)	Loddiswell (46008)	Reservoir in catchment affects runoff. Some regulation from surface and groundwater abstractions.	1971-2009	Between 81-90	No (limited flow records)
Plym	Carn Wood (47011)	Burrator Reservoir influences flows. Runoff reduced by public water supply abstraction, industrial and agricultural abstraction and/or recharge and runoff increased by effluent returns.	1971-2009	Between 81-90	No (limited flow records)
Tavy	Lopwell (47003)	Runoff reduced by public water supply abstraction, and influenced by groundwater, industrial and agricultural abstraction and recharge, and effluent returns. Regulation for hydro-electric power.	1957-1980	Between 1960-1973	No (limited flow records)
Tamar	Gunnislake (47001)	Roadford Reservoir may have significant effect on low flows from 1989. Abstraction for public water supply, industry and agriculture; some effluent returns.	1957-2009	-	Yes
Lynher	Pillation Mill (47004)	Imports from Sibleyback Reservoir exceed direct public water supply abstraction, moderate net affect at low flows.	1963-2009		Yes
Fowey	Restormel (48011)	Substantial modifications to flow from associated public water supply exports, Colliford and Sibleyback reservoirs.	1963-2009	2001	No (sign. modified flow)
Camel	Denby (49001)	Crowdy Reservoir affects runoff and flows modified by public water supply abstraction and sewage effluent returns from Bodmin.	1965-2009		Yes
Taw	Umberleigh (50001)	Significant modification to flows owing to public water supply abstraction.	1958-2009		No (sign. modified flow)
Torridge	Torrington (50002)	Moderate modification to flow from Meldon Reservoir. Runoff also affected by abstraction for public water supply	1964-2009	2000	Yes
Yealm	Puslinch (47007)	Moderate influence from public water supply and industrial/agricultural abstractions and imports.	1965-2006	2001, 2002	No (limited flow records)
North West Rivers					
Ribble	Samlesbury (71001)	Small reservoirs u/s has no significant effect.	1961- 2009	1981	Yes
Wyre	Scorton Weir -72016	Lune transfer (see 72002) and gravel workings (adjacent) affect high flow regime. Siltation of stilling well affects low flow measurement; this was a serious problem in 2009.	1967- 2009	1997, 1998	No (sign. modified flow)
Lune	Killington New Bridge -72005	Natural to within 10% at the 95 percentile flow.	1969-2009	1975, 1979, 1980, 2005	Yes
Kent	Sedgwick (73005)	Runoff reduced by industrial and/or agricultural abstraction. Natural to within 10% at the 95 percentile flow.	1969-2009		Yes
Leven	Newby Bridge FMS (73010)	Just d/s of Windermere: highly regulated, compensation flows (occasional very low flows; major abstractions for public water supply from Windermere.	1967-2009		No (sign. modified flow)
Crake	Low Nibthwaite (73002)	Reservoir(s) in catchment affect runoff. Runoff reduced by public water supply abstraction. Lowest flows unreliable.	1963-2005	1968, 1999	No (sign. modified flow)
Duddon	Duddon Hall (74001)	Abstractions for Barrow PWS from Ulpha pumping station u/s. Variable compensation flow from Seathwaite Tarn	1969-2009	1999, 2004	No (sign. modified flow)
Esk (Cumbria)	Cropple How (74007)	Natural to within 10% at the 95 percentile flow	1976-2009	1995, 2004	No (limited flow records)
Irt	Galessyke (74002)	1km d/s of Wast Water outlet which is important for PWS and major industrial purposes, greatly affecting low flows.	1968-2009	1990, 2003, 2006	No (sign. modified flow)
Ehen	Braystones(74005)	Bypassed in extreme floods. Low flows dominated by compensation from Ennerdale Water; major exports. Considerable uncertainty over the daily mean flows for the flood of 19-20/11/2009.	1974-2009	1997, 2006, 2007	No (sign. modified flow)
Derwent	Ouse Bridge (75003)	Derwent Water, Bassenthwaite Lake and Thirlmere Reservoir moderate flood discharges.	1968-2009	1976	No (sign. modified flow)
Ellen	Bullgill (75017)	Minor abstractions in headwaters and small discharges of sewage and industrial effluent; very limited net impact on runoff.	1976-2009	1977, 1978, 1980	No (limited flow records)
Eden	Kirkby Stephen (76014)	N: Natural to within 10% at the 95 percentile flow.	1972-2009	1978, 1979, 1980, 1989	No (limited flow records)

C1. Continued.

North East Rivers					
Aln	Hawkhill (22004)	Station discontinued 1980	1969-1980		No
Coquet	Morwick (22001)	Responsive natural regime except for annual flush and drain of dam u/s of gauge on Duke of Northumberland estate. Natural to within 10% at the 95 percentile flow.	1967-2009	2006	Yes
Tyne	Bywell (23001)	Riding Mill abstraction point is 500m u/s. Some export of water, and regime influenced by pulsed hydropower releases from Kielder, but limited impact on annual runoff.	1956-2009		No (sign. modified flow)
Wear	Witton Park (24008)	Catchment contains three reservoirs (including Burnhope), commanding 45 km2; net export of water. Transfers from Kielder (Tyne catchment) in drought years	1974-2009	1977, 1979, 1982, 2003	No (sign. modified flow)
Tee	Broken Scar (25001)	Significant export of water from direct supply reservoirs (six reservoirs totalling 22.1% of catchment) and u/s abstraction	1957-2009	1967, 1987, 1992	No (sign. modified flow)
Esk (Yorkshire)	Sleights (27050)	Natural to within 10% at the 95 percentile flow.	1971-1997	1981, 1982, 1986	No (limited flow records)
Ouse (Yorkshire)	Skelton (27009)	Pre 1980 records less reliable at epescially at low flows. Public water supply abstraction upstream impacts low flows and some artificial groundwater augmentation.	1969-2005	2003, 2004, 2005, 2006, 2007, 2008	No (sign. modified flow)
Welsh Rivers					
Wye	Cefn Brwyn (55002)	Natural and very responsive flow regime, however very small catchment area.	1951- 2005		No
Usk	Llandetty -56004	Cray and Usk Reservoirs in catchment affect runoff	1965- 1980		No (limited flow records)
Taff	Pontypridd (57005)	Small impounding reservoir in upper catchment. Some groundwater abstractions and effluent returns in valleys.	1970-2009		No (sign. modified flow)
Ogmore	Brynmenyn (58005)	All flows contained. Effluent discharge to river upstream	1970-2009		No (sign. modified flow)
Afan	Marcroft Weir (58012)	Runoff reduced by public water supply. Minewater discharges in upper catchment affect flows.	1978-2009	1980, 1983, 1989, 2003	No (limited flow records)
Neath	Resolven (58002)	Public water supply reservoir in upper catchment. Industrial abstractions and effluent returns.	1963-2009		No (sign. modified flow)
Tawe	Ynystanglws (59001)	Runoff reduced by industrial abstraction.	1957-2009	1972, 1973, 1974	No (sign. modified flow)
Loughor	Tir-y-dail (59002)	Public water supply abstraction from main spring source. Groundwater and industrial abstractions and effluent returns.	1967-2009		No (sign. modified flow)
Tywi	Nantgaredig (60010)	Llyn Brianne in headwaters regulates flow down to major abstraction upstream of station	1958-2009	1978, 2004, 2006	No (sign. modified flow)
Eastern Cleddau	Canaston Bridge (61002)	Impounding reservoir for public water supply in upper catchment regulates the river down to the gauging station.	1960-2009		No (sign. modified flow)
Western Cleddau	Prendergast Mill (61001)	Generally natural, some effects of abstractions and effluent returns.	1965-2009		Yes
Nevern		No gauging station			No
Teifi	Glan Teifi (62001)	Public water supply impounding reservoirs in upland and minor agricultural abstractions; Tregaron bog has partial effect on flows. However, a sensibly natural regime.	1959-2009	1970	Yes
Aeron		No gauging station			No
Ystwyth	Pont Llolwyn (63001)	Natural to within 10% at the 95 percentile flow. However, post-1985 flows below 3 cumecs are unreliable due to blockage of lower inlet pipe, and post 1998 unreliable due to channel re-graded and weir refurbished.	1963-2009		No
Rheidol	Llanbadarn Fawr (63002)	Public water supply abstractions from river gravels. Impounding reservoir for hydro-electric station at Cwm Rheidol have major effects on flows.	1965-2009	1984-1995	No (sign. modified flow)
Dyfi	Dyfi Bridge (64001)	Natural to within 10% at the 95 percentile flow.	1962-2009	1967, 1971, 1972, 1973, 1974, 1975	Yes
Dysynni	Pont-y-Garth (64002)	Natural to within 10% at the 95 percentile flow.	1966-2009	1988, 1997	Yes
Mawddach	Tyddyn Gwlady (64010)	Natural to within 10% at the 95 percentile flow.	1994-2009		No (limited flow records)
Artro		No gauging station			No
Dwyryd		No gauging station			No
Glaslyn	Beddgelert (65001)	Reservoir in catchment affects runoff and regulation for hydro-electric power.	1961-2009		No (sign. modified flow)
Dwyfawr	Garndolbenmaen (65007)	Station built as the control point for the Cwmystradllyn Reservoir regulation scheme.	1975-2009	2003	No (sign. modified flow)
Llyfni	Pont Y Cim (65015)	Acceptable quality at low-medium flows, but significant problems when attempting to calibrate weir in high flow conditions.	1995-2009		No (limited flow records)
Gwyrfai	Bontnewydd (65004)	Significant abstraction from Llyn Cwellyn reservoir u/s.	1970-2005		No
Seiont	Peblig Mill (65006)	Regulation for hydro-electric power	1976-2009	1989, 1990	No
Ogwen		No gauging station			No
Conwy	Cwm Llanerch (66011)	Largely natural flow regime, runoff reduced by public water supply abstraction	1969-2009		Yes
Clwyd	Pont-y-Cambwll (66001)	Low flows augmented using groundwater. Flood discharges affected by floodplain storage in Vale of Clwyd upstream	1960-2009		No (sign. modified flow)
Dee	Manley Hall (67015)	Low flows maintained by reservoirs releases.	1937-2009		No

C2: Classification of number of years in each of the national level regime types for each of the 17 rivers listed (1977- 2009, excluding 1980, 1992, 2000, 2002, 2003 and 2006).

		Regime number						
		1	**2**	**3**	**4**	**5**	**6**	**7**
Wales	**Teifi**	10	6	4	3	1	1	1
	Dysynni	8	7	4	4	1	1	1
	Dyfi	8	7	4	4	1	1	1
	Cleddau	10	6	4	3	1	1	1
	Conwy	8	7	4	4	1	1	1
South West	**Tamar**	10	6	4	3	1	1	1
	Lynher	10	6	4	3	1	1	1
	Frome	20	1	5	0	0	0	0
	Dart	10	6	4	3	1	1	1
	Camel	10	6	4	3	1	1	1
	Axe	10	6	4	3	1	1	1
North	**Tweed**	10	6	4	3	1	1	1
	Tyne	12	4	4	3	1	1	1
	Ribble	8	7	4	4	1	1	1
	Lune	7	7	4	5	1	1	1
	Kent	8	7	4	4	1	1	1
	Coquet	12	5	3	2	2	1	1
Sum		171	100	68	54	17	16	16

C3. Number of rivers which overlap for 1 day maximum, 1 day minimum, Q95 and high flow frequency based on the top 15 years for each parameter in the southwest.

	6 overlap	**5 overlap**	**4 overlap**	**3 overlap**	**2 overlap**	**No overlap**
1 day Maximum	2 (80,95)	3 (66,90,93)	6 (74,81,87,99, 03,08)	2 (68,69)	10 (72,73,75,78, 82, 86,88,96,07,0 9)	13 (65,70,71,79,83,85,89,94,97,98,01, 02,07)
1 day Minimum	4 (76,77,89,90)	6 (75,79,84,85, 95,96	1 -91	3 (74,83,02)	5 (73,77,78,82, 07)	13 (65,70,71,72,80,92,93,94,97,98,01, 03,04
Q95	4 (76,84,89,90)	5 (75,77,78,95 96)	2 (71,01)	4 (81,83,03,05)	5 (72,73,82,87, 91)	11 (65,69,70,74,80,86,88,92,97,99,04)
High flow frequency	0	6 (68,69,72,81, 88,04)	5 (67,75,83,91, 05)	8 (71,74,86,96, 98,02,08,09)	4 (73,79,92,99)	8 (66,68,80,82,85,92,97,02)

C4. Number of rivers which overlap for 1 day maximum, 1 day minimum, Q95 and high flow frequency based on the top 20 years for each parameter for the southwest.

	6 overlap	**5 overlap**	**4 overlap**	**3 overlap**	**2 overlap**	**No overlap**
1 day Maximum	3 (66,95,99)	6 (69,80,90,93,07,08)	8 (68,72,74,75,81,87,03,09)	5 (73,82,88,98 02)	6 (71,78,83,84,86,96)	13 (65,66,70,77,79,80,88,89,94,97,99,01,04)
1 day Minimum	6 (76,77,89,90,91,96)	5 (75,84,85,95,97)	5 (73,79,83,02,07)	5 (70,74,78,82,99)	7 (71,72,80,81,87,88,04)	10 (65,69,79,92,93,98,01,03,05,06)
Q95	4 (76,84,89,90)	5 (75,77,78,95,96)	4 (65,71,82,01)	10 (66,67,70,72,74,83,87,92,03,05)	8 (68,73,79,80,81,88,91,02)	9 (69,81,86,93,97,98,99,04,07)
High flow frequency	3 (67,68,88)	9 (69,72,74,75,81,83,93,98,04)	7 (86,91,99,02,05,08,09)	3 (71,92,96)	7 (73,79,80,82,87,94,07)	6 (66,70,77,85,89,97)

C5. Similarity index for years 1966 to 2009 (excluding 2000) for the Rivers Dart, Axe, Lynher, Tamar, Frome and Camel.

YEAR	1 DAY MAX	HIGH FLOW FREQ	Q95	1 DAY MIN
1966	13	30	0	0
1967	0	2	0	0
1968	5	2	0	0
1969	6	8	0	0
1970	0	0	0	0
1971	0	6	2	0
1972	0	18	7	2
1973	2	2	2	2
1974	9	4	2	2
1975	2	4	2	4
1976	0	0	8	4
1977	0	0	37	42
1978	2	0	6	37
1979	0	2	10	0
1980	32	2	0	8
1981	6	15	0	0
1982	4	2	0	0
1983	2	0	4	0
1984	0	0	4	4
1985	0	2	30	10
1986	4	11	0	6
1987	6	0	0	0
1988	2	8	2	0
1989	0	0	0	0
1990	15	0	17	10
1991	0	4	15	17
1992	0	2	2	2
1993	13	0	2	2
1994	2	0	0	0
1995	10	0	0	0
1996	4	2	10	8
1997	7	0	6	8
1998	2	4	2	4
1999	8	0	0	0
2000	0	0	2	0
2001	0	0	0	0
2002	2	5	6	0
2003	11	0	0	2
2004	0	10	2	2
2005	0	11	0	2
2006	0	0	0	0
2007	0	0	0	0
2008	2	6	0	0
2009	2	16	0	0
2010	0	0	0	0

C6. Similarity index for years 1970 to 2009 (excluding 1975, 1979, 1980, 1981, 1997, 2002, 2003, 2005 and 2006) for the rivers Lune, Ribble, Kent, Coquet, Tweed and Tyne.

Year	1 day Max	High flow frequency	1 day min	Q95
1970	0	2	20	2
1971	2	4	2	9
1972	0	13	0	20
1973	0	0	16	11
1974	2	0	8	8
1976	0	0	25	15
1977	0	6	10	2
1978	7	9	4	8
1982	18	0	2	2
1983	5	13	10	11
1984	0	0	22	25
1985	4	11	4	0
1986	13	10	0	0
1987	2	6	0	0
1988	2	13	0	2
1989	4	4	10	20
1990	9	0	4	2
1991	8	0	2	8
1992	15	2	2	0
1993	6	6	0	0
1994	2	0	2	0
1995	20	0	15	17
1996	0	0	18	12
1998	0	16	0	0
1999	12	10	0	0
2000	8	14	0	0
2001	12	6	5	0
2004	6	0	2	0
2007	4	18	0	0
2008	4	4	0	0
2009	9	13	0	0

C7. Similarity index for years 1975 to 2009 (excluding 1988 and 1997) for the Rivers Teifi, Dyfi, Conwy, Western Cleddau, and Dysynni

Year	1 day Max	High flow frequency	1 day Min	Q95
1975	0	4	9	8
1976	0	0	18	23
1977	0	2	18	2
1978	0	7	2	0
1979	11	9	2	2
1980	4	4	6	6
1981	20	0	0	4
1982	4	11	4	4
1983	2	2	8	6
1984	2	0	15	35
1985	0	25	4	0
1986	2	4	0	0
1987	4	0	0	2
1989	4	4	6	15
1990	9	0	6	8
1991	0	0	4	0
1992	0	4	0	0
1993	14	2	0	0
1994	0	4	0	0
1995	8	0	6	15
1996	0	0	8	6
1998	9	9	7	0
1999	2	4	0	0
2000	0	13	0	0
2001	4	2	0	0
2002	6	0	0	0
2003	4	4	5	6
2004	8	2	2	0
2005	9	0	0	0
2006	14	4	16	8
2007	2	6	0	0
2008	8	13	2	0
2009	0	11	0	0

APPENDIX D

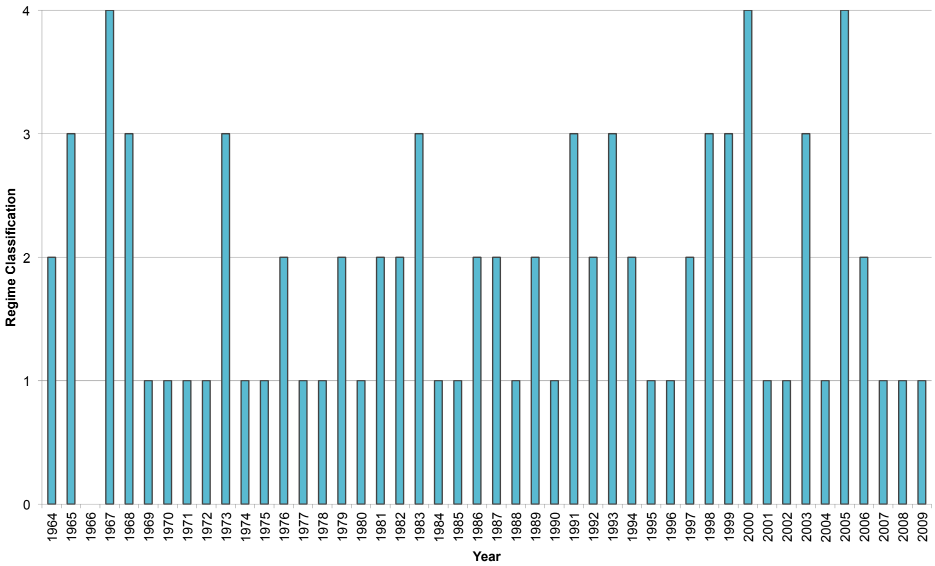
D1. Selected IHA parameters output data from the six southwest rivers1966-2009 (excluding 1992, 2000 and 2006).

	Regime 1		**Regime 2**		**Regime 3**		**Regime 4**		**Regime 5**		**Regime 6**	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	2.11	0.88	2.24	0.96	1.9	1.22	2.76	1.2	1.78	1.94	5.07	0.93
October	2.92	1.15	5.53	1.33	8.05	1.02	2.89	1.06	8.04	1.03	5.07	1
November	5.28	1.55	6.54	1.25	8.04	0.96	13.68	0.94	7.04	0.9	5.08	1.03
December	7.81	1.04	10.26	1.09	7.43	0.63	10.73	1.07	6.28	1.32	5.07	0.9
January	11.2	0.89	9.98	1.05	6.42	1.3	6.6	1.27	6.76	1.17	7.98	2.41
February	12	0.85	5.24	0.89	6.26	1.33	8.54	0.81	8.94	1.3	4.92	1.69
March	7.22	0.97	8.11	1.09	4.72	1.35	5.01	0.97	6.31	1.54	5.8	2.27
April	5.16	0.92	5.39	1.02	3.69	1.27	4.46	0.65	5.27	1.29	3.81	1.88
May	3.91	0.97	3.99	1.01	3.19	1.62	4.15	0.55	2.27	0.63	3.8	1.76
June	2.74	0.87	3.38	1.17	2.03	1.57	3.35	0.8	2.74	1.19	2.67	1.34
July	2.32	0.89	2.41	1.14	1.46	1.46	3.31	0.56	2.54	0.81	5.12	1.56
August	2.28	1.02	1.63	0.99	1.33	1.63	2.7	0.57	1.76	0.78	8.4	2.21
1-day minimum	1.26	0.92	1.11	0.59	0.61	0.92	1.6	0.5	1.26	0.62	1.78	0.66
1-day maximum	53.33	1.31	58.57	1.45	53.73	1.13	55.13	1.3	58.75	1.15	80.9	0.97
High flow peak	15.56	0.3	15.89	0.29	13.58	0.23	14.46	0.35	15.89	0.44	23.58	0.53
High flow timing	24	0.18	18.5	0.26	337.3	0.21	319	0.47	332.5	0.27	300.5	0.41
High flow frequency	9	0.67	10.5	0.67	8.5	0.56	9	0.61	12	0.48	16	0.56
Large flood peak	218.4	0.41	248	0.14	222.9		254.2		188		196.9	
Large flood timing	363	0.13	355	0.36	309		324		265		15	

D2. Selected IHA parameters output data of the four regime types on the River Lynher, 1964-2009 (1966 was removed).

	Regime 1		**Regime 2**		**Regime 3**		**Regime 4**	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	0.846	2.186	0.9848	2.501	1.47	1.839	3.07	2.501
October	1.794	1.906	3.23	1.554	2.87	1.211	9.449	0.2447
November	4.96	0.7001	5.511	0.9594	3.964	1.112	9.312	0.7455
January	7.488	0.5657	3.434	0.927	8.719	0.3624	5.34	0.4305
March	3.994	0.492	4.892	0.8239	2.945	0.8053	3.503	0.9894
May	2.016	0.8209	1.856	0.4778	2.727	0.5779	2.53	0.5138
July	1.075	1.004	1.03	0.3791	2.427	1.129	0.976	0.8852
1-day minimum	0.579	0.6554	0.574	0.6633	0.824	0.5291	0.708	0.4082
1-day maximum	31.27	0.3775	33.84	0.628	37.76	0.371	48.3	0.8795
High flow peak	6	0.5	5.5	0.3636	6	0.25	8	0.25
High flow timing	21	0.3019	10.5	0.1206	53	0.4399	41	0.1817
High flow frequency	10	0.55	10	0.55	12	0.2917	10	0.7
Large flood peak	48.5	0.1443	62					
Large flood timing	29.5	0.0847	362					

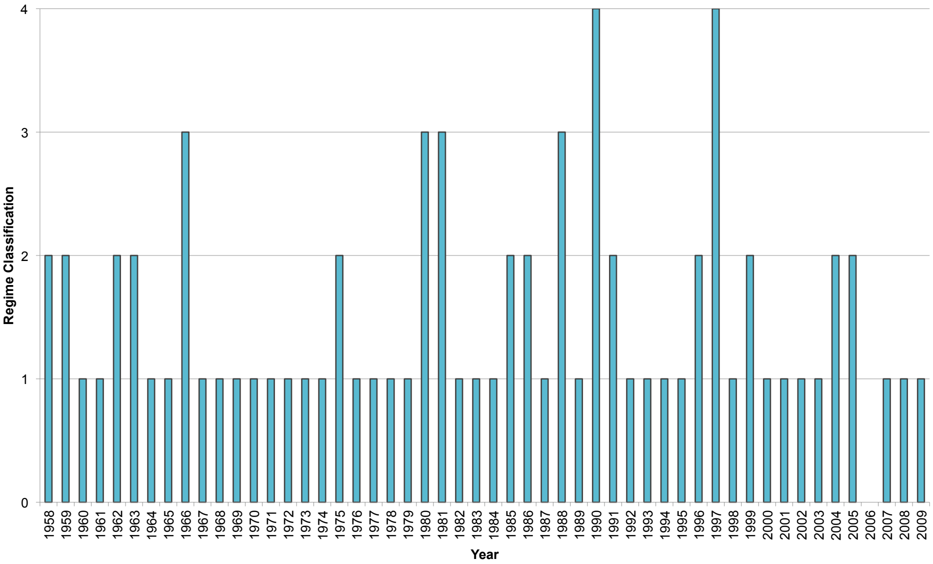
D3. Time line of when the three different regimes on the River Lynher occurred through 1964-2009 (1966 was removed).



D4. Selected IHA parameters output data of the four regime types on the River Tamar, 1959-2009 (where 2006 was removed).

	Regime 1		**Regime 2**		**Regime 3**		**Regime 4**	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	3.989	2.145	3.813	1.943	8.15	0.5731	6.877	9.652
October	10.95	2.128	6.933	1.244	43.97	1.774	10.69	1.589
November	26.47	1.144	20.7	2.003	25.89	3.024	24.91	1.286
January	36.19	0.5759	37.13	0.4296	29.85	0.9578	36.94	1.676
March	18.29	0.5873	13.71	0.9787	21.43	1.186	11.66	4.956
May	7.8	0.7997	7.501	0.4075	11.39	1.537	5.339	12.24
July	3.472	1.317	3.602	1.24	6.225	0.7806	4.833	13.31
1-day minimum	2.197	0.5626	2.343	0.525	2.148	0.4301	2.613	0.7398
1-day maximum	197.9	0.3919	178.5	0.5744	231.5	0.2665	150.2	0.3695
High flow peak	56.69	0.3569	53.08	0.4105	80.63	0.5683	88.9	0.06328
High flow timing	43	0.2411	80	0.1055	339.5	0.4167	364	0.1844
High flow frequency	12	0.4583	11	0.2727	12.5	0.44	4	1.25
Large flood peak	335.9	0.4948	321.6		256.6		188.7	
Large flood timing	339	0.1585	331		355		45	

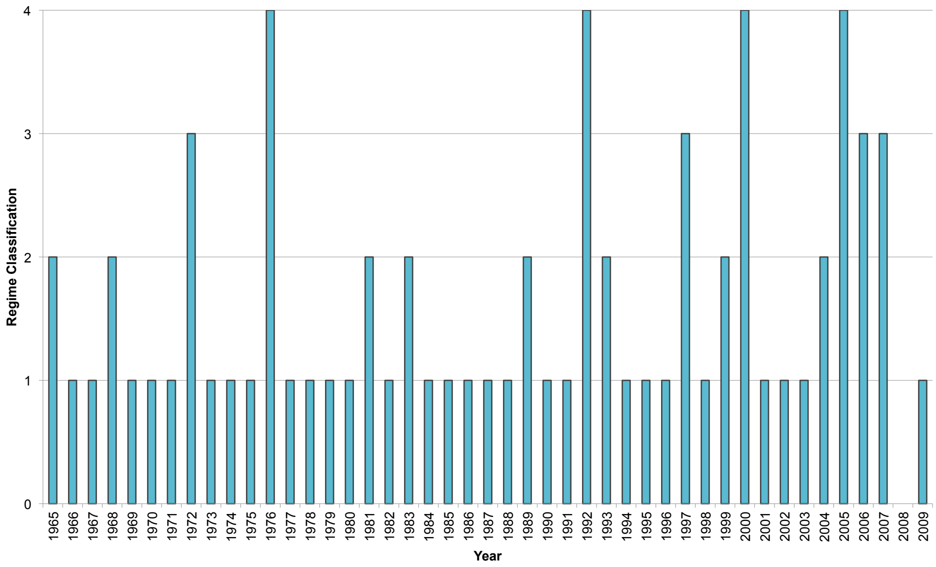
D5. Time line of when the four different regimes on the River Tamar from 1958-2009 (where 2006 was removed).



D6. Selected IHA parameters output data of the four regime types on the River Axe, 1965-2009 (where 2008 was removed).

	Regime 1		**Regime 2**		**Regime 3**		**Regime 4**	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	1.563	0.3376	2.149	0.5969	1.683	0.7595	1.85	0.8581
October	2.186	1.089	3.314	0.8114	2.639	0.4812	3.948	2.018
November	4.783	0.8981	3.285	0.577	3.19	1.545	5.844	1.09
January	7.432	0.5151	5.962	0.5519	5.175	1.123	3.452	0.8191
March	4.482	0.5945	3.835	0.8746	3.975	0.2254	2.604	0.4661
May	2.471	0.447	2.738	0.9399	2.504	0.2634	2.015	1.035
July	1.646	0.2838	1.695	0.2817	1.798	0.792	1.35	0.885
1-day minimum	1.145	0.2414	1.168	0.2572	1.157	0.245	0.858	0.8587
1-day maximum	59.98	0.4774	57.47	0.5209	75.89	0.3587	70.14	0.8671
High flow peak	11.81	0.2945	11.79	0.6651	13.78	0.418	12.81	0.406
High flow timing	25.5	0.1718	14	0.252	83	0.4484	34.25	0.3152
High flow frequency	14	0.2679	16.5	0.5	13.5	0.1852	15.5	0.5968
Large flood peak	118.1	0.4506	80.8		92.49		91.85	
Large flood timing	18	0.1202	359		219		366	

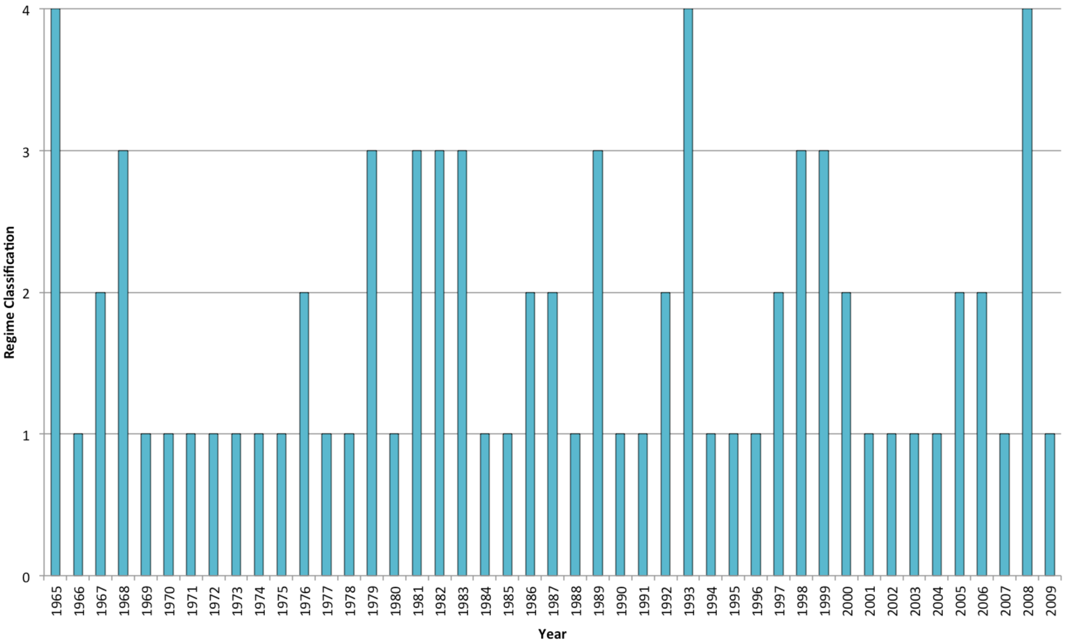
D7. Time line of when the four different regimes on the River Axe occurred through 1965-2009 (2008 was removed).



D8. Selected IHA parameters output data of the four regime types on the River Camel, 1965-2009.

	Regime 1		Regime 2		Regime 3		Regime 4	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	1.465	1.567	3.072	1.103	2.02	0.9765	6.222	0.6501
October	2.337	1.734	8.232	0.841	2.692	3.09	8.886	0.6562
November	6.079	1.246	11.51	0.405	7.216	0.8535	4.789	1.094
January	10.63	0.4768	6.697	0.8254	8.979	0.6106	12.18	0.5206
March	5.641	0.5637	5.018	0.6004	6.023	1.268	5.145	0.7098
May	2.599	0.6191	2.914	0.7899	3.689	0.9295	3.799	0.3277
July	1.524	1.083	1.543	0.8556	1.646	1.671	5.508	0.3667
1-day minimum	0.729	0.4136	1.039	0.6316	1.016	0.4636	1.6	0.4413
1-day maximum	36.95	0.6265	49.31	0.4167	44.39	0.5751	53.65	2.124
High flow peak	8.5	0.3235	9	0.5139	9	0.1667	10	0.3
High flow timing	332	0.4262	37.75	0.1865	85	0.2568	181	0.3634
High flow frequency	15	0.3667	14.5	0.5172	14	0.3571	17	0.5294
Large flood peak	63.5	0.1417	78					
Large flood timing	29.5	0.0847	286					

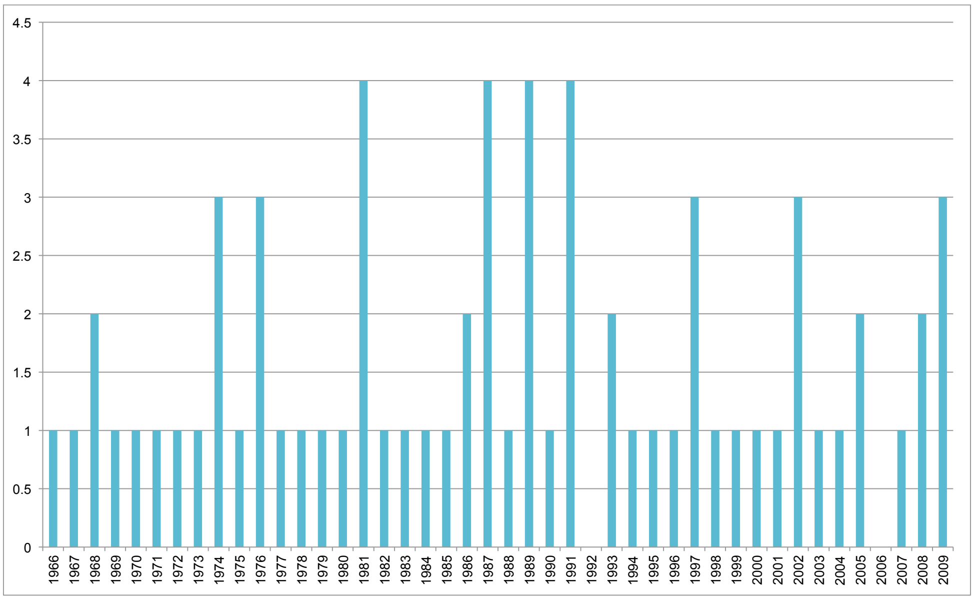
D9. Time line of when the four different regimes on the River Camel occurred through 1965-2009.



D10. Selected IHA parameters output data of the four regime types on the River Frome, 1966-2009 (1992, 1994, 2000 and 2006 were removed).

	Regime 1		**Regime 2**		**Regime 3**		**Regime 4**	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	2.842	0.3424	4.273	1.107	2.542	1.057	3.089	1.416
October	3.067	0.5348	7.717	0.4587	5.187	0.9	5.261	0.8906
November	4.125	0.6999	8.336	0.5452	9.03	1.223	5.562	0.6304
January	10.15	0.3431	9.028	0.2411	3.837	1.068	6.189	0.769
March	9.725	0.4284	5.749	0.3562	7.982	0.4047	8.935	0.722
May	5.792	0.3757	3.907	0.1408	4.176	0.3192	5.28	0.4743
July	3.51	0.3047	2.535	0.5776	3.197	0.4762	3.352	0.7469
1-day minimum	2.374	0.3309	2.197	0.2482	1.792	0.6632	1.742	0.9796
1-day maximum	20.53	0.1219	22.37	0.1974	19.84	0.1929	19.56	0.372
High flow peak	9.5	0.1711	9.5	0.1842	8	0.25	8.25	0.1061
High flow timing	352.3	0.1834	344.5	0.2203	324.5	0.4385	327.8	0.3733
High flow frequency	8	0.5313	10	0.375	7	0.8571	11	0.7727
Large flood peak	23	0	26					
Large flood timing	46	0	2					

D11. Time line of when the three different regimes on the River Frome occurred through 1966-2009 (1992, 2000 and 2006 were removed).



APPENDIX E

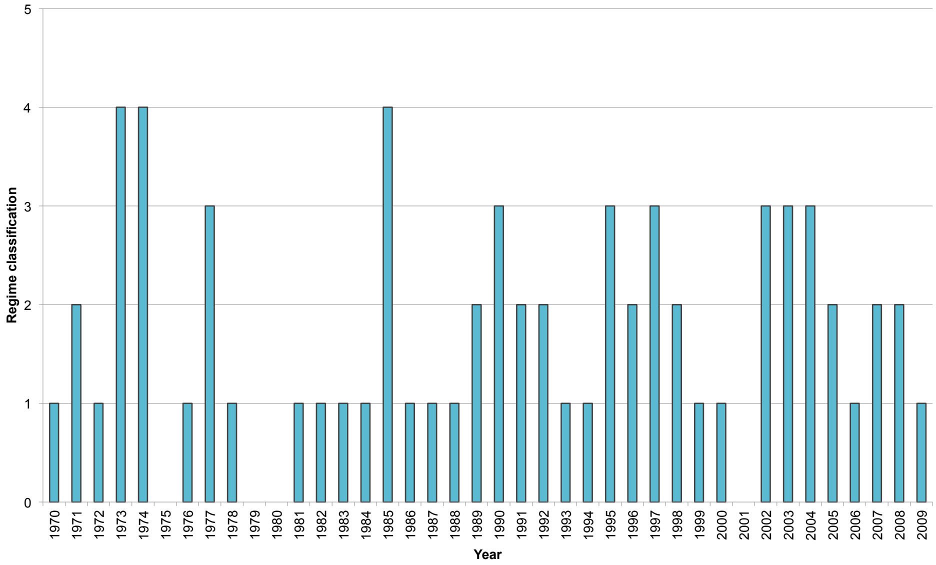
E1. Selected IHA parameters output data from the six northern rivers 1970-2009 (excluding 1975, 1976, 1980, 2002, 2003 and 2006).

	Regime 1		Regime 2		Regime 3		Regime 4		Regime 5		Regime 6	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	3.57	2.08	6.96	1.27	2.05	3.8	2.14	1.64	12.74	1.2	6.74	1.26
October	7.08	1.54	9.73	2.37	11.82	2.3	5.51	0.87	5.22	1.82	4.27	1.15
November	10.76	1.58	7.55	2.26	14.61	1.24	4.91	1.47	5.46	1.63	11.21	1.98
December	11.57	1.8	10.7	1.65	8.83	1.91	5.13	0.21	12.83	1.04	9.64	1.96
January	13.91	1.71	16.53	2.57	11.49	2.04	6.59	1.9	7.23	1.29	9.09	1.92
February	9.78	1.92	6.43	2.58	7.19	2.61	5.57	2.29	4	2.81	7.78	2.97
March	8.45	1.63	10.03	1.82	12.1	1.69	7.97	1.6	5.5	1.58	13.56	2.93
April	5.44	1.76	5.66	1.85	4.64	2.85	5.22	1.25	9.8	2.74	8.46	2.69
May	3.99	1.97	3.25	2.04	3.09	3.32	3.58	1.85	3.73	1.83	5.02	2.55
June	3.17	2.02	2.79	2.32	5.11	1.59	3.48	1.25	2.88	1.89	1.98	2.77
July	2.75	2.11	4.72	1.66	1.79	3.31	2.27	1.3	9.58	1.16	1.48	3.44
August	3.16	1.94	8.61	3.21	2.18	3.14	5.98	2.98	16.76	2.63	4.09	2.2
1-day minimum	1.02	2.82	1.1	2.66	0.91	0.86	0.97	0.71	1.31	0.25	0.74	0.99
1-day maximum	125.9	1.45	156.2	1.73	175.6	1.26	130.1	1.05	198.5	0.75	224	1.18
High flow peak	30.48	0.28	34.52	0.31	39.26	0.25	23.26	0.23	28.31	0.23	32.86	0.56
High flow timing	24.5	0.42	39	0.33	330.3	0.47	333.5	0.3	297.5	0.38	294	0.3
High flow frequency	12	0.85	15	0.93	15	0.83	11	1.18	18	0.81	13.5	1.19
Large flood peak	407	0.43	423	0.09	393		300.3		350		442.6	
Large flood timing	356	0.24	7	0.04	42		293		356		5	

E2. Selected IHA parameters output data of the three regime types on the River Lune, 1970-2009 (1973, 1974, 1975, 1979, 1980, 1985 and 2001 were removed).

	Regime 1		Regime 2		Regime 3	
	Medians	CoD	Medians	CoD	Medians	CoD
September	3.978	1.23	2.143	1.4	3.037	1.017
October	7.83	0.754	6.935	1.09	4.023	1.435
November	7.992	1.283	8.098	0.9506	6.508	1.342
January	11.26	0.9347	12.77	0.9489	13.27	0.8608
March	5.596	1.27	9.616	0.8025	7.078	0.7381
May	2.96	0.8582	2.482	0.8874	4.603	1.058
July	1.902	1.621	1.171	2.729	2.119	0.5951
1-day minimum	0.8755	0.5226	0.642	0.1869	0.799	0.4406
1-day maximum	110.9	1.028	128.3	0.5924	171.6	0.9364
High flow peak	26.48	0.1337	23.09	0.1955	23.75	0.5697
High flow timing	338.5	0.2698	69	0.4925	53	0.3852
High flow frequency	21.5	0.3488	23	0.5	20	0.45
Large flood peak	339.9		441		318	
Large flood timing	5		7		31	

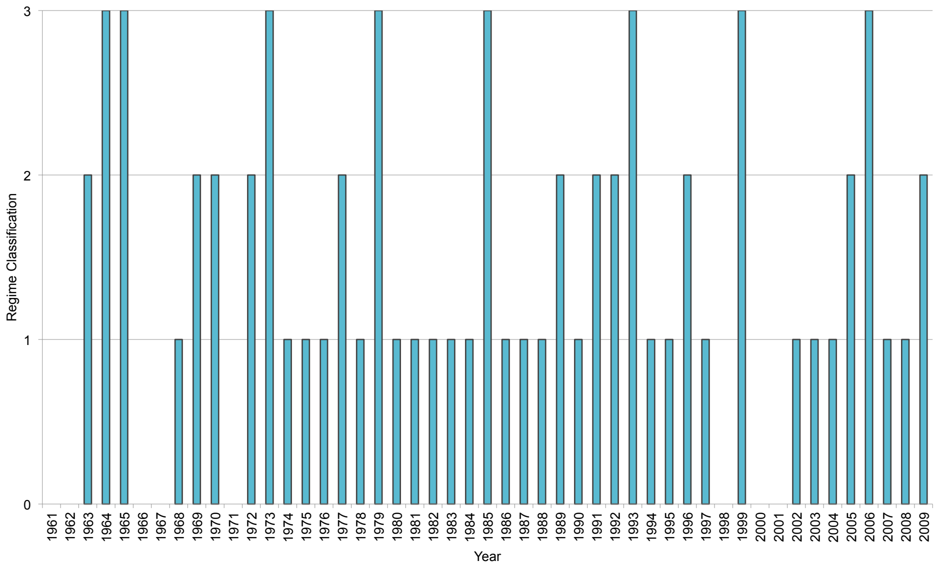
E3. Time line of when the three different regimes on the River Lune occurred through 1970-2009 (1973, 1974, 1975, 1979, 1980, 1985 and 2001 were removed).



E4. Selected IHA parameters output data of the three regime types on the River Ribble, 1961-2009 (1961, 1962, 1966, 1967, 1971, 1981 and 1998 were removed).

	Regime 1		**Regime 2**		**Regime 3**	
	Medians	CoD	Medians	CoD	Medians	CoD
September	13.38	1.038	6.43	1.644	13.22	1.619
October	20.22	0.9975	15.48	0.7003	13.42	0.4508
November	23.4	0.844	46.5	0.9871	16.54	1.775
January	51.86	0.5639	23.6	0.6623	18.46	2.067
March	23.34	1.095	15	1.598	13.04	1.326
May	7.593	1.245	12.28	0.6289	11.52	0.5833
July	7.159	0.9983	7.233	0.8693	9.104	0.8652
1-day minimum	3.57	0.5387	3.79	0.1575	4.348	0.2616
1-day maximum	306.2	0.3875	323.7	0.4306	345.5	0.6342
High flow peak	86.8	0.3096	69.19	0.133	83.38	0.4242
High flow timing	9	0.2165	46	0.1148	27.5	0.2671
High flow frequency	21	0.381	21	0.2381	22	0.2159
Large flood peak	644.3	0.0953	546.6		613.5	
Large flood timing	349	0.2623	356		347	

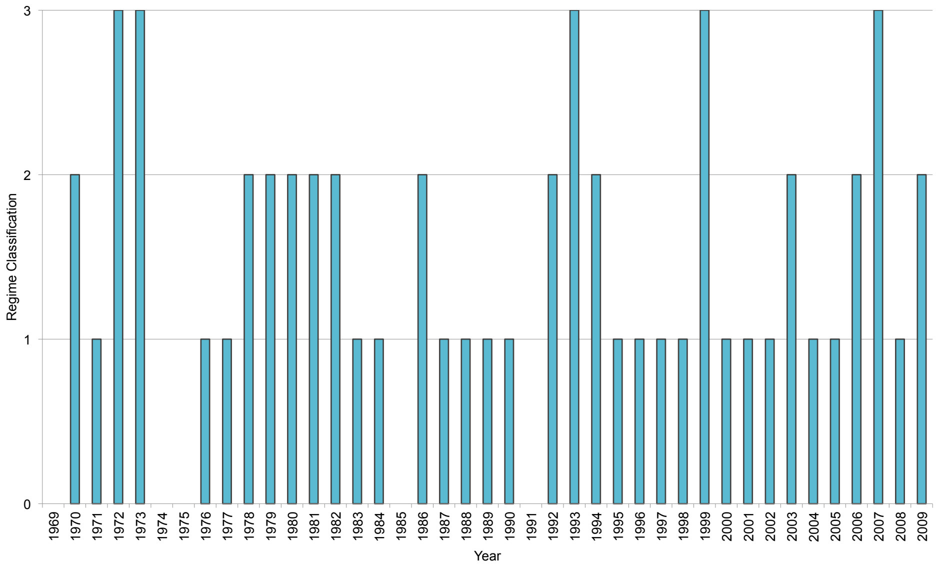
E5. Time line of when the three different regimes on the River Ribble occurred through 1961-2009 (1961, 1962, 1966, 1967, 1971, 1981 and 1998 were removed).



E6. Selected IHA parameters output data of the three regime types on the River Kent, 1969-2009 (1969, 1974, 1975, 1985 and 1991 were removed).

	Regime 1		**Regime 2**		**Regime 3**	
	Medians	CoD	Medians	CoD	Medians	CoD
September	3.308	1.714	4.863	1.126	3.349	0.4533
October	10.2	0.5685	5.499	1.231	3.678	0.8002
November	8.184	0.8185	16.02	0.4666	4.929	1.009
December	8.173	0.8504	12.52	0.9747	12.21	1.145
January	14.86	0.6199	9.851	0.5692	17.59	0.705
March	7.216	0.7608	9.415	0.8476	5.022	0.8209
May	2.535	0.7728	3.87	1.343	3.845	0.2719
July	1.69	1.343	2.119	0.5111	3.836	1.236
1-day minimum	0.805	0.477	0.946	0.4572	1.2	0.5804
1-day maximum	80.43	0.5702	83.37	0.4536	63.96	1.025
High flow peak	21.5	0.1421	22.6	0.3203	16.54	0.4723
High flow timing	354	0.1858	28.75	0.2992	81	0.2227
High flow frequency	18	0.3333	20	0.4	17	0.4118
Large flood peak	176.6	0.209	162.7		157.7	
Large flood timing	19	0.06557	3		5	

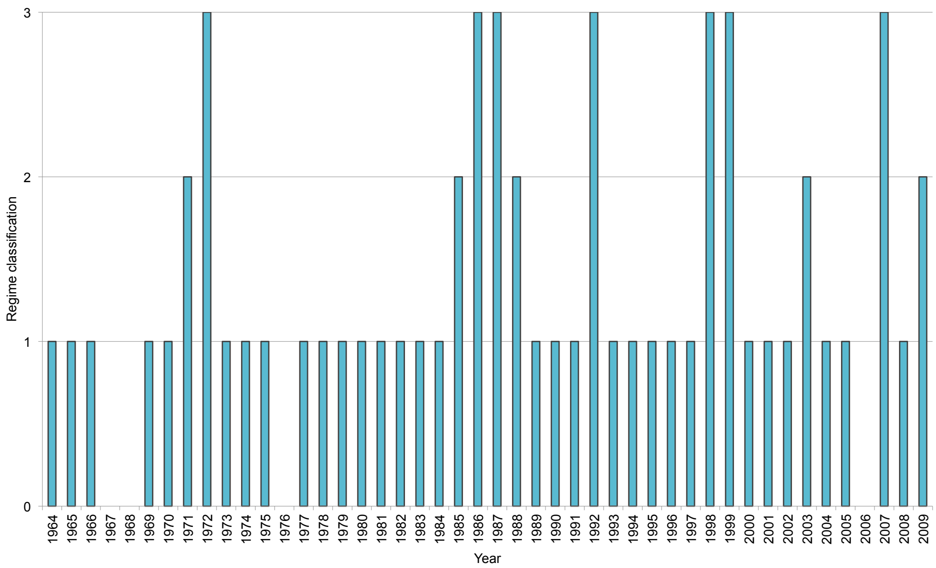
E7. Time line of when the three different regimes on the River Kent occurred through 1969-2009 ((1969, 1974, 1975, 1985 and 1991 were removed).



E8. Selected IHA parameters output data of the three regime types on the River Coquet, 1964-2009 (1967, 1968, 1976 and 2005 were removed).

	Regime 1		**Regime 2**		**Regime 3**	
	Medians	CoD	Medians	CoD	Medians	CoD
September	1.811	0.6475	3.627	1.668	3.623	1.596
October	2.739	1.526	7.923	0.847	7.231	1.233
November	6.564	1.233	6.834	0.6292	10.27	0.4016
January	10.37	0.7103	11.33	0.4865	9.492	0.8713
March	7.762	0.515	7.327	0.5399	8.013	1
May	3.304	0.7502	3.202	0.2047	3.996	0.3973
July	1.624	0.7297	2.246	0.828	1.74	1.191
1-day minimum	0.935	0.4422	1.35	0.1858	1.28	0.4281
1-day maximum	92.26	0.6176	108.7	0.6232	134.5	0.9462
High flow peak	18.6	0.3575	23.01	0.145	32.68	0.3501
High flow timing	21.75	0.1458	77.25	0.3289	11.5	0.2336
High flow frequency	12.5	0.68	16.5	0.1364	18	0.5278
Large flood peak	173	0.389	126.1		279.9	
Large flood timing	3	0.2814	335		92	

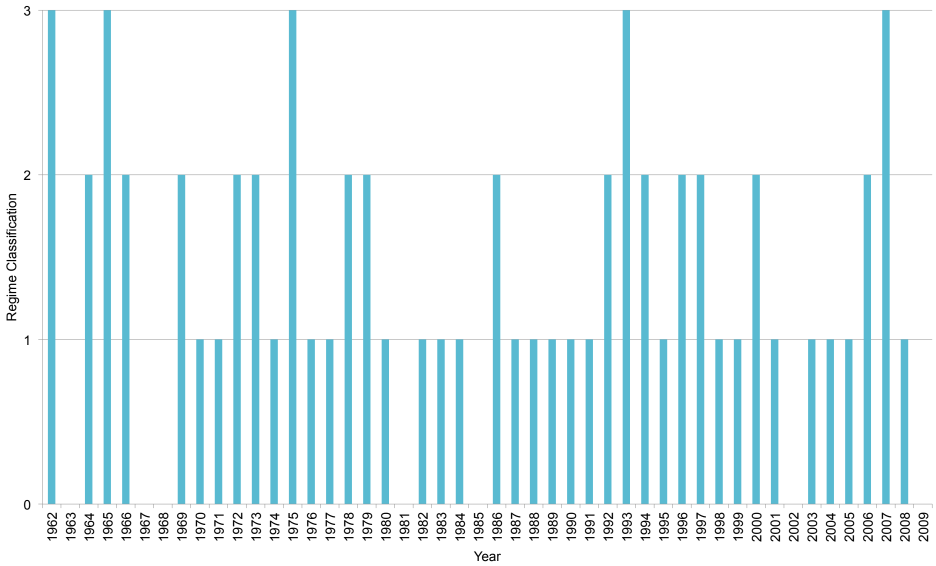
E9. Time line of when the three different regimes on the River Coquet occurred through 1964-2009 (1967, 1968, 1976 and 2005 were removed).



E10. Selected IHA parameters output data of the three regime types on the River Tweed, 1962-2009 (1963, 1967, 1968, 1981, 1985, 2002 and 2004 were removed).

	Regime 1		**Regime 2**		**Regime 3**	
	Medians	CoD	Medians	CoD	Medians	CoD
September	11.93	1.014	15.08	1.441	29.42	0.7825
October	36.61	0.8142	20.88	1.01	19.88	0.4779
November	37.27	0.8288	40.51	0.7456	16.54	1.235
January	61.92	0.5001	37.14	0.6142	83.13	0.3508
March	32.16	0.7181	32.21	0.8141	17.05	0.8655
May	12.91	0.6203	20.48	0.5551	15.69	0.7867
July	10.59	0.8059	8.568	0.2117	11.84	1.469
1-day minimum	5.703	0.3399	6.048	0.2574	5.565	0.4913
1-day maximum	297.6	0.5737	255.7	0.4651	314.3	0.2428
High flow peak	57.5	0.3674	55	0.3545	39	0.1923
High flow timing	359	0.292	327.5	0.3671	171.5	0.2978
High flow frequency	18	0.4583	17.5	0.4143	19	0.5526
Large flood peak	495.5	0.2402	548			
Large flood timing	337	0.1749	346			

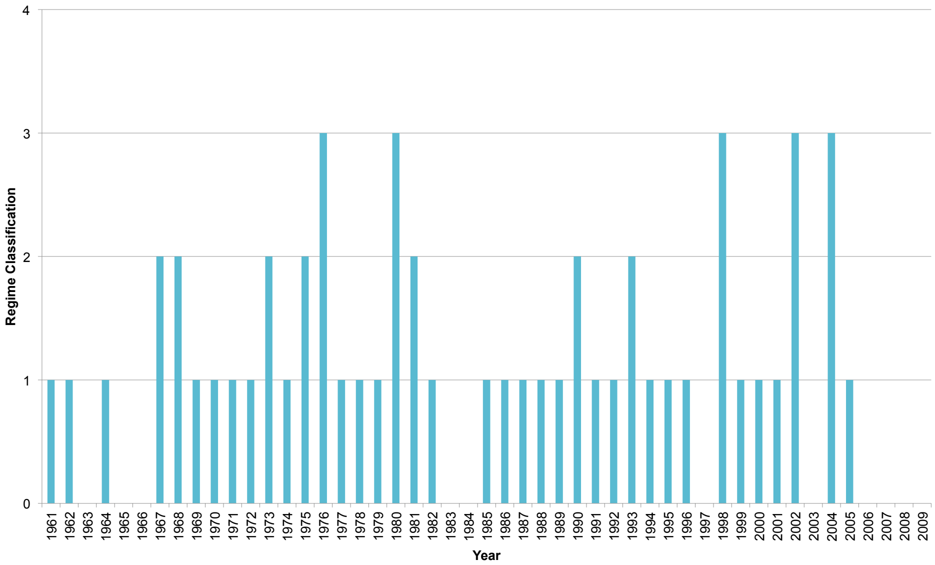
E11. Time line of when the three different regimes on the River Tweed, 1962-2009 (1963, 1967, 1968, 1981, 1985, 2002 and 2004 were removed).



E12. Selected IHA parameters output data of the three regime types on the River Tyne, 1961-2009 (1963, 1965, 1966, 1983, 1984, 1997, 2003, 2006, 2007, 2008 and 2009 were removed).

	Regime 1		**Regime 2**		**Regime 3**	
	Medians	CoD	Medians	CoD	Medians	CoD
September	0.8308	0.7152	0.767	1.775	1.233	0.6247
October	0.9325	0.9461	2.154	0.4545	3.076	1.025
November	1.866	0.7037	2.26	1.281	4.792	0.7394
January	3.689	0.7003	2.227	1.281	3.327	1.129
March	2.578	0.5317	1.641	1.127	1.978	0.6567
May	1.373	0.4967	1.429	2.182	1.157	0.392
July	0.852	0.3433	0.794	0.3514	0.966	1.225
1-day minimum	0.5325	0.4897	0.517	0.3868	0.761	0.6097
1-day maximum	28.92	1.072	40.75	0.7401	40.79	0.8782
High flow peak	3.75	0.5667	5	0.5	4	0.6875
High flow timing	36.5	0.2391	21	0.2213	158.5	0.4085
High flow frequency	13	0.6538	13	0.3077	18	0.4444
Large flood peak	87	0				
Large flood timing	202	0.3989				

E13. Time line of when the three different regimes on the River Tyne, 1961-2009 (1963, 1965, 1966, 1983, 1984, 1997, 2003, 2006, 2007, 2008 and 2009 were removed).



APPENDIX F

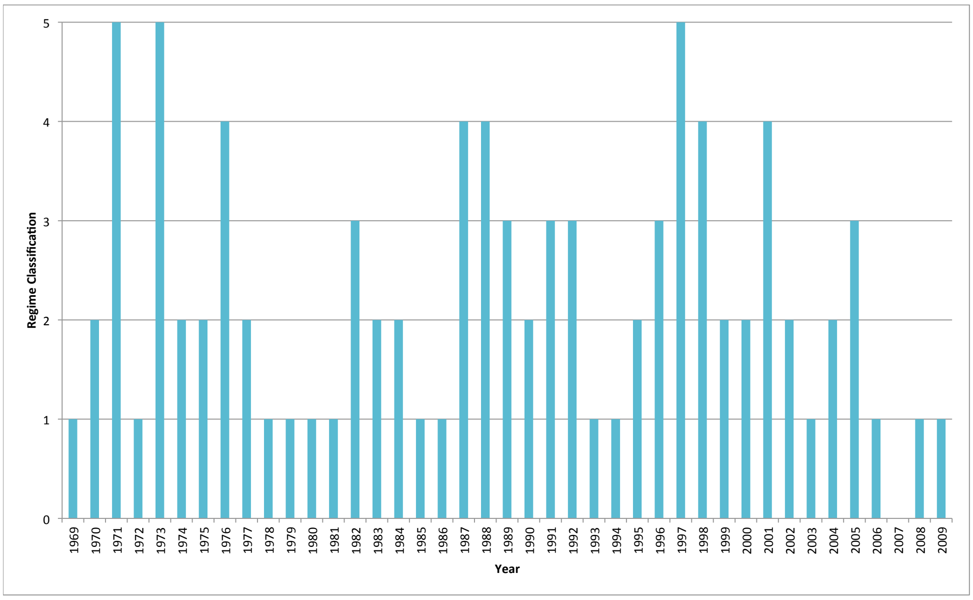
F1. Selected IHA parameters output data for the six regime shapes from the Welsh database 1979-2009 (excluding 1997).

	Regime 1		Regime 2		Regime 3		Regime 4		Regime 5		Regime 6	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	4.16	1.43	4.35	2.41	5.65	2.47	4.05	2.26	9.34	0.85	9.47	1.27
October	6.88	1.95	19.39	1.5	11.54	1.85	13.09	0.93	5.06	1.09	16.5	1.97
November	18.7	1.59	19.03	1.2	6.91	1.84	17.97	1.6	7.02	1.02	15.85	0.88
December	18.15	1.56	11.68	1.52	19.29	1.79	10.01	1.43	18.9	2.01	13.2	1.07
January	17.12	1.4	12.27	1.87	36.18	1.15	14.24	1.44	9.94	2.95	32.7	1.34
February	11.18	1.91	8.83	1.66	14.14	1.17	8.82	1.89	6.01	1.52	12.7	1.11
March	11.15	1.93	7.49	1.56	16.15	0.98	20.4	1.62	4.84	1.33	16.3	1.59
April	5.18	1.77	10.42	1.32	5.54	2.4	5.71	1.59	12.88	1.19	9.3	1.37
May	3.68	2.62	4.26	1.23	5.02	1.32	3.56	1.46	4.66	1.77	3.65	1.88
June	3.04	1.28	4.13	1.6	3.64	1.06	3.14	2.33	7.91	1.22	2.24	2.29
July	2.49	1.19	2.52	1.92	4.41	3.04	2.08	1.48	5.17	1.59	5.3	1.67
August	2.56	2.47	3.28	1.85	4.62	1.15	2.17	1.29	9.46	2.84	19.2	1.24
1-day minimum	0.82	1.24	0.91	1.65	0.95	1.56	0.79	0.72	1.3	0.68	1.41	0.99
1-day maximum	170.6	1.08	175.9	1.02	190.2	0.88	216.3	0.96	150.8	0.93	214	0.24
High flow peak	32.79	0.54	31.68	0.54	37.27	0.76	35.27	0.38	29.92	0.64	37.7	0.53
High flow timing	345.5	0.4	326	0.47	12.25	0.29	19.5	0.28	240	0.43	320	0.46
High flow frequency	9	1.11	11	0.82	11.5	0.74	9	0.78	14	0.7	20	0.53
Large flood peak	301.4	0.07	373.6	0.15	255.9	0.04	318.4		264.3		276	
Large flood timing	349.5	0.27	7	0.38	29.5	0.18	81		356		20	

F2. Selected IHA parameters output data of the five regime types on the River Conwy, 1969-2009 (2007 was removed).

	Regime 1		Regime 2		Regime 3		Regime 4		Regime 5	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	7.377	1.073	10.59	1.159	4.336	2.118	12.81	5.079	4.638	1.301
October	6.862	2.274	14.75	0.6834	13.9	0.4091	22.87	2.864	8.322	0.4913
November	17.2	0.5552	18.52	1.125	23.28	0.7115	15.39	4.422	12.45	0.8563
December	23.25	1.067	16.42	1.185	10.35	1.475	13.17	5.271	7.861	1.487
January	16.98	0.716	26.96	0.625	13.59	0.737	20.13	1.042	8.913	1.922
March	13.62	1.359	10.79	0.6449	16.84	1.265	10.79	1.025	10.92	0.8983
May	9.145	1.076	4.226	1.085	4.107	1.475	4.161	0.6238	5.576	1.392
July	2.89	1.084	3.398	1.137	2.833	0.7715	4.735	1.673	2.062	1.094
1-day minimum	0.8015	0.7832	0.7945	0.8332	0.786	0.7087	1.131	0.3612	0.649	0.6703
1-day maximum	218.4	0.3658	197.2	0.5789	243	0.3822	196.5	0.2959	182.1	0.2784
High flow peak	48.32	0.3282	47.49	0.3212	38.53	0.2766	46.6	0.1376	34.7	0.201
High flow timing	34.25	0.2852	10.5	0.1216	71.5	0.2176	340	0.4044	318.5	0.2582
High flow frequency	24.5	0.1837	24	0.2292	27	0.3148	27	0.5741	24	0.5
Large flood peak	318.4		341.5		375		241.7		218.6	
Large flood timing	81		50		7		66		48	

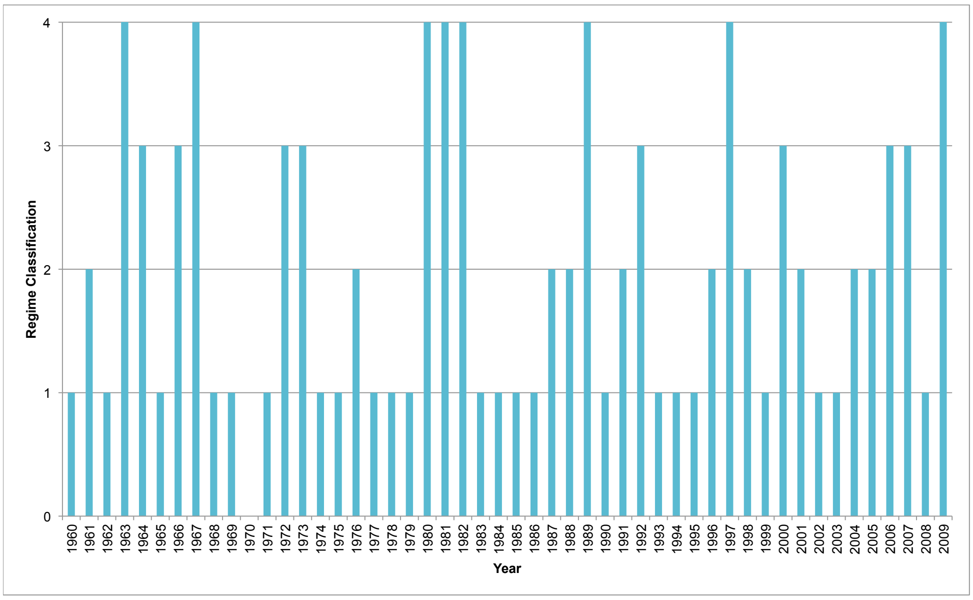
F3. Time line of when the five different regimes on the River Conwy, 1969-2009 (2007 was removed).



F4. Selected IHA output data of the five regime types on the River Teifi, 1960-2009 (with 1970 removed).

	Regime 1		Regime 2		Regime 3		Regime 4		Regime 5	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	7.305	1.759	12.8	1.35	7.492	1.261	10.94	2.96	11.89	0.7146
October	16.06	1.382	43.51	0.5899	19.17	1.08	49.34	0.7625	15.46	0.3299
November	32.17	1.22	37.77	0.6973	32.25	0.8143	42.24	0.4423	50.31	0.9824
December	45.92	0.6067	25.9	0.7168	52.95	0.7713	47.29	0.1796	14.05	2.181
January	53.8	0.3888	40.03	0.6322	33.51	0.9352	32.67	0.4624	6.085	10.12
March	20.11	0.7802	21.28	0.8533	21.36	0.6922	47.1	0.6264	14.6	2.532
May	14.24	1.021	10.28	0.3867	17.76	0.6353	7.279	2.552	17.73	0.05922
July	5.041	1.13	5.282	0.9602	9.205	1.802	4.988	0.6087	13.65	1.788
1-day minimum	2.492	0.689	3.032	0.6671	3.076	0.8051	2.751	0.5818	3.03	0.9119
1-day maximum	172	0.4558	190	0.3655	199.4	0.6673	190.6	0.5058	122.9	0.7347
High flow timing	15	0.1448	26.75	0.2097	48	0.3453	363.5	0.1626	159	0.1421
High flow frequency	11	0.4545	9.5	0.7632	11	0.5	11	0.7727	7	0.5714
High flow peak	65.9	0.3926	61.76	0.2608	57.14	0.2602	62.47	0.4593	51.51	0.3258
Large flood peak	260.6	0.1113	373.6		302.7		247		203	
Large flood timing	13	0.0929	292		337		82		323	

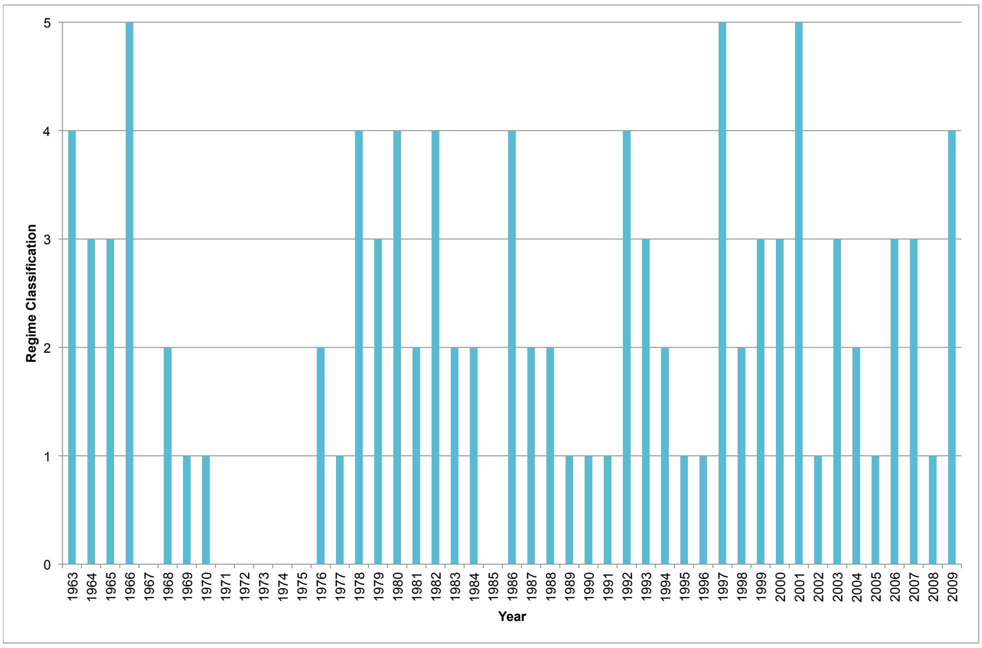
F5. Time line of when the five different regimes on the River Teifi occurred through 1960-2009 (with 1970 removed).



F6. Selected IHA parameters output data of the five regime types on the River Dyfi 1963-2009 (where 1967, 1971, 1972, 1973, 1974, 1975 and 1985 were removed).

	Regime 1		**Regime 2**		**Regime 3**		**Regime 4**		**Regime 5**	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	5.244	1.507	15.73	0.6137	9.243	0.8541	10.14	0.5162	11.2	4.047
October	15.59	0.8225	29.36	0.8387	15.39	1.421	10.14	1.728	12.9	3.338
November	29.45	0.844	26.12	0.8558	25.69	1.018	42.08	0.5695	16.4	2.391
December	17.7	0.6045	26.11	0.7876	49.43	0.6116	29.65	1.148	46.4	0.5772
January	20.37	0.9838	36.88	0.3923	32.94	0.8391	25.43	0.8034	9.854	1.828
March	17.05	0.678	21.68	1.177	13.71	1.217	27.6	0.6149	14.39	0.2349
May	6.115	1.462	6.139	1.199	9.327	0.6927	10.2	1.123	12.43	0.7608
July	4.567	1.043	5.165	1.644	5.833	1.584	5.517	1.795	6.824	0.8025
1-day minimum	0.402	0.7015	1.716	1.07	0.517	0.2263	0.722	0.633	1.903	0.6795
1-day maximum	33.46	0.4393	197.7	0.5434	30.86	0.523	48.88	0.34	224.9	0.2174
High flow peak	10.35	0.3153	54.34	0.6399	8.287	0.4117	12.27	0.2402	52.39	0.4144
High flow timing	16	0.2602	334.5	0.4317	70	0.2937	44.75	0.4863	2	0.2199
High flow frequency	15	0.3	14.5	0.3966	14	0.2857	19.5	0.6923	15	0.4667
Large flood peak	82.27	0.3706	317.7		41.4		68.79		246.1	
Large flood timing	312	0.06011	66		313		70		179	

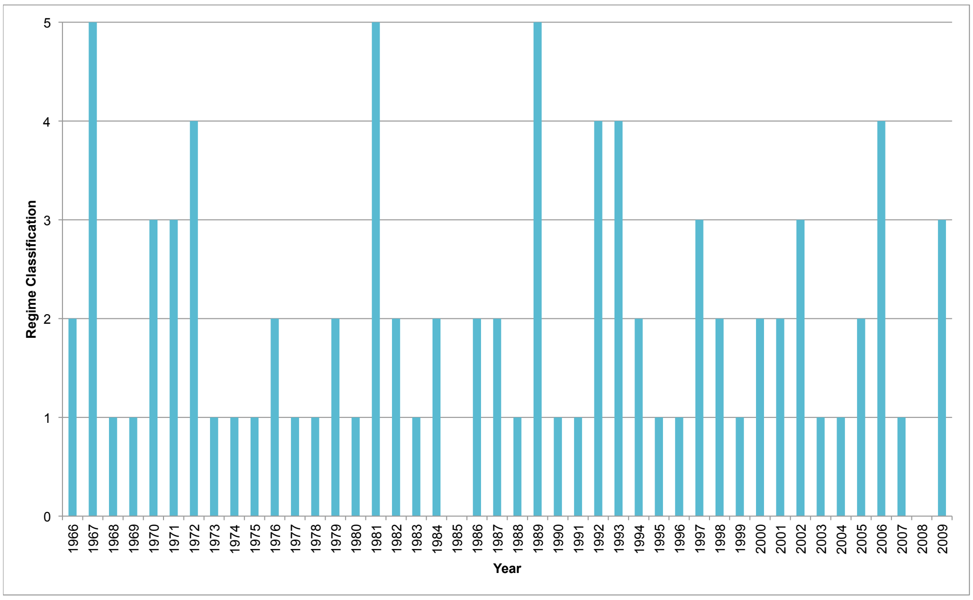
F7. Time line of when the five different regimes on the River Dyfi 1963-2009 (where 1967, 1971, 1972, 1973, 1974, 1975 and 1985 were removed).



F8. Selected IHA parameters output data of the five regime types on the River Western Cleddau, 1966-2009 (where 1985 was removed).

	Regime 1		**Regime 2**		**Regime 3**		**Regime 4**		**Regime 5**	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	1.198	1.011	1.152	1.312	1.576	2.113	2.13	1.405	3.809	1.794
October	2.594	1.778	7.392	0.9771	3.66	0.7422	3.058	0.9632	10.34	0.5864
November	5.522	0.7214	10.99	0.5381	11.8	1.237	5.982	0.469	8.637	0.1671
January	10.53	0.4156	8.629	0.6201	7.36	1.317	7.092	0.7485	5.166	0.5908
March	5.254	0.7047	5.301	0.5865	4.253	0.4425	5.697	0.5375	12.52	0.6308
May	2.491	0.703	2.787	0.6872	3.19	0.4831	4.019	0.5676	3.562	1.394
July	1.1	0.6636	1.132	0.6888	1.912	1.524	2.527	0.7315	1.58	1.164
1-day minimum	0.6005	0.5129	0.708	0.7571	0.905	0.5912	1.297	0.5663	0.54	2.806
1-day maximum	32.57	0.4046	34.39	0.4114	32.77	0.5827	37.26	0.6677	45.04	0.347
High flow peak	10.41	0.1507	12.85	0.2087	10.07	0.1246	8.081	0.4283	10.3	0.2202
High flow timing	9.75	0.2247	13	0.1352	70.5	0.2725	84.5	0.1663	294.5	0.3265
High flow frequency	11.5	0.4565	12.5	0.32	12	0.5417	15.5	0.4032	14	0.3571
Large flood peak	53.01		65.58		45.95		58.23		49.04	
Large flood timing	300		292		332		337		71	

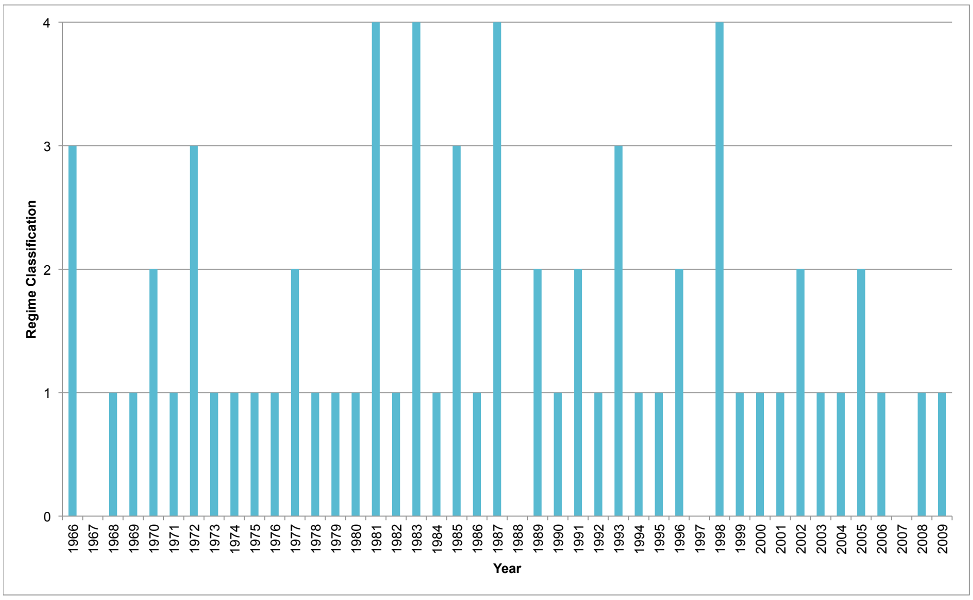
F9. Time line of when the five different regimes on the River Western Cleddau, 1966-2009 (where 1985 was removed).



F10. Selected IHA parameters output data of the four regime types on the River Dysynni, 1966-2009 (excluding 1967,1988,1988, 1997 and 2007).

	Regime 1		**Regime 2**		**Regime 3**		**Regime 4**	
	Medians	CoD	Medians	CoD	Medians	CoD	Medians	CoD
September	2.657	0.6978	1.837	1.109	3.302	1.814	4.683	0.487
October	4.639	0.708	3.686	0.6435	2.87	1.922	7.157	0.4002
November	5.289	0.6635	6.885	0.2694	4.098	0.9282	5.405	0.839
December	6.249	0.6212	3.34	0.4512	7.585	0.3584	4.656	0.6577
January	5.393	0.5982	3.457	0.5325	3.586	0.9217	6.8	0.8038
March	3.28	0.6918	2.715	0.6855	2.2	0.6087	5.464	0.3486
May	1.46	1.124	1.465	0.9195	2.21	0.5567	1.716	0.8641
July	1.335	0.8528	1.173	0.8994	2.904	0.4323	1.992	0.8465
1-day minimum	0.402	0.7015	0.517	0.2263	0.683	0.6684	0.722	0.633
1-day maximum	33.46	0.4393	30.86	0.523	24.16	0.4553	48.88	0.34
High flow peak	10.35	0.3153	8.287	0.4117	9.94	0.2687	12.27	0.2402
High flow timing	16	0.2602	70	0.2937	123.3	0.4737	44.75	0.4863
High flow frequency	15	0.3	14	0.2857	18.5	0.4189	19.5	0.6923
Large flood peak	82.27	0.3706	41.4		30.46		68.79	
Large flood timing	312	0.06011	313		29		70	

F11. Time line of when the four different regimes on the River Dysynni occurred through 1966-2009 (excluding 1967,1988,1988, 1997 and 2007).



APPENDIX G

G1. Summary of available Atlantic salmon catches and release survival studies

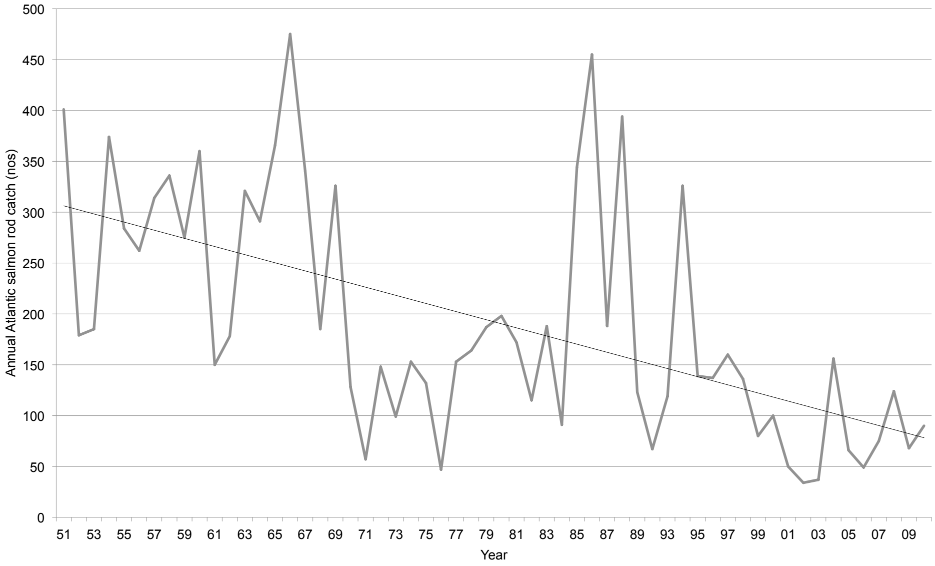
Number of Salmon in Study (N)	***Duration- (days)***	***Survival (%)***	***Country***	***Reference***
300	Oct-14	95-99.7	North America	Warner, 1976
149	5	87	North America	Warner, 1978
177	02-May	65-96*	North America	Warner and Johnson, 1978
1221	Mar-14	94-95	North America	Warner, 1979
421	-	100	Iceland	Grant, 1980
25	Until Spawning	84	Scotland	Webb, 1998
62	1	98.4	Russia	Whoriskey *et al*., 2000
49	40	91.8	Canada	Dempson *et al*., 2002
30	-	97	Norway	Thorstad *et al*., 2002
1970	-	79-96		
36	Until Spawning	97	Ireland	Ireland Central Fisheries Board, 2006
18	Until Spawning	100	Norway	Thorstad *et al*., 2007

*fish caught with worms in juvenile nursery areas

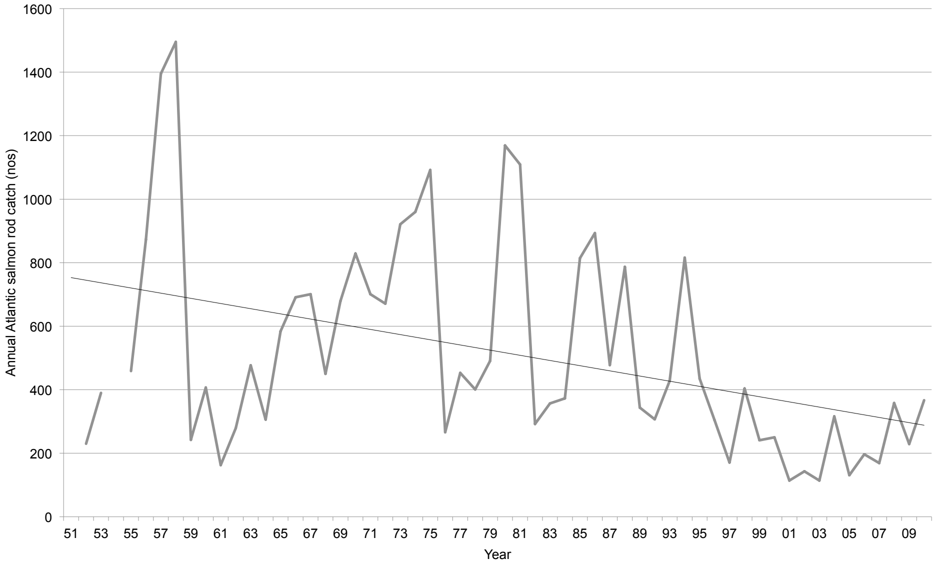
G2. Buy off arrangements operating on net fisheries in 2010 (modified from the EA/Cefas 2009 and 2010 reports).

River/Fishery	**Method (all/some licenses affected)**	**Period without netting (starting year) (full season in parenteses)**	**Brokers/Funding agency**
Tavy	Seine nets (all)	Complete season (commenced 2004) (1 June-31 August)	Environment Agency, South West Water Plc, English Nature, Maristowe Estate, Lynher River Association and Tamar & Tributaries Fisheries Association (10 year buy off)
Tamar	Seine nets (all)	Complete season (commenced 2004) (1 June-31 August)	
Lynher	Seine nets (all)	Complete season (commenced 2004) (1 June-31 August)	
Fowey	Seine nets (some)	Complete season (commenced 2008) (2 March-31 August)	Environment Agency, South West Water Plc
Camel	Drift nets (some)	1 July- 31 August (commenced 2008) (1 June-31 August)	Environment Agency, Riparian and fishing interests
Dart	Seine nets (some)	Complete season (commenced 2006) (15 March-14 August)	Local Fisheries interests
Teign	Seine nets (some)	Complete season (commenced 2006) (15 March-31 August)	Local Fisheries interests
Lyn	Fish trap (all)	Complete season (in perpetuity) (commenced 2003) (1 June- 31 August)	Environment Agency
Exe	Seine nets (some)	Complete season (commenced 2007) (1 June-14 August)	Exe Mitigation Group
Avon and Stour	Seine net (all)	All salmon caught to be released (Scheme operating since 1997) (1 June- 31 July)	Environment Agency
Piddle and Frome	Seine net (all)	All salmon and sea trout to be released (Scheme operating since 2008) (1 June-31 July)	Environment Agency
Severn	Putcher rank (one)	Complete season (one year only) (1 June-15 August)	Wye and Usk Foundation consortium
Tywi	Seine net (some -6)	Complete season (commenced 2008) (1 March-31 July)	Carmarthen Fishermans Federation

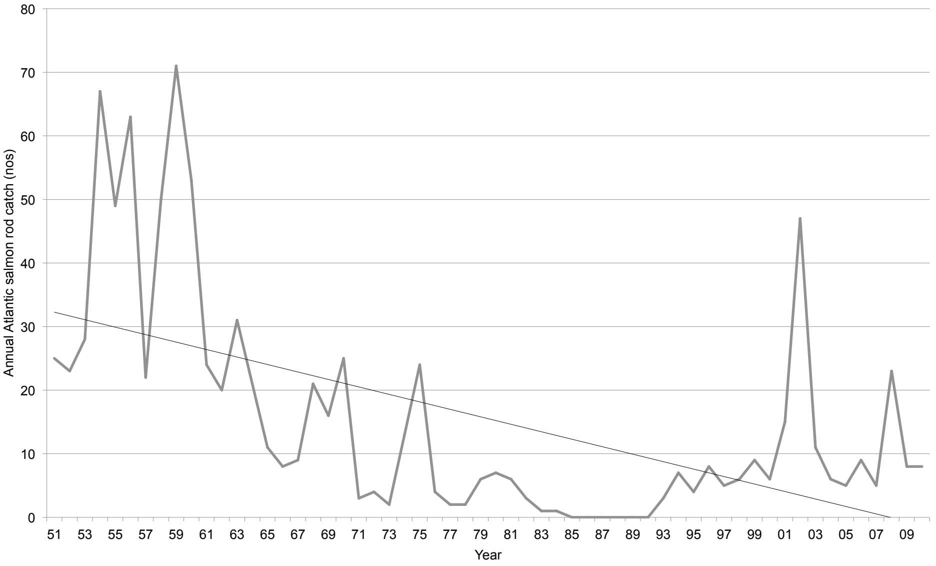
G3. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Dart.



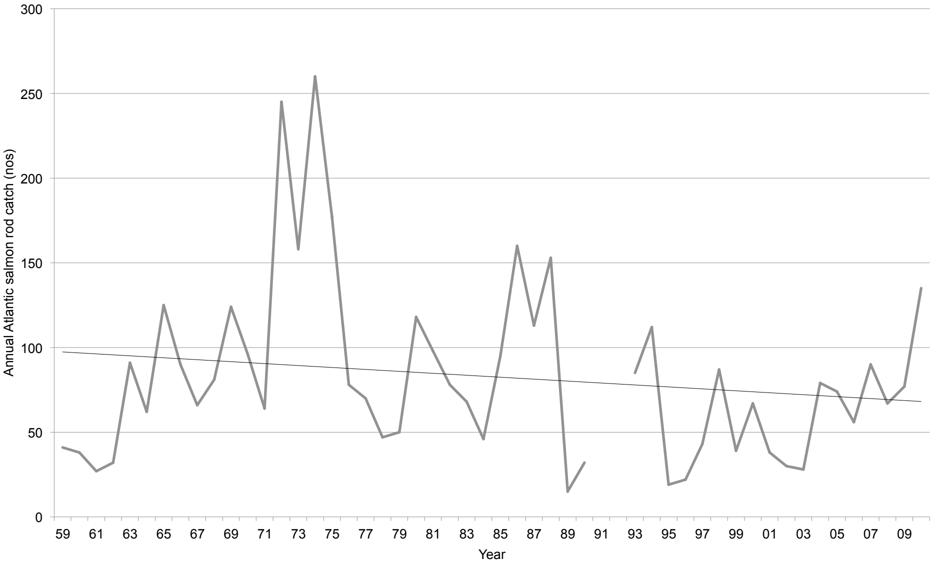
G4. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Tamar.



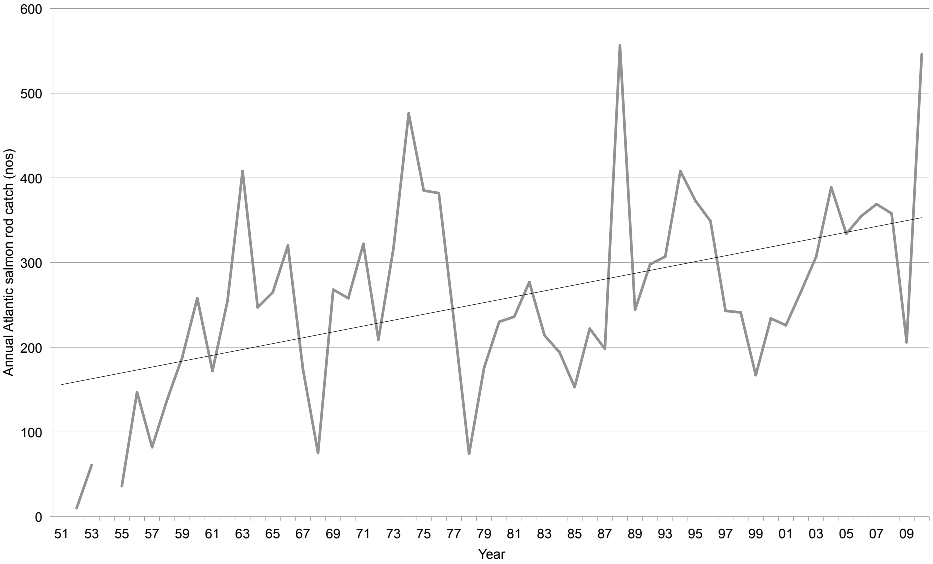
G5. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Axe



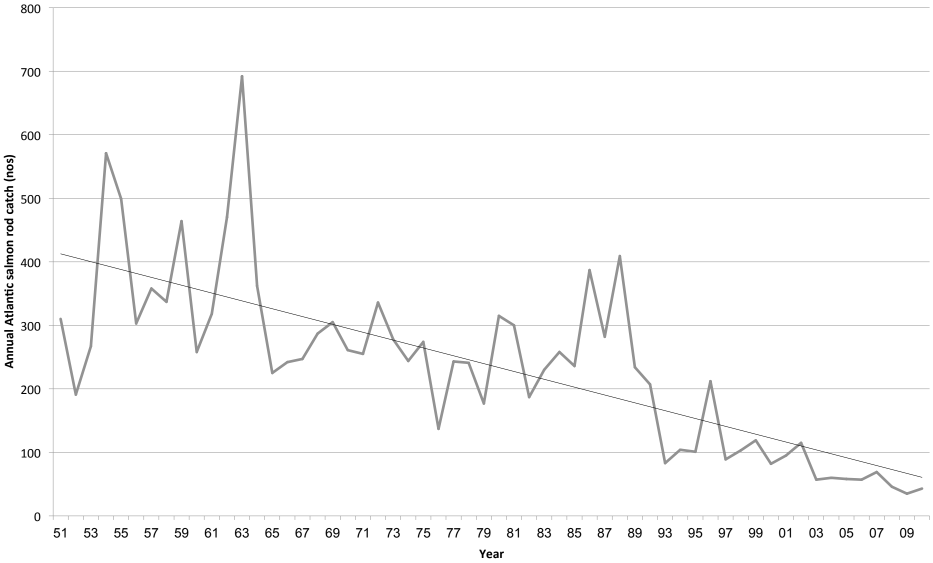
G6. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Lynher.



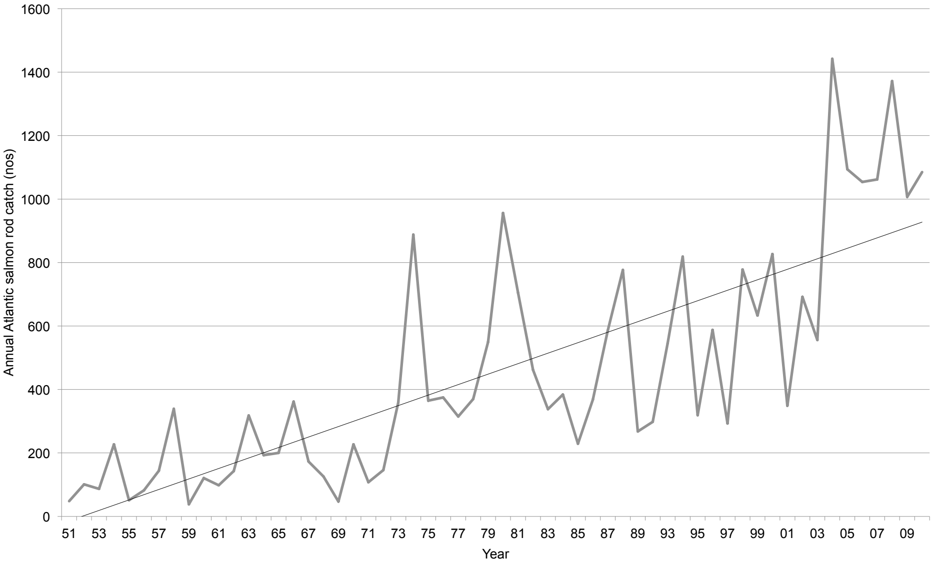
G7. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Camel.



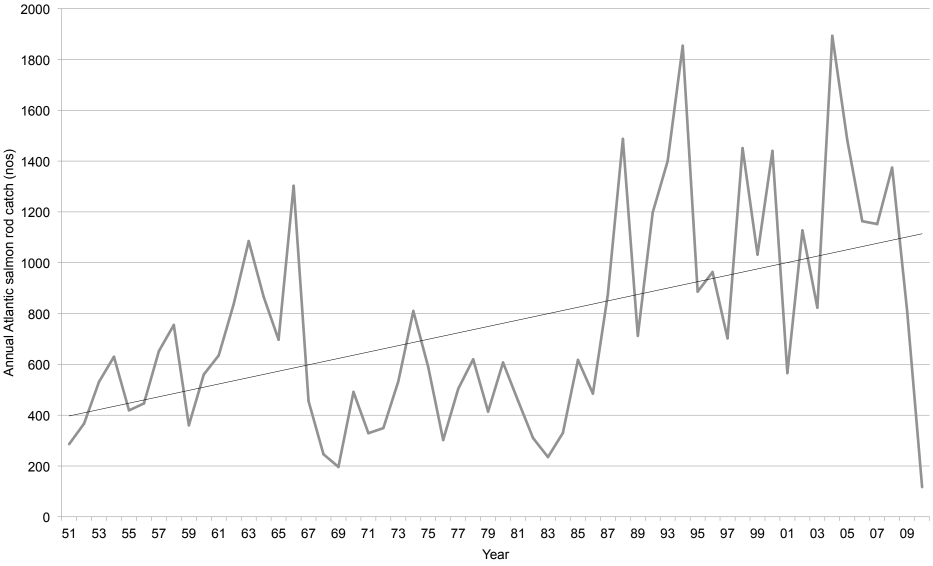
G8. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Frome.



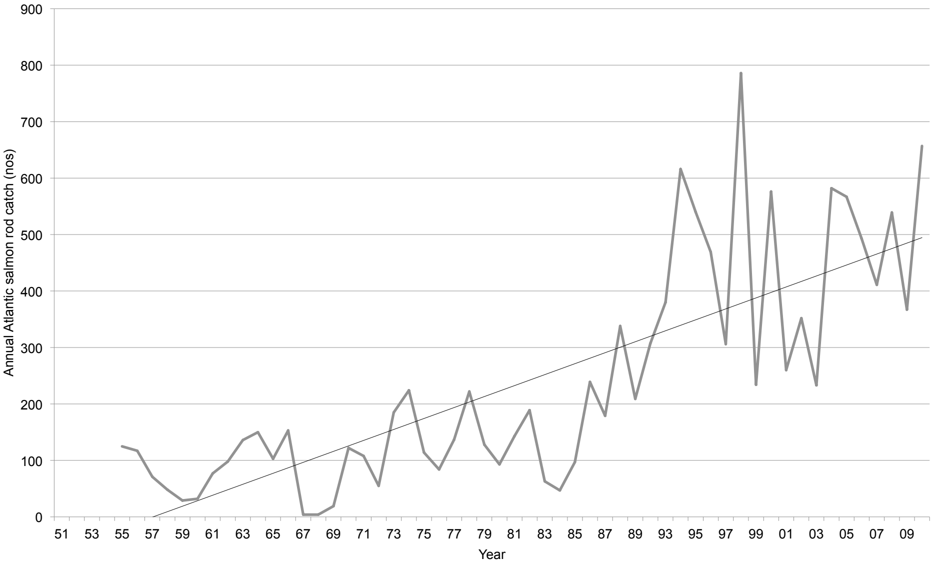
G9. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Ribble.



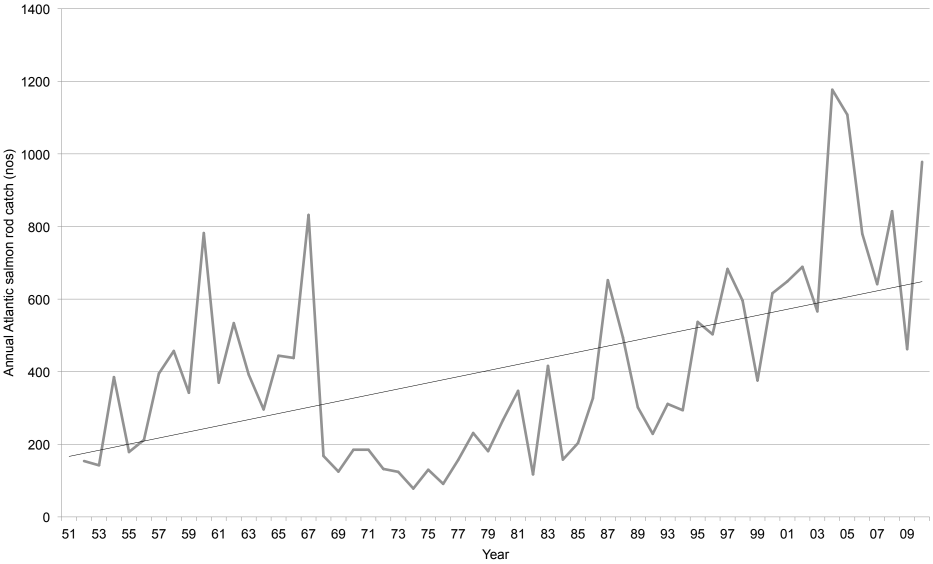
G10 Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets). For the River Lune.



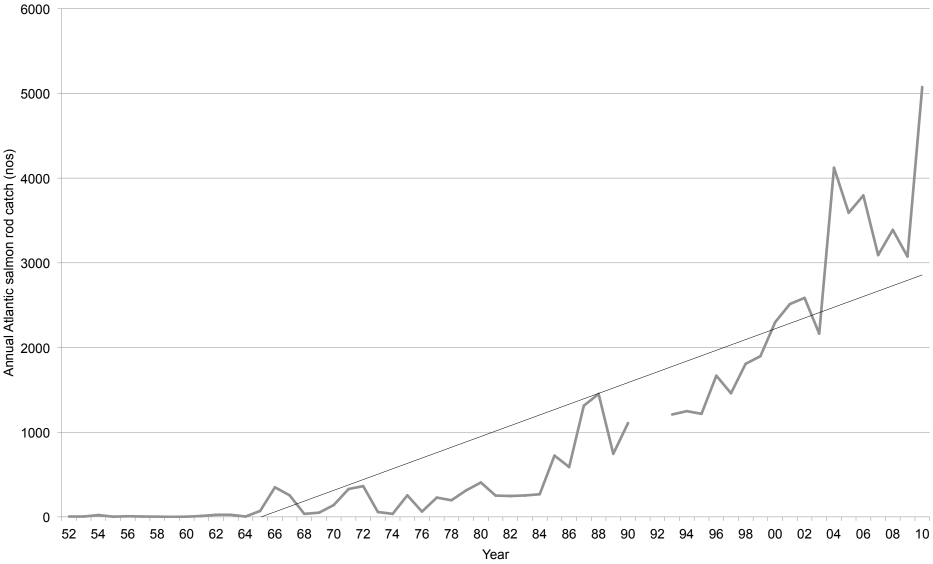
G11 Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Kent.



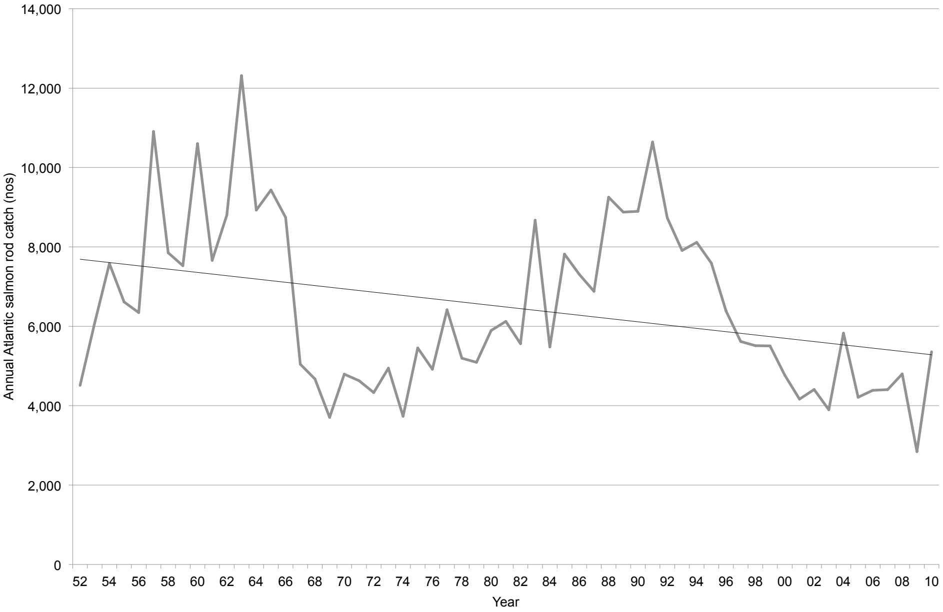
G12. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Coquet.



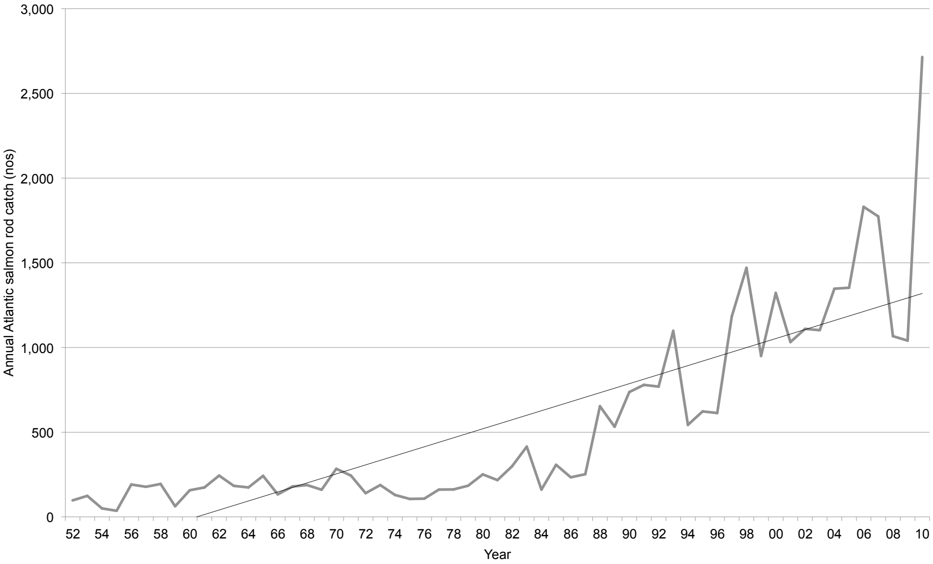
G13. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Tyne



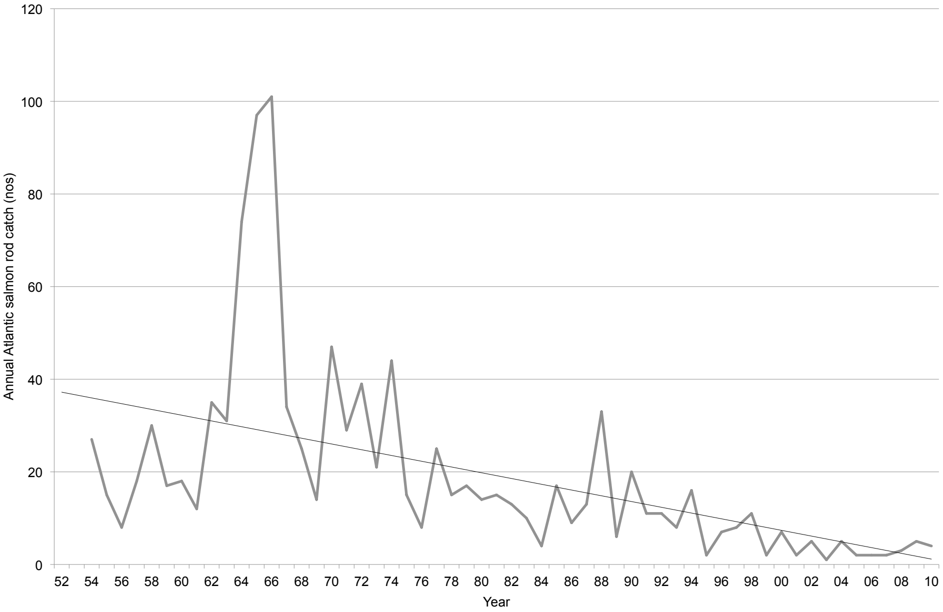
G14. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Tweed.



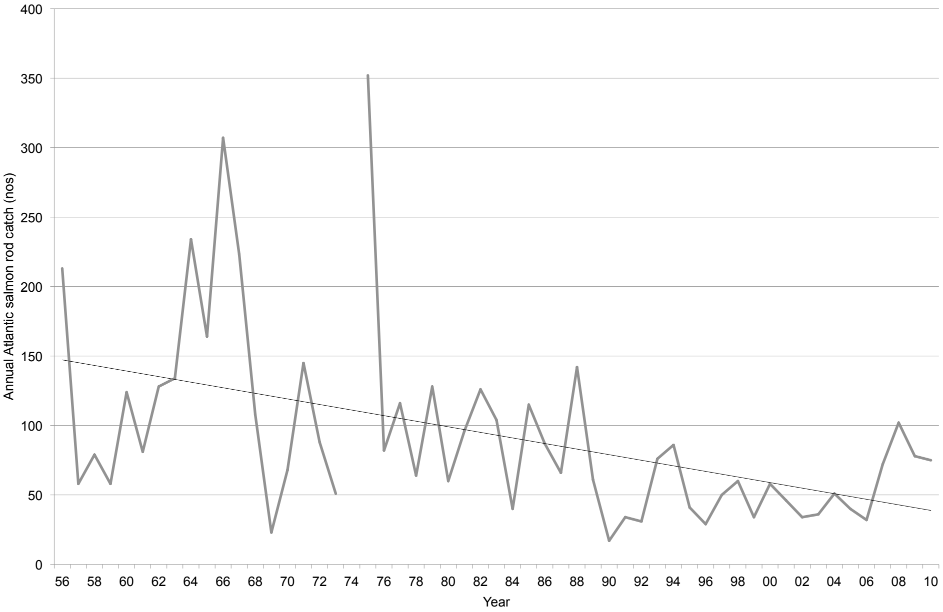
G15. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Tweed for grilse and salmon.



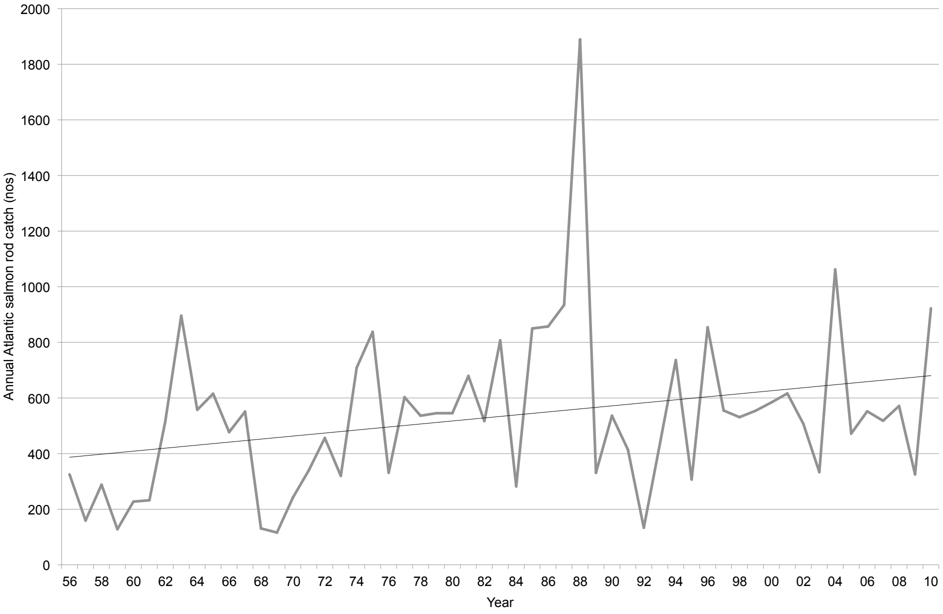
G16. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Dysynni



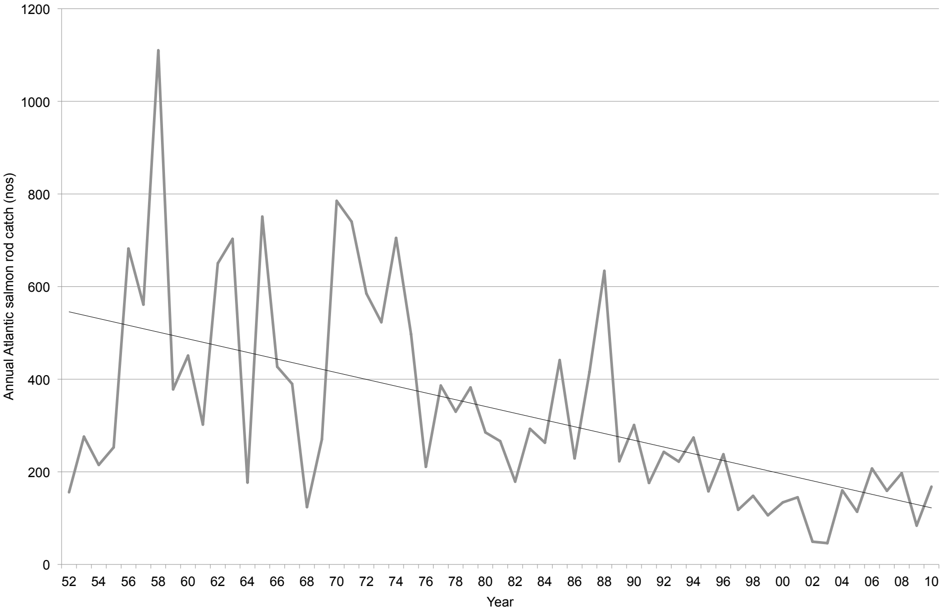
G17. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Cleddau.



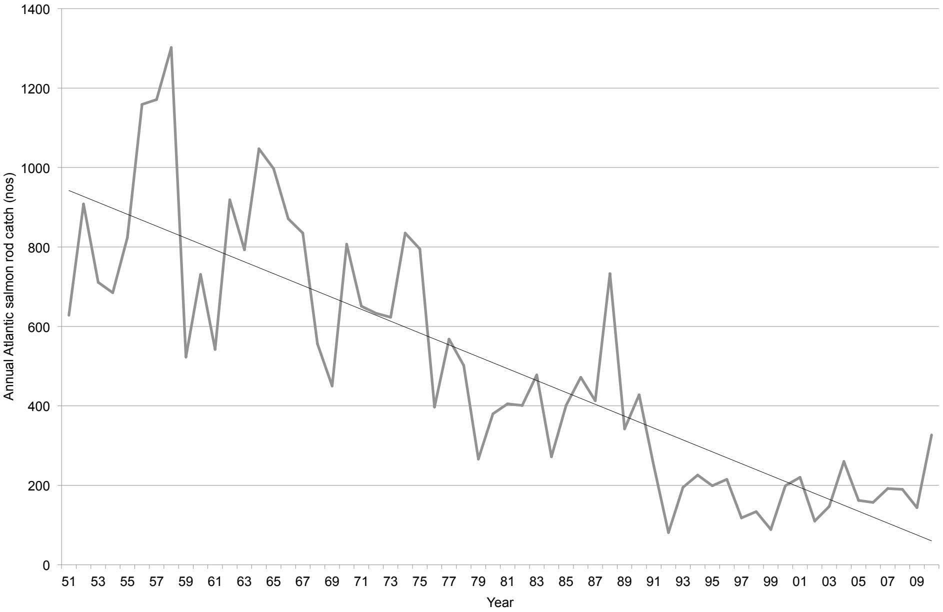
G18. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Teifi



G19. Annual Atlantic salmon rod catch data from 1951-2010 (where 1991 and 1992 are missing from all datasets) for the River Dyfi.



G20 Annual Atlantic salmon rod catch data for the River Conwy from 1951-2010 (where 1991 and 1992 are missing from all datasets)



G21. UK Annual rainfall averages according to the Met Office.

Year	UK Annual flow average
1951	1198.3
1952	1009.6
1953	952.9
1954	1309.1
1955	899.8
1956	1047.7
1957	1101.3
1958	1135.9
1959	993.2
1960	1198.8
1961	1054.3
1962	1004.6
1963	975.6
1964	895.5
1965	1111.5
1966	1159.8
1967	1174.5
1968	1045.6
1969	980
1970	1095
1971	912.9
1972	961.2
1973	905.2
1974	1153.1
1975	899.4
1976	951.5
1977	1079
1978	1039.7
1979	1144.8
1980	1129
1981	1156.4
1982	1170.3
1983	1061.8
1984	1066
1985	1074.3
1986	1185
1987	1036.3
1988	1133
1989	1020.7
1990	1175
1991	999.7
1992	1188.8
1993	1122.5
1994	1186.6
1995	1025.2
1996	918
1997	1025.6
1998	1267.1
1999	1239.1
2000	1337.3
2001	1052.8
2002	1283.7
2003	904.2
2004	1213.6
2005	1086.2
2006	1179.2
2007	1200.3
2008	1295
2009	1213.3
2010	950.5

Descriptive Statistics						
N	Minimum	Maximum	Mean	Std deviation	1st Quartile	3rd Quartile
60	895.5	1337.3	1088.1	115.4	1003.4	1176.1

Key

🟩	Dry years
🟨	Wet years

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