Fisheries research review 2019

Edited by Rasmus Lauridsen

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The Fisheries team who contributed to work in this Review (in alphabetical order): C Artero, WA Beaumont, WRC Beaumont, S Gregory, R Lauridsen, T Lecointre, J Marsh, D Osmond, J Picken, D Roberts, L Scott and O Simmons.

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Acknowledgements

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We would also like to thank the Freshwater Biological Association for renting us facilities and all the riparian owners along the River Frome and other areas for access to the rivers. Without their permission our work would not be possible.

Foreword

David Mayhew
Chairman of the GWCT Fisheries Research steering committee

2019 has been a very busy year for the fisheries team. I am told they have spent more time in the field this year, than probably any other year, in the last 10 years. This started in March, with the 24/7 operation of the Frome smolt trap for six weeks; netting adult sea trout at sea in April and May; recapturing the sea trout with data storage tags on three rivers in May, June and July; catching and tagging 13,000 trout and salmon parr in August and September on the River Frome and then spending December on the River Tamar catching and tagging sea trout kelts last winter.

All the hard work is paying off, with a tremendous amount of data collected, fish tagged, and information obtained. Of note was that despite a strong output of smolts from the Frome in 2018, very few one-sea-winter salmon (grilse) returned in 2019. Normally there is a good relationship between the numbers of smolts leaving the river and the numbers of adults that return. However, a key difference in 2018 was that despite good numbers, the size of the smolts was smaller, the smallest we have ever recorded, and we believe this might have caused the poor return rate of these fish as adults in 2019 (see page 7).

I'm happy to report that two of our PhD students, Jessica Marsh and Jessica Picken, submitted their theses on the importance of instream vegetation for salmonids (see page 20) and the effect of low flows on salmonid ecosystems (see page 18), respectively, in 2019. I am also delighted to report that, as of last December, Jessica Marsh is now Dr Marsh. Jessica Picken will have her *viva* in 2020 and I wish her all the best.

Wareham harbour. River Frome.

David Mayhew (right) wtith Dylan Roberts.

2019 was personally a very important year for me, where we achieved a long-standing ambition of mine, of getting fisheries conservation organisations to work more closely together. Therefore, I am excited to announce that in November 2019, at Fishmongers Hall in London, we launched the Missing Salmon Alliance. This is a partnership between the Atlantic Salmon Trust, the Game & Wildlife Conservation Trust and the Angling Trust with Fish Legal. Our aim is to work more collaboratively going forward and to share resources and combine fundraising efforts to help solve the mystery of the missing salmon (see page 26).

THE MISSING SALMON ALLIANCE

2020 Covid-19 update

While the world has been in turmoil and lockdown due to the awful Covid-19 virus, I am grateful to the dedication of the fisheries team staff and their partners which enabled us to run the smolt trap on the Frome in spring 2020. The data collected from the smolt trap greatly increases the information obtained from the 13,000 trout and salmon parr that we tagged last September. I am also grateful to the Environment Agency for beginning the operation of their fish trap on the River Tamar in late May, just in time to recapture our returning sea trout with data storage tags.

River Frome salmon population

The GWCT fisheries research group is based at East Stoke on the banks of the River Frome in Dorset, and the Atlantic salmon population in the River Frome is at the core of our work. For nearly 50 years, the number of adult salmon returning to the Frome has been quantified and over the years of studying this population, we have built up an unparalleled monitoring infrastructure at East Stoke and elsewhere in the catchment (see site plan on page 7). Like many rivers feeding the North Atlantic, the number of adult salmon returning to the River Frome showed a marked decline in the early 1990s (see Figure 1).

Because this collapse was observed in rivers across the salmon's distribution, the consensus opinion is that the decline is caused by problems in the marine environment, such as warmer sea temperatures. However, this highlighted the importance of being able to separately analyse the changes affecting survival that occur in freshwater and those that occur at sea.

Only by monitoring both smolt output (freshwater production) and returning adults (marine survival) are we able to separately analyse the two components of the salmon life cycle. Estimating the density of juveniles and the number of emigrating smolts on a catchment scale is difficult. However, it is possible to estimate population size by marking a proportion of the population and then resampling the population at a later time and seeing what proportion of the individuals captured on the second sampling are marked.

At the beginning of the millennium the fisheries group decided to take advantage of developments in Passive Integrated Transponder (PIT) tag technology and use these tags (microchips) to obtain population estimates at the catchment level for juveniles, smolts and returning adults. Whereas conditions at sea are impacted by global activities, managing the freshwater and coastal environments is much more tangible, and optimising the number and the quality of smolts output from freshwater will help to offset a lower marine survival rate and hopefully boost the population.

KEY FINDINGS

- Low numbers of adult salmon returned to the River Frome in 2019, reflecting a very poor smolt run in 2017 and low return rate from the 2018 smolt cohort.
- Poor overwinter survival of juveniles resulted in a mediocre 2019 smolt run despite a bumper density of parr the previous autumn.
- Mean parr size is negatively correlated to density at the catchment level.

Each PIT tag contains a unique code, hence our PIT tag systems not only provide us with population level data, but also life history data of individuals. Using PIT tags, we can quantify and compare parameters such as growth and survival in different parts of the catchment, as well as the impact of the freshwater phase on their probability of marine survival. Hence, we can identify environmental drivers of changes within the population. It is exactly such knowledge that can inform us how best to manage the river catchment to optimise the output of smolts.

Adult salmon estimate

We estimate the number of returning adults using a resistivity counter that detects the change in electrical resistance of the water caused by a salmon swimming over the counter. As well as providing population data, the adult counter provides

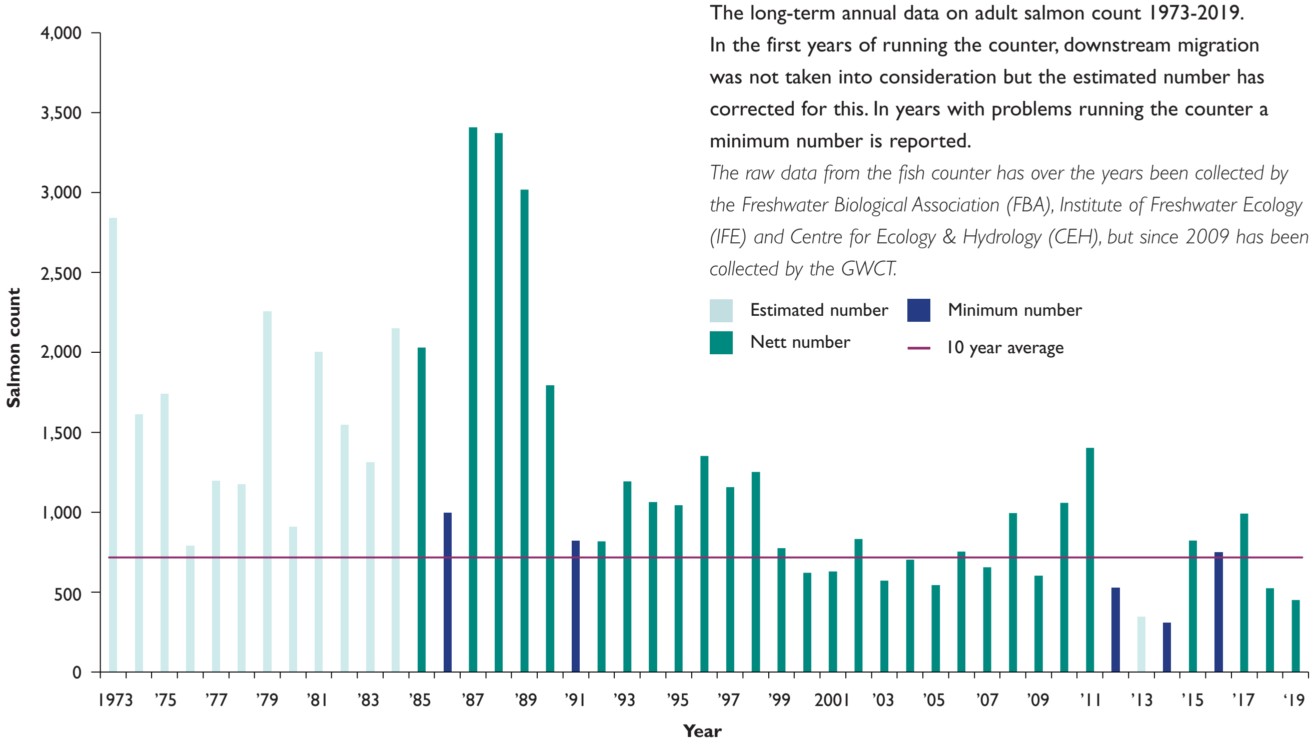


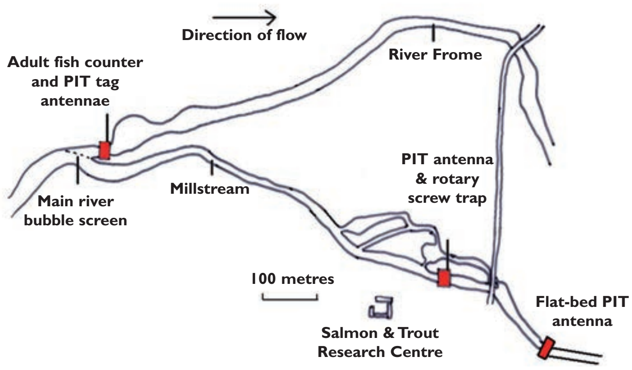
Figure 1

The long-term annual data on adult salmon count 1973-2019. In the first years of running the counter, downstream migration was not taken into consideration but the estimated number has corrected for this. In years with problems running the counter a minimum number is reported.

The raw data from the fish counter has over the years been collected by the Freshwater Biological Association (FBA), Institute of Freshwater Ecology (IFE) and Centre for Ecology & Hydrology (CEH), but since 2009 has been collected by the GWCT.

information on migration timing and the environmental factors that influence this (please contact us for a detailed report from the salmon counter if you're interested). For individuals captured by the video attached to the counter, it also provides estimates of adult fish length, enabling us to look at changes in marine growth over time.

A large part of the effort in running the East Stoke adult counter is focused on verifying and matching the 'counts' from the monitoring equipment. Counts generated by the resistivity counter are identified and verified by a combination of trace waveform analysis and video analysis. An additional estimate of the adult return is made from the PIT tag data obtained from tagged adults as they migrate back into the river. The relationship between the freshwater production of smolts and returning adults enables us to quantify the marine survival of separate smolt cohorts. The combination of adult counter and PIT tag data offer a unique opportunity to answer questions about salmon life history that would be difficult to repeat on other rivers.



Site plan of the counting equipment at the Salmon & Trout Research Centre at East Stoke.

The run of adult salmon in Figure 1 & 2 is presented for the period 1 February to 31 January inclusive. Past data and personal observations indicate that most of the upstream movement in January is caused by the continued migration of fish from the previous calendar year migrating to spawn, not fish migrating to spawn in 11 months' time.

The resistivity counter at East Stoke has been in the river for more than 30 years and it has been clear for some time that it needed to be refurbished. With the help of our SAMARCH project, 2019 saw the fish counter refurbished with a new fibreglass base installed at the bottom of the river (see picture on page 6). The new base has improved the quality of both the electrical signal and the video image, and in 2020 we will update the electronics decoding the signal from the electrodes. This complete overhaul of the resistivity counter ensures that we can continue our long-term data series on adult counts from East Stoke going back to 1973.

A low number of adults returned to the Frome in 2019 (see Figure 1 & 2). The run of two-sea-winter (2SW) Atlantic salmon in 2019 was very poor but this was expected as these 2SW fish originate from the all-time low smolt run of 2017. The run of 1SW fish was also relatively weak, which was a surprise as the smolt run in 2018 was very strong. The 2018 smolts were the smallest recorded since we started monitoring, with a mean length of 128mm compared with a 10-year average of 133mm. Even though 5mm doesn't seem like a big difference, we have shown that larger smolts within the normal size range of one-year old smolts (120-160mm) on the River Frome are more than three times as likely to return from the marine migration than smaller smolts. Size of the smolts in 2018 is probably part of the explanation for the poor return rate but other factors will have affected this also. The poor run of adults in 2019 and resultant low egg deposition is a serious concern for recruitment of juveniles in 2020.

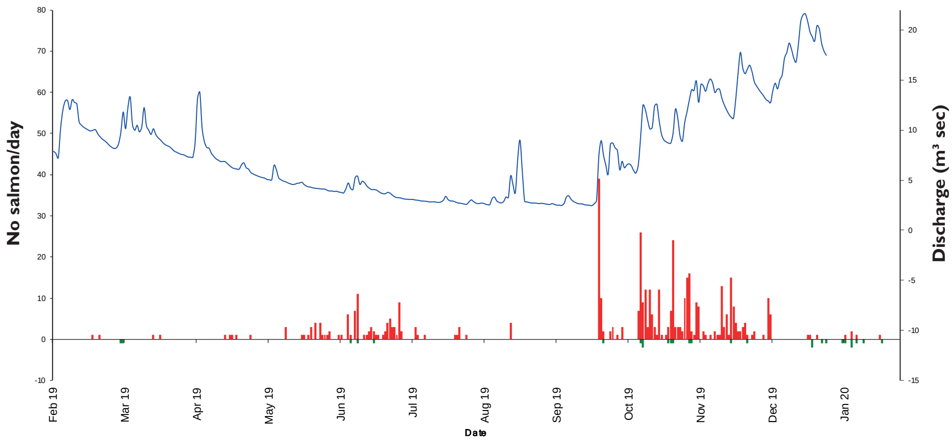


Figure 2

The monthly run data for 2019 is shown in the below table and a graph showing the adult daily gross up- and down-stream numbers and river discharge. During the months January-March post-spawning salmon oscillate up and down over the counter and only detections that are likely to originate from fresh fish are recorded in the nett upstream count.

MONTH	FEB 19	MAR 19	APRIL 19	MAY 19	JUNE 19	JULY 19	AUG 19	SEPT 19	OCT 19	NOV 19	DEC 19	JAN 20	TOTAL
Gross u/s	2	2	5	22	66	13	4	56	152	124	20	5	**471**
Gross d/s	0	1	0	0	2	0	0	1	6	4	4	7	**26**
Nett u/s	2	2	5	22	63	13	4	55	146	120	16	3	**451**

Estimate of juvenile salmon

In September each year since 2005, we have electric-fished and tagged approximately 10,000 juvenile salmon (8-15% of the juvenile salmon population in the catchment) with PIT tags. These small tags (just 12mm long x 2mm in diameter) are inserted into parr and enable us to identify individual fish when they swim past our detector antennae. The PIT tag stays with the fish for life and passage of tagged fish out to sea, and any fish returning from the sea, are recorded by the tag detecting equipment installed throughout the catchment.

Despite a relatively low number of spawners in 2018 we encountered reasonable numbers of parr during our 2019 parr-tagging campaign. In most parts of the catchment there was good weed cover *(Ranunculus sp.)*, which we have shown benefits parr densities as well as their growth rate (see page 20). Similar to 2018, dry settled weather prevailed during the parr-tagging campaign, but it still took two teams of seven people, 21 days to catch and tag the target 10,000 salmon parr and 3,000 trout parr.

We can determine how many juveniles there were in the catchment at the time of tagging from the number of tagged juveniles and the proportion of PIT tagged smolts the following spring. The estimated juvenile population in the catchment in 2018 was 127,505, which is the third highest number recorded and well above the 10-year average (97,432, see Figure 3).

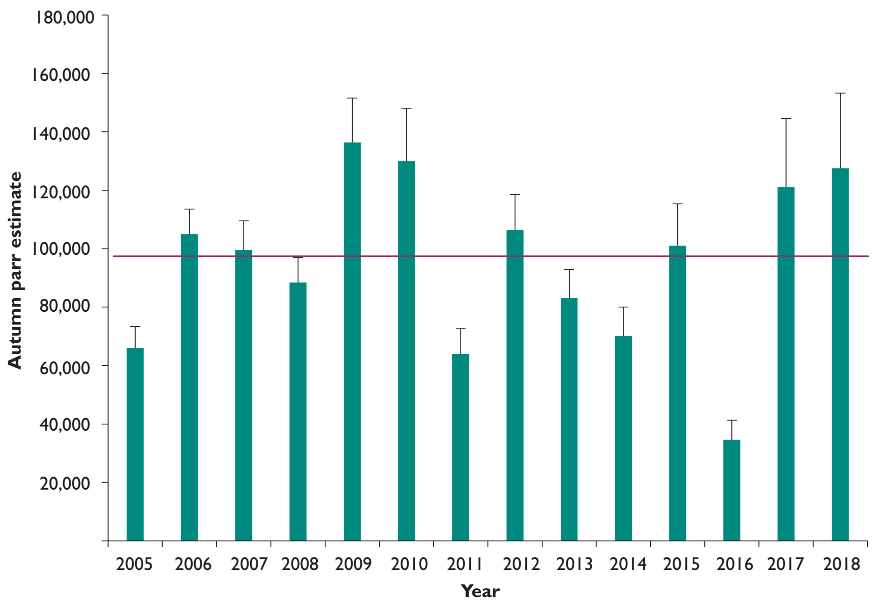


Figure 3

Estimated number of salmon parr in the Frome catchment in September with upper 95% confidence limit (2005-2018)

10 year average

Smolt estimate

We have estimated the number of smolts emigrating from the river since 1995 but the installation of our first PIT antennae in 2002 marked a milestone in the accuracy of these estimates. This methodology has allowed us to provide a very accurate estimate and to calculate potential variation around this estimate (with 95% confidence intervals).

During the smolt run we normally use a device called a Bio-Acoustic Fish Fence (BAFF) to divert the fish into the Millstream at East Stoke (see site plan on page 7). However, in 2019 heavy rain in March and April resulted in high flows during the smolt run. Consequently, for the second consecutive year we were unable to deploy our BAFF before commencing trapping on 25 March. In place of the BAFF we resorted to installing a fence consisting of bubbles only, which deflected smolts albeit less efficiently, but on 15 April the water level had dropped enough for us to deploy the BAFF system and operate it for the remainder of the smolt run. In the Millstream, a proportion of the deflected fish are trapped using a rotary screw trap (RST).

Despite the logistical issues caused by the unusually high river levels, we were able to catch enough individuals in the trap to get good smolt biometric data, to estimate the tagged to non-tagged ratio and successfully estimate the size of the 2019 smolt cohort.

In 2019 an estimated 9,185 (±1,578) smolts left the River Frome (see Figure 4). This is slightly below the 10-year average (9,341), which is disappointing given that the number of parr in the catchment in 2018 was the third highest recorded since estimates started in 2005 (see above). In the Frome catchment there is a negative correlation between number of parr in the catchment and their mean size, whereby mean size reduces by approximately 0.8mm per 10,000 parr in the catchment (see Figure 5). So, as expected, with high numbers of parr in 2018, average size was small. In fact, it was the smallest on record and more than 5mm smaller than the 10-year average. The small size of the parr will have impacted their fitness, but it is likely that other factors contributed to the poor overwinter survival and resulting disappointing smolt run in 2019.

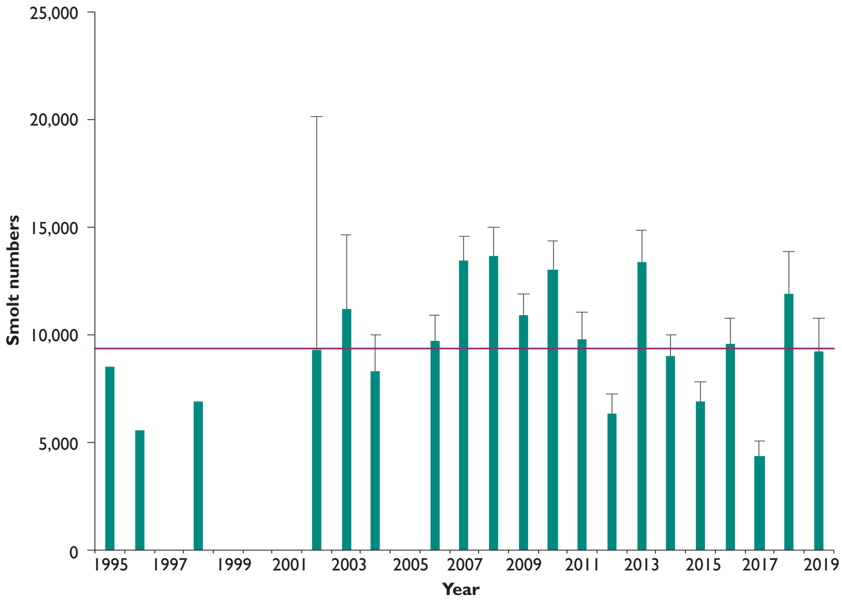


Figure 4

Estimated spring smolt population with upper 95% confidence intervals 1995-2019

— 10 year average

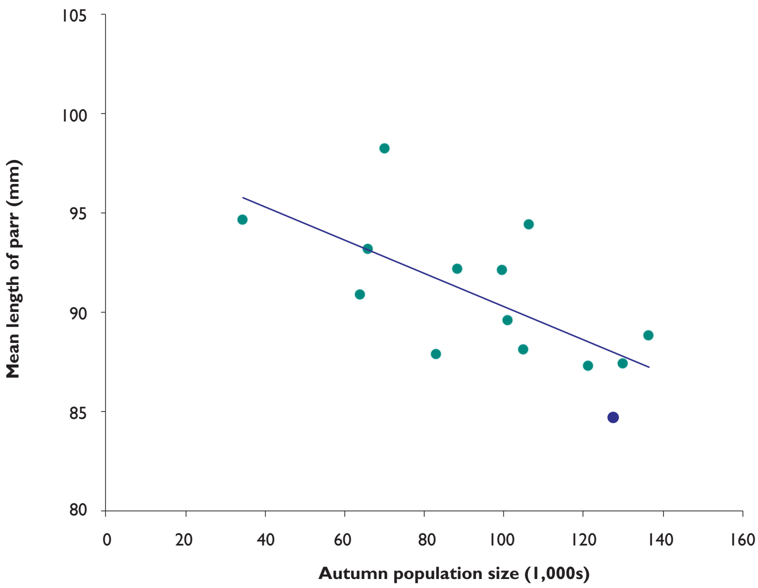


Figure 5

The relationship between the population size of juvenile Atlantic salmon in the catchment and their average size. Each dot represents a year and the blue dot is 2018. ($y = -0.084x + 98.67$, $R^2 = 0.454$) ; slope $\neq 0$ $p<0.01$

Rasmus Lauridsen is head of GWCT Fisheries Research. He primarily does research on the migration strategy of young salmon and the drivers and consequences of different life history choices.

Smolt tracking

During the springs of 2018 and 2019, we inserted acoustic tags into Atlantic salmon and sea trout smolts captured in four rivers discharging into the English Channel (Rivers Tamar and Frome in the UK and Rivers Bresle and Scorff in France) to follow their downstream migration to sea. Acoustic receivers recording the identity of individual fish and the date and the time of their passage were deployed along their migration path in the four estuaries.

The resulting data enable us to follow a fish from the moment we tagged it until it reaches the open sea, where the last acoustic receiver is located. We focused our study on the estuarine environment to investigate the importance of this transitional environment for salmon and sea trout smolts: how long they stay there and how many are lost while crossing these areas that are characterised by highly variable water parameters, predators and diverse human activities.

Across the whole study, 444 salmon smolts and 336 sea trout smolts were detected in our study estuaries. Of these 364 (82%) salmon and 296 (88%) sea trout were detected reaching the sea. The percentage of 'successful' individuals varied among estuaries: the highest success rate was on the Tamar estuary (84% and 97% for salmon and sea trout, respectively) and the lowest on the Frome estuary (70% and 79%, respectively). Within each individual estuary, sea trout smolts had higher migration success compared with salmon smolts (see Figure 1).

There was a progressive loss of individuals along their migration path, but none of the measured parameters of the fish, including age, size and sex, appear to explain the patterns observed in smolt migration success. Further investigations will be necessary to confirm and understand these findings.

This study also demonstrated that sea trout smolts spent some time in estuaries (three to 16 days), perhaps to feed in this highly productive environment. In contrast, Atlantic salmon smolts crossed this environment with minimum delay (2.5 days on average), to continue their migration to the North Atlantic.

We are sharing these findings and information with environmental managers in the UK and France, which will enable them to implement actions to improve local species management where necessary.

KEY FINDINGS

- Depending on the estuary and year, between 16-30% of salmon smolts and 3-21% of sea trout smolts never reach the sea.
- In the estuary, salmon and sea trout smolts migrated to the sea at a mean speed of 1.7 and 1.2km per hour respectively.
- Salmon smolts dashed through the estuarine environment in less than 2.5 days, whereas sea trout smolts spent up to 16 days in the estuary.

Céline Artero has a PhD in fish ecology and conservation and is a marine biology and ecology specialist. Prior to joining the GWCT, Céline worked at the French Institute of Research for Exploitation of the Sea (Ifremer).

In-river range testing of acoustic tags.

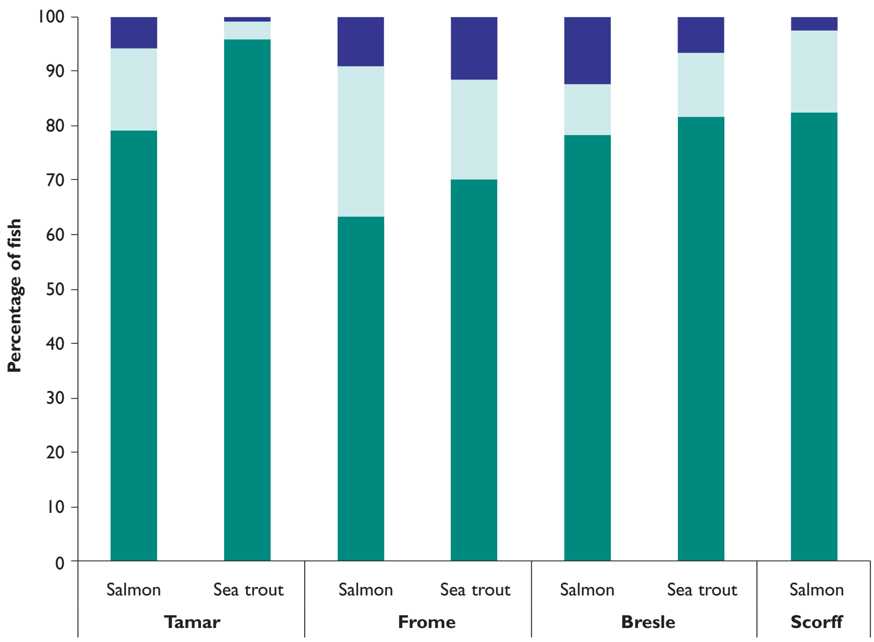


Figure 1

Percentage of migration success of salmon and sea trout smolts in the Rivers Tamar, Frome (UK), Bresle and Scorff (France). There are no sea trout on the River Scorff, so only salmon were surveyed

- Reaching the sea
- Not reaching the sea
- Not detected after tagging

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Protecting salmon and sea trout at sea

Populations of Atlantic salmon have declined significantly across the UK in recent years. There are also growing concerns regarding the resilience of some sea trout stocks following notable declines in numbers of older fish. There is currently much debate as to the reasons for this with the finger of blame often pointed towards climate change within the marine environment. This may well be affecting migratory pathways as well as the location, quality and quantity of their food at sea. However, to place all of the blame on climate change would conveniently underestimate the impact of other anthropogenic activities.

This is particularly relevant to salmon and sea trout within transitional and inshore coastal waters where both species are potentially under threat from a range of activities that we could address and manage. To investigate the need for additional stock protection measures, SAMARCH seeks to shed light on the biology and behaviour of salmonids as they move through and use inshore and coastal waters.

Commercial fishing activity represents one such potential threat and some of the facts surrounding the extent of commercial fishing practice are rather surprising. For instance, in 2017, there were 6,148 registered UK commercial fishing vessels. Of these, 4,834 vessels were small boats of less than 10 metres in length. The vast majority of these smaller vessels are taking mid-water fish, landing an estimated 400,000 tonnes of pelagic fish in 2017, compared with 180,000 and 130,000 tonnes of bottom-dwelling fish and shellfish respectively. Salmon and sea trout use the upper and middle levels of our oceans before returning to their natal rivers to spawn.

Many of the smaller vessels use gill nets to catch species such as mackerel, herring, bass and mullet. It is estimated that around the coast of Cornwall each week there are some 1.16 million metres (m) of nets used, which can be compared with Scotland where there is a total ban on gill netting in inshore waters using monofilament nets.

KEY FINDINGS

- In the English Channel the rules to protect salmon and sea trout from coastal gill nets include that the top of nets should be set at least three metres below the surface because it is assumed that sea trout swim near the surface.
- Our data suggest sea trout dive to 50 metres and spend most of their time below three metres.
- Some 1.16 million metres of gill nets are set off the coast of Cornwall each week.
- We caught 34 sea trout and six salmon while fishing just three gill nets, in 23 overnight netting sessions, off the coast of Cornwall and Dorset.

Sea trout captured in coastal trial nets set in the English Channel.

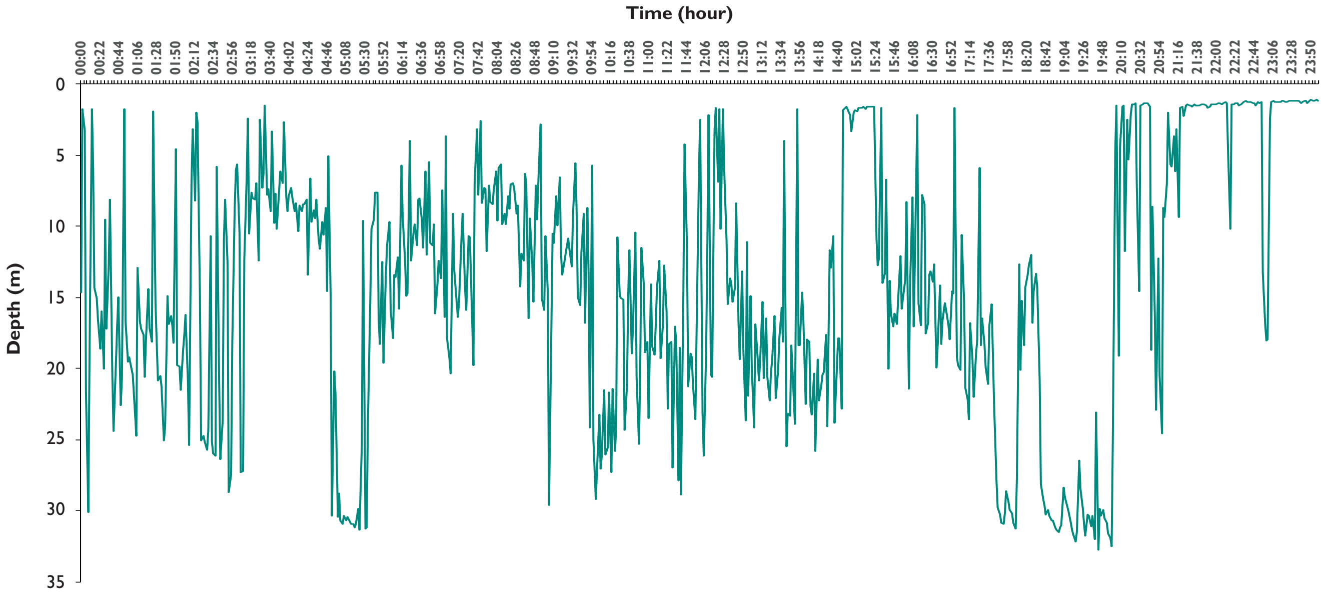

Figure 1

Example of the daily vertical behaviour of an adult sea trout during its marine migration

To protect stocks, bylaws are in place to prohibit fishing with gill nets in England and Wales in areas where salmon and sea trout may congregate, especially in and around estuaries. In addition, within six miles off the coast of England gill nets cannot be set within three metres and seven metres of the surface, in the south and north of England respectively. This is called a headline rule, however, in Wales, headline rules are largely not applied but nets are limited to 200m in length and must have a 100m gap between each net. The headline rule assumes that salmon and sea trout swim near the surface and are therefore protected.

These bylaws may be inadequate to fully protect these species, especially given that sea trout in particular remain close to shore and in most cases do not undergo the long marine migration of their salmon cousins to the north and west Atlantic. There is also very limited evidence that sea trout spend all their time near the surface. Therefore, to inform future management of sea fishing activities it is crucial that we gather robust evidence on where and when these fish are at sea, together with information relating to their swimming depths.

You will have read in our *Review of 2018* (see page 30) that we are undertaking a study using specialist data tags in sea trout to obtain information on their locations and swimming depths at sea. Early results suggest that they spend most of their time below five metres, which has major implications for the current effectiveness of the headline rule.

In 2019, under dispensation from the Environment Agency, we initiated some trials which entailed setting commercial gill nets off the coast of Cornwall and Dorset. The aim was to monitor their catches and record any salmon and sea trout caught. The netsmen set 800m of nets on 23 evenings between April and July, leaving the nets overnight before recovering them. Among their catch were 34 sea trout and six salmon. We made full use of their carcasses by investigating their genetics, diet, parasitology, toxicology and even the presence of plastics.

We are working closely with our SAMARCH partners the Environment Agency, which has responsibility for managing salmon and sea trout within six miles of the coastline in England, to ensure that this information influences the current bylaw reviews being drawn up by the Inland Fisheries Conservation Authorities (IFCA), which manage coastal netting. This work is part-funded by the EU's Interreg Channel VA programme.

Dylan Roberts is head of GWCT Fisheries and project manager for the SAMARCH project. Dylan has worked for GWCT since 1998 and is passionate about the conservation of migratory salmonids.

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Capturing post-spawning sea trout

The 2019 challenge for the fisheries team

As part of the SAMARCH project we are catching post-spawning sea trout in the river, to track their subsequent marine migration. We are undertaking this work in the Rivers Tamar and Frome, both in the UK, and the River Bresle in France. In the River Bresle, downstream fish traps are used to capture outward migrating kelts (see picture 1). However, for the UK rivers there are no such facilities and little knowledge existed on the timing and behaviour of post-spawning sea trout and how best to capture them.

As no installations existed on the Tamar or the Frome, it was necessary to establish a methodology to capture post-spawning sea trout kelts. This methodology must be gentle on the fish because the goal is to release them alive and in good condition. Furthermore, capture must occur at the right time while avoiding disturbing the spawning event of sea trout and Atlantic salmon.

At our first attempt during winter 2017/2018, we electric-fished a short distance downstream of the main sea trout spawning areas, by wading in the shallow areas and from a small inflatable boat in deeper, but calm, areas. The electric-fishing methodology worked but very few individuals were captured and tagged on each river.

The tracking data from the 16 fish tagged during the winter 2017/2018 informed us why only a few fish were captured with this methodology: the tagged fish left their spawning sites immediately after the spawning event and migrated to the lower river where they rested for a few months before going back to sea, hence looking for them

KEY FINDINGS

- Sea trout kelts leave their spawning sites immediately after the spawning event and migrate to the lower river where they rest for a few months.
- Capture of post-spawning sea trout during autumn/winter is technically and physically challenging.
- Electric-fishing the lower river is the most efficient way to capture sea trout on Rivers Frome and Tamar.

Picture 1 *A downstream fish trap on the River Bresle.*

Picture 2 *Electric-fishing on the lower River Frome using a large boom boat.*

in the upper river after the spawning event is not a good strategy.

With the knowledge acquired during the first year, we developed a new strategy to capture the post-spawning individuals during the winter of 2018/2019. This strategy was two pronged: A) to trap the individuals when they move from their spawning sites to their resting sites in the lower river and B) to electric-fish in the lower river (see Picture 2). Two rotary screw traps (see Picture 3), floating conical chamber with a screw thread inside, rotated by the river current that end with an enclosed trap, were deployed on Tamar tributaries before the spawning and an old trap for silver eel was used on the River Frome. Unfortunately trapping resulted in very few individuals caught despite lots of manhours spent running the traps. A number of factors contributed to the low catch in the traps: 1) it wasn't possible to use the rotary screw traps during peak spate; 2) it was dangerous to run the rotary screw traps when the river carried lots of leaves and trees; 3) the number of sea trout returning to reproduce in the River Tamar was at a historic low that year.

Picture 3 *A rotary screw trap ready to be deployed in the Tamar catchment.*

Unlike trapping, electric-fishing the lower River Frome from a boat was very successful and we captured and tagged 39 individuals using this methodology.

Hence it was clear that electric-fishing with a boom boat in the lower river was the most efficient methodology to capture post-spawning sea trout on the River Frome, but how to adapt this methodology from River Frome, a low energy chalk stream, to the very spatey River Tamar?

During 2019, the fisheries team designed a new boom boat that enabled the team to electric-fish the River Tamar during the winter of 2019/2020. This new 'rafting boom boat' consisted of two people sitting across the pontoons of an inflatable dinghy while paddling it like a rafting boat. A third person was at the downstream end of the boat by the fixed anodes ready to net out the incapacitated fish (see Picture 4). The methodology was tested on the River Tamar in December 2019. Resting sites on the main river were electric-fished successfully despite very challenging river conditions: very high water level, turbidity and current. With this method we captured and tagged 72 post-spawning sea trout on the two rivers during the 2019/2020 winter.

Picture 4 *Electric-fishing the River Tamar with a rafting boom boat.*

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Why was 2016 such a bad year for salmon recruitment?

It was widely reported that numbers of juvenile Atlantic salmon were substantially reduced in rivers around the southern part of their European distribution, including England and Wales, in 2016. For example, it was highlighted in a recent GWCT-authored scientific paper on River Frome salmon, the *GWCT Fisheries research review 2018* and the ICES Working Group on North Atlantic Salmon 2017 report.

This observation gave rise to significant and widespread concerns about the status and vulnerability of stocks, many of which were already depleted, because poor juvenile recruitment will normally result in poor adult returns, as has been observed on the River Frome and elsewhere (see the *GWCT Fisheries research review 2018*).

Given the likely negative effect of poor recruitment on already depleted salmon populations, managers and researchers were asking questions: was 2016 a poor salmon recruitment year compared with the recent past? And if so, what caused it?

In an effort to answer these questions in Wales, Natural Resources Wales (NRW) carried out follow-up electric-fishing survey work (2016-2018) on seven rivers broadly representative of rivers around Wales (see Figure 1), and commissioned the GWCT and the WRC Plc to analyse these and associated fisheries and environmental data sets, to examine the extent and possible causes of the 2016 recruitment failure. The analysis included historic time-series of electric-fishing survey data and egg deposition estimates extending back to 1992, along with associated river flow and temperature data.

We explored these data visually and using advanced statistical models. There were some clear patterns in the electric-fishing abundance data (see Figure 2): in nearly all the catchments the 2016 abundances were the lowest on record, while those for the Dee and Wye were among the lowest on record.

Exploration of the river flow and air temperature (used as a proxy of water temperature) data confirmed the prevailing but hitherto untested opinion that the decline coincided with extreme winter weather conditions.

Specifically, we explored the influence of a range of ecologically and behaviourally relevant environmental explanatory variables, for the period 1992-2018, and showed that warm temperatures and high flows adversely affected recruitment in these populations. Moreover, it appeared that 2016 was unusually warm and wet (see Figure 3).

Our findings highlight the vulnerability of already weakened salmon populations to extreme weather events that are forecast to become more frequent and intense under future climate change scenarios. More imminently, it is being reported that the winter of 2019/2020 was the

KEY FINDINGS

Commissioned by Natural Resources Wales (NRW), this study:

- Confirmed that 2016 was a recruitment crash for salmon in Wales.
- Uncovered evidence that the crash was due to unfavourable river conditions.
- Overwinter river temperatures were too high for spawning.
- Spring floods overwhelmed the few eggs that were spawned or hatched.
- 2019 was the warmest winter on record, and climate change threatens to bring worse overwinter conditions for salmon in the future.

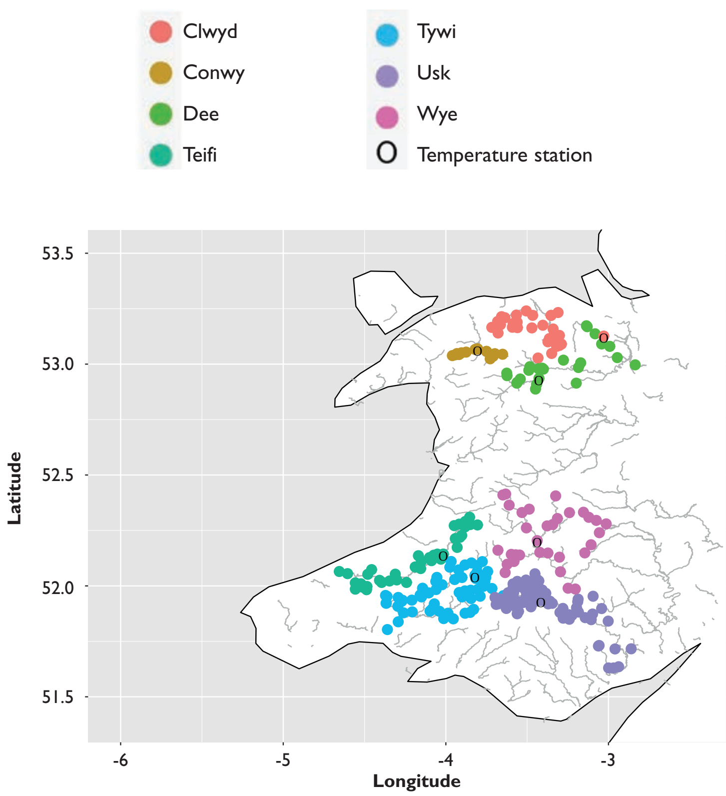

Figure 1

Location of electric-fishing sites, coloured by river catchment.

warmest on record and it was probably among the wettest, raising further concerns for returning adult runs in 2022 and beyond.

Stephen Gregory is our fisheries ecologist and statistician. He is a keen conservationist who uses population dynamics modelling to inform management of endangered populations and species.

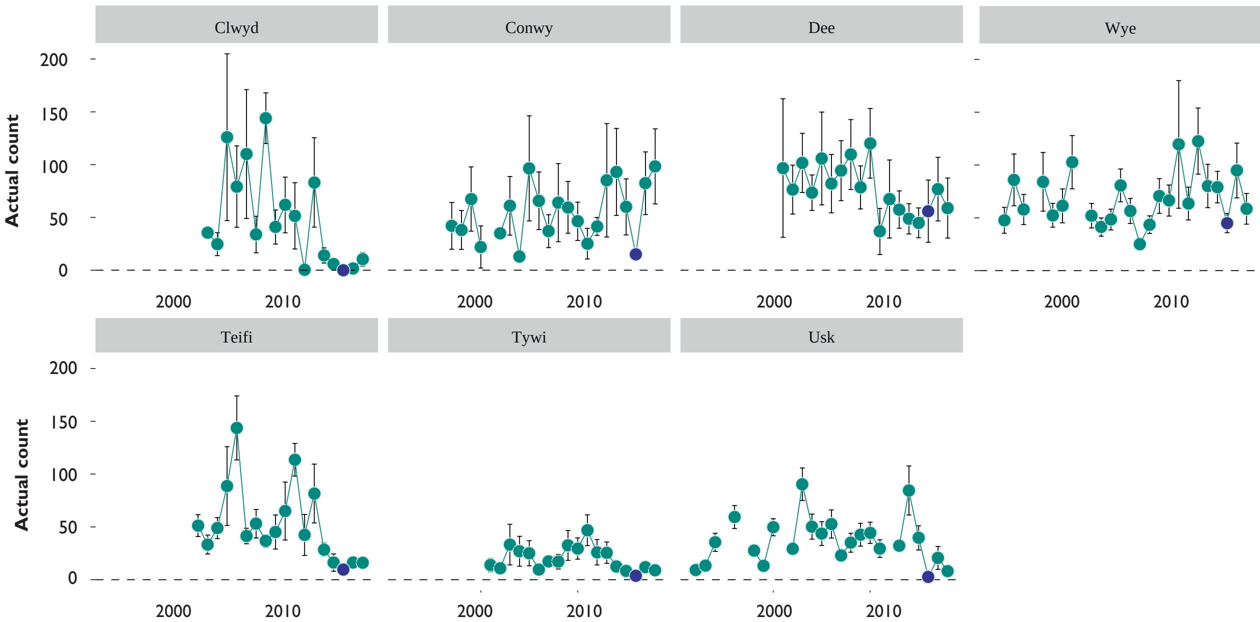

Figure 2

A line plot showing the mean (with standard error) of juvenile salmon counts over all sites in each catchment. The blue point shows the 2016 sampling year.

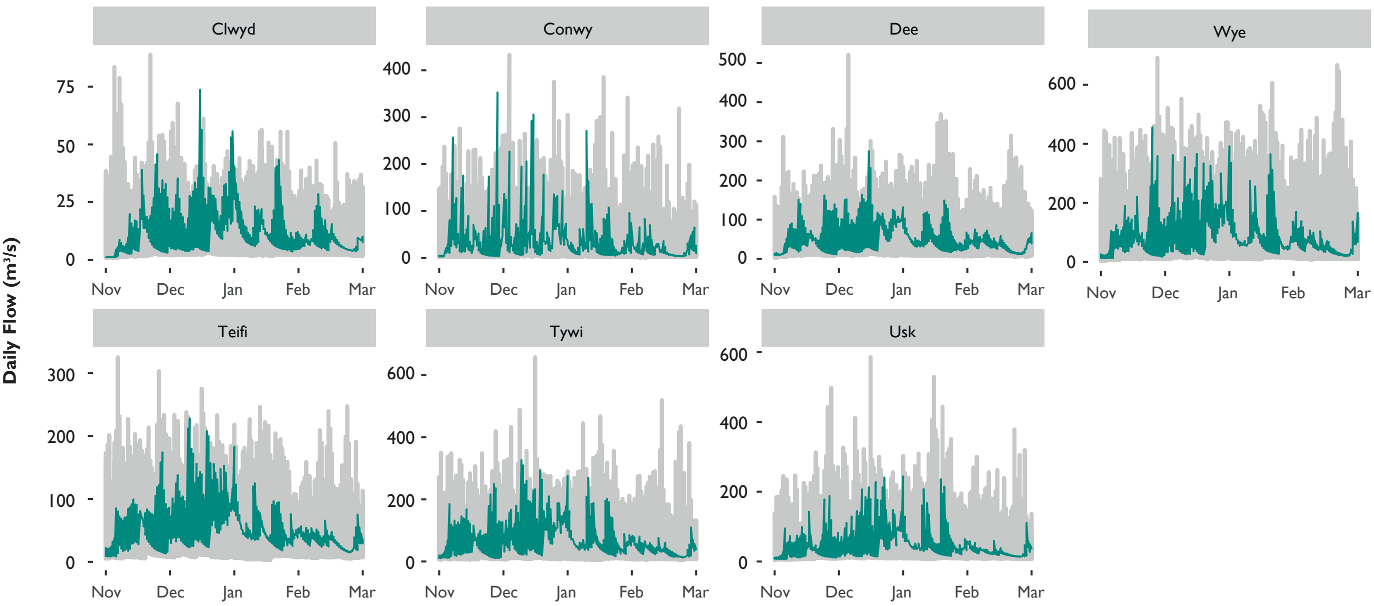

Figure 3

Daily flows for November through to March in 2015/2016 (green) compared with flows for 1992 to 2018 (grey) in the background

Effects of low summer discharge on salmonid ecosystems

The chalk streams of England are predominantly groundwater fed and, as a consequence, have a high base flow index. Increasing water demand and resulting abstraction from the groundwater aquifers, coupled with reduced recharge of aquifers as a consequence of projected climate change, are among the biggest threats to chalk stream ecosystems. Despite this, the ecological implications of the potential changes in river discharge have received limited attention, at relevant scale. This PhD research used a large (stream)-scale discharge manipulation experiment in three chalk streams within the Hampshire Itchen catchment, where sluice gates at the top of each stream enabled complete control of discharge, to investigate the ecosystem level response to simulated drought (reduced summer discharge). Experimental summer discharge reductions of 50% and 90% were selected based on long-term records of summer discharge (1975-2018) on the River Itchen and River Test, and implemented on each of the three streams over three consecutive years using a temporal block design.

Stream physical characteristics, basal resources and macroinvertebrates were monitored, as was salmonid diet, habitat use, growth, movement and population size. Sampling occurred before, during and after a 30-day long reduction in discharge each summer. Changes in the physical habitat were quantified by repeated recordings of water depth, velocity, wetted width and temperature, and samples of basal resources (detritus and benthic algae) were taken. The response of macroinvertebrates and prey availability for salmonids was determined by collecting Surber and drift net samples. Salmonid diet was quantified by analysing stomach contents and salmonid movements were monitored using Passive Integrated Transponder (PIT) tag technology. Salmonid populations were monitored using electric-fishing.

Figure 1 represents the hypothesised and realised effects of reduced discharge on the salmonid ecosystem.

KEY FINDINGS

- Increased abstraction and climate change will likely reduce summer flow in southern chalk streams in the future.
- A 30-day experimental discharge reduction in the Itchen catchment significantly impacted depth, velocity and wetted width of the streams
- Despite changing the physical characteristics of the streams, we observed limited impact on basal resources, macroinvertebrates and the fish community composition.
- Fish behaviour was impacted by discharge reduction with site loyalty reduced for many groups and evidence for older trout leaving the affected streams during discharge reduction.

Despite substantial reductions in water depth, velocity and wetted width, and an increase in mean and variation of water temperature, there were limited changes in basal resources and no effect on macroinvertebrate density as a result of discharge reduction. Reduced discharge did result in a significant change in macroinvertebrate community composition, but the size of the effect was small in comparison with the variation between sampling occasions (seasonal response). In addition to a limited response by invertebrates, salmonids displayed high dietary plasticity. For example, 0+ trout consumed larger prey items within the discharge reduction treatments compared with the control.

Site loyalty decreased for salmon, 0+ and ≥2+ trout during the 90% discharge reduction. Older (≥2+) trout were more likely to move out of the affected area during a 90% discharge reduction, which corresponded with reduced site loyalty. Salmon was the only species to move back into

Nets sampling invertebrate drift.

the study area after the reinstatement of pre-manipulation discharge, potentially due to reduced competition by older (≥2+) trout.

There were no lasting effects of discharge reduction on site loyalty, which indicates that these salmonids were resilient to reduced discharge conditions. Yearling (1+) trout adopted a 'sit it out' strategy during reduced discharge conditions. Adopting this strategy increased growth rate and allowed for the expansion of area used once discharge was reinstated to pre-manipulation levels. There were no effects of discharge reduction on population size, although there was a slight (but not significant) effect on salmonid population density after the streams had experienced a 90% discharge reduction. This research highlights that, despite a marked response in the recorded physical characteristics of the streams, macroinvertebrates and salmonids within these chalk streams display a remarkable resistance/resilience to short-term summer discharge reduction. This suggests that they are highly adaptable species and during short-term summer discharge reduction it may be better for river managers not to intervene, even under severe discharge reductions.

Blackfly larvae and cased cadis flies were among the common macroinvertebrates.

However, the discharge reductions were limited to 30 days and hence this study does not inform on the effect of prolonged or increased frequency of drought periods.

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Cefas

Jessica Picken is a PhD student working with the GWCT, Queen Mary University of London, Cefas and Cardiff University, looking at aquatic macroinvertebrates and salmonids in chalk streams to investigate the effects of low flow on these ecosystems.

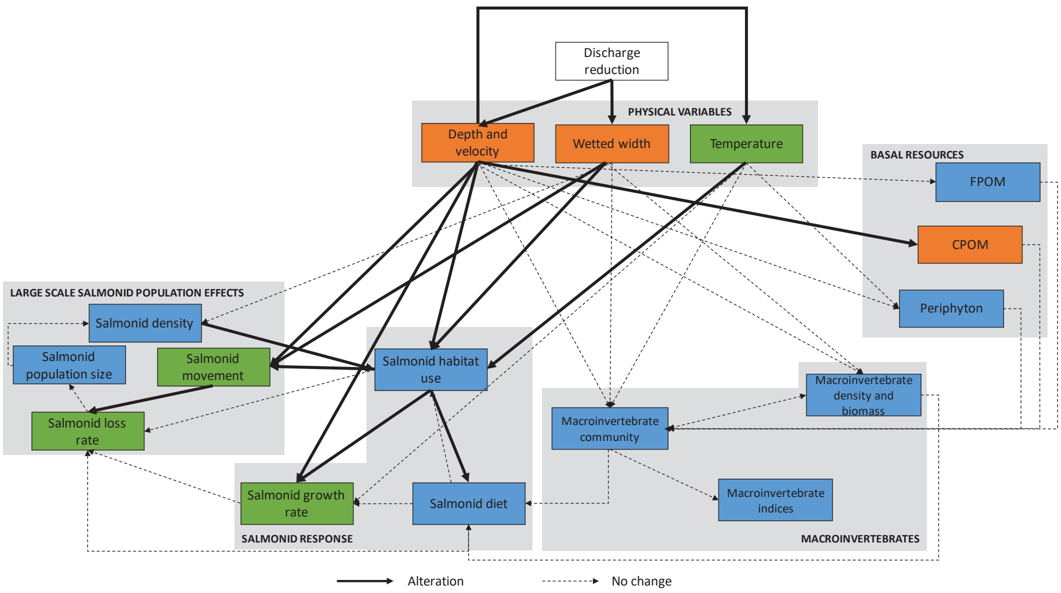


Figure 1 Effects that experimental discharge reduction had on salmonid ecosystems. The links are based on hypothesised effects and solid lines indicate confirmed effects. Coloured boxes indicate increase (green), decrease (orange) and no-directional change (blue) as a result of experimental discharge reduction.

Weeding out the difference

How *Ranunculus* cover is beneficial for juvenile salmon

After showing that greater abundances of juvenile Atlantic salmon were associated with higher cover of the aquatic plant *Ranunculus* (see last year's *Fisheries Review* page 26), we completed an in-river experiment to quantify the effect of *Ranunculus* on juvenile salmon and their river habitat. This experiment ran for two years (2016-17) in nine sites situated on the North Stream of the River Frome. In Spring 2016, we manipulated *Ranunculus* cover to achieve three 'low' (less than 10%), three 'medium' (30-40%) and three 'high' (greater than 60%) cover sites. The desired cover level was achieved by removing existing *Ranunculus* plants and re-planting as required, and we maintained the cover levels throughout summer until autumn when the plants naturally died back.

We sampled the nine sites throughout the experiment to monitor the manipulated *Ranunculus* cover, the river habitat (eg. water depth and velocity), and the aquatic invertebrate prey resource. We also monitored the juvenile salmon. Specifically, between June and October of each year, we electric-fished each site to determine the abundance of juvenile salmon. We collected length and weight measurements of individuals and captured fish were tagged with a PIT tag so that we could track the growth of individuals. For a random sample of salmon, we also collected gut contents using non-lethal stomach flushing. This sampling allowed us to test whether the cover of *Ranunculus* influenced abundance, growth rate and diet of juvenile salmon.

We calculated the relative growth rate of recaptured individuals to assess how much weight had been gained relative to their initial weight. The total diet biomass of each individual fish was estimated based on the size and taxa of the invertebrates contained in the diet. We developed statistical analyses to test the effect of *Ranunculus* on abundance, relative growth rate and total diet biomass. The effect of *Ranunculus* on these response variables was strongest in the summer (June-August), so here we show results from this period.

Electric-fishing the experimental reaches.

KEY FINDINGS

- The influence of *Ranunculus* cover on abundance and growth rates of juvenile salmon was strongest in the summer (June-August).
- During summer, greater abundances of salmon were supported by higher *Ranunculus* cover.
- Salmon caught in high *Ranunculus* cover also had greater biomass of prey in their stomachs, and their growth rates were greater suggesting more successful feeding opportunities.

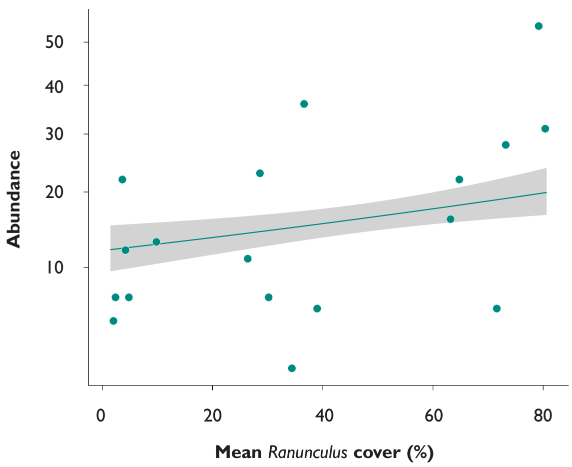
Our results showed that in August there was a positive effect of *Ranunculus* cover on the abundance of juvenile salmon, that is there were significantly more salmon caught in high cover sites relative to low cover sites (see Figure 1a). Between June and August, the relative growth rate of recaptured individuals was also positively influenced by *Ranunculus* cover, albeit a weaker effect (see Figure 1b). In other words the growth rate of individuals that were caught and recaptured in high cover sites was greater than those repeatedly captured in low cover sites. Additionally, we showed that salmon that were caught in high *Ranunculus* cover sites had on average a greater biomass of diet contents in their stomachs, than those caught in low *Ranunculus* cover sites (see Figure 2).

Together these results suggest that high *Ranunculus* cover was supporting not just greater numbers of juvenile salmon, but also providing ample growth opportunities even at higher densities. This relationship was possibly driven by better feeding opportunities in high cover sites, which could have been influenced by *Ranunculus* creating more suitable habitat for aquatic invertebrate prey, and/or creating conditions that favoured salmon feeding behaviours. These findings highlight the importance of *Ranunculus* cover to juvenile salmon during their critical summer feeding period, and should contribute to management strategies of in-stream and riparian habitats.

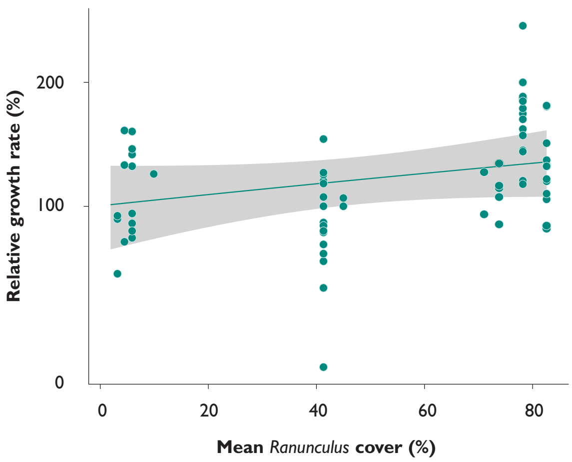
Figure 1

The partial effect of *Ranunculus* cover on (a) juvenile salmon abundance in August, and (b) relative growth rates of individuals that were captured in June and recaptured in August at the same site. This is the effect of *Ranunculus* whilst holding all other tested effects in the analysis constant at their mean value. The solid line is the mean effect and the shaded grey area is the associated uncertainty. The circles are the observed abundance and growth rate data. The scale of the y-axis in (a) is square-root transformed."

(a)



(b)



Top: Patches of Ranunculus *plants that had been planted into a site in spring to achieve 'high'* Ranunculus *cover.*

Bottom: Estimating the percentage of Ranunculus *cover in one of the nine experimental sites.*

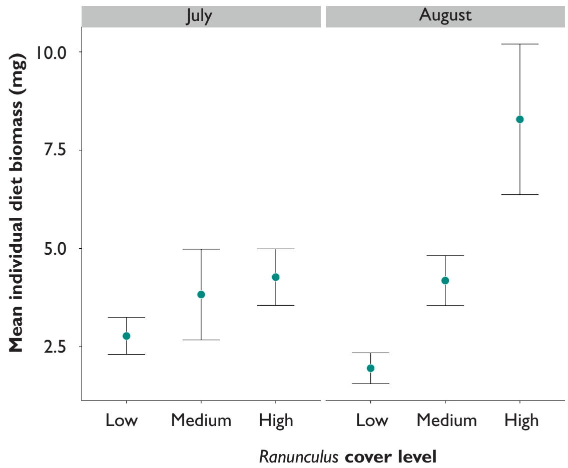


Figure 2

Mean individual diet biomass of juvenile salmon caught in low, medium or high *Ranunculus* cover in June and August. The point is the average individual diet biomass and the error bars represent the standard error around the mean.

Dr Jessica Marsh is a former PhD student working with GWCT Fisheries Team and Queen Mary, University of London River Communities Group. She successfully defended her PhD thesis entitled 'The importance of *Ranunculus spp*. for juvenile salmonids in lowland rivers' in December 2019.
This PhD was funded by the G and K Boyes Trust.

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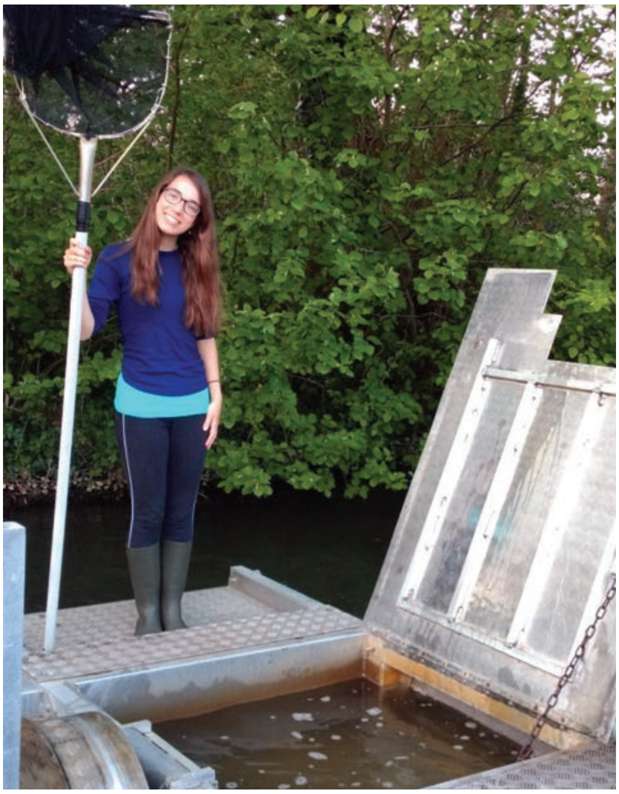
Towards understanding smolt migration timing and factors affecting it

Atlantic salmon (*Salmo salar)* spend part of their lives in freshwater and part of their lives at sea. To cope with this anadromous lifestyle, juvenile Atlantic salmon (called 'parr') undergo a physiologically intense and energetically demanding metamorphosis to become a 'smolt' before they migrate to sea. During this challenging time, many factors can impact several aspects of their ecology and behaviour, such as their condition, survival and migration timing. Smolt migration timing is crucial to their success during the early phase of their at-sea migration; too early and conditions at sea will be too cold and prey abundance may be low, too late and they may face greater predation risks and the abundance of their preferred prey may have declined.

We explored the impacts of various environmental, biological, and behavioural variables on smolt migration timing in the River Frome. We used data from 13 years, where individually tagged salmon smolts were captured in a rotary screw trap as they migrated downstream. Individuals were identified and measured (fork length) before being released to continue their migration. Based on local expertise and



Olivia smolt trapping at East Stoke on the River Frome.

KEY FINDINGS

- Both water temperature and river discharge affect the probability of Atlantic salmon smolts migrating each day of the smolt run
- Larger smolts are more likely to migrate earlier in the smolt run than smaller smolts
- More smolts migrate during the night than during the day throughout the smolt run; in the beginning of the smolt run smolts migrate only at night.

scientific literature, we hypothesized that six variables would affect the probability of each individual smolt migrating on any given day during their spring-time migration period (called the 'smolt run').

Our environmental variables included the mean water temperature and the mean daily river discharge for each day during the smolt run. We hypothesised that the probability of a smolt migrating on a particular day would increase on days with warmer mean water temperatures and lower mean discharge. Our biological variables included the body length of each smolt and how far each smolt had to migrate down the river. We hypothesised that larger smolts and individuals that reared as parr further upstream were more likely to migrate earlier in the smolt run. Finally, our behavioural variable was whether each smolt was a 'daytime' migrant or a 'night-time' migrant. We hypothesised that night-time migrants were more likely to migrate earlier in the smolt run than daytime migrants. We also explored how the timing of the smolt run varied between years across our time series.

Over 13 years (2006-2018), we captured 3,899 salmon smolts that had been tagged six months earlier. Visual examination of these data offers some interesting insights. Figure 1 shows the number of tagged smolts that were captured each day of the smolt run, over each of the 13 years we've been trapping. The days are determined as the number of days from 1 January each year, so that day 80 is 20 March and day 140 is 19 May. Generally, during the smolt run fewer smolts migrate in the beginning and towards the end of the spring migration period, while most smolts migrate towards the middle of the smolt run. Figure 2 shows the raw data for each of the other variables we tested.

We see that during the smolt run mean daily water

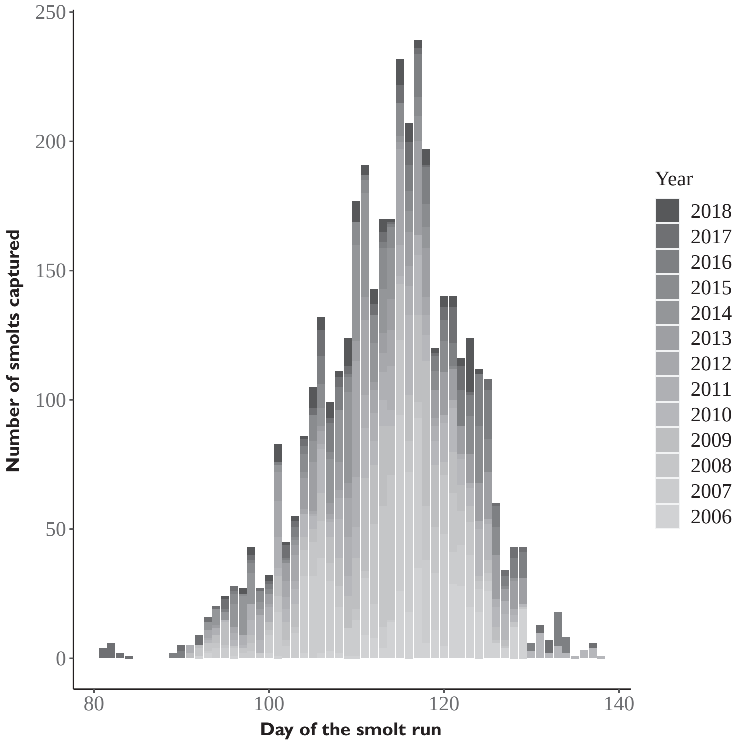


Figure 1

The number of tagged migrating smolts captured in the rotary screw trap each year. The horizontal axis shows what day the smolts were captured, where 80 is the 80th day of the year (20 March) and 140 is the 140th day of the year (19 May).

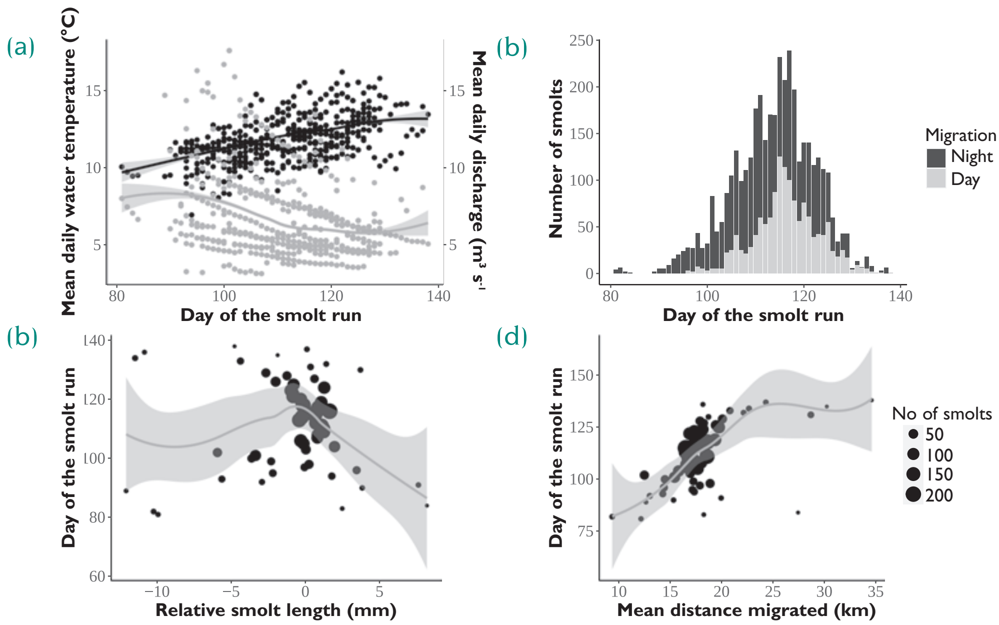


Figure 2

Plots showing: A) daily mean water temperature (black points and line) and daily mean discharge (grey points and line) for each day of the smolt run, B) the number of night-time migrants and daytime migrants on each day of the smolt run, C) the body length of tagged smolts during the smolt run, and D) the mean distance migrated by smolts caught on each day of the smolt run. In plots C) and), the size of each point corresponds to the number of smolts at each length, or that migrated each distance, respectively.

temperatures generally increased, mean daily discharge generally decreased, and each day there were more night-time migrants than daytime migrants. There also appears as be a positive relationship between body length and mean distance migrated, with the day of migration.

With these features of the data in mind, the next step of this work is to test our hypotheses using carefully designed statistical models. Studying the migratory phases of the salmon's life is important for their conservation and management; this is particularly true for vulnerable young salmon at the early stages of their epic journey.

Olivia Simmons is a PhD student working with the GWCT and Bournemouth University studying juvenile salmon size and behaviour on their seaward migration and subsequent sea survival.

Adapting to life in metal-polluted rivers

Implications for conservation, diversity and fisheries management in brown trout

Brown trout (*Salmo trutta*) exhibit a large native range, occupying freshwater systems from Iceland to Afghanistan, having also readily colonised a number of rivers and lakes across the southern hemisphere after artificial introductions. Enough variation exists within the trout genome to enable adaption to life in differing environments from nutrient-poor upland rivers to stable lowland chalk rivers. Populations of trout have been documented to recolonise and survive in some of the most dramatically metal-impacted rivers in the UK. Metal pollution, from the historic legacy of metal mining within the UK, is a significant threat to freshwater ecosystems, causing 9% of rivers in England and Wales to fail ecological and chemical targets. This project seeks to better understand adaption within metal-impacted trout populations from across the UK, and how metal pollution has affected genetic diversity within impacted populations.

Previous work, led by Josie Paris during her PhD with Jamie Stevens at the University of Exeter, examined the genetic structure of trout populations in a number of metal-impacted rivers in Cornwall. Using 23 selectively neutral microsatellite markers (see glossary on page 25), this work identified two historic genetic bottleneck events (dramatic reduction in population size) in trout sampled from the River Hayle in west Cornwall, an area with extensive metal deposits. The first genetic bottleneck occurred approximately 960 years ago, during a productive period of medieval mining activity, and appears to differentiate populations of trout within the Hayle from those in other nearby rivers. The second bottleneck event, 150 years ago, corresponds to a period of concerted metal-mining activity in the region during the industrial revolution, and resulted in the splitting of Hayle trout into two discrete groupings, separated by the heavily polluted Godolphin mine region.

Dan collecting trout samples.

KEY AIMS

- Identify evidence of genes under selection within metal-impacted trout populations, highlighting adaptive mechanisms.
- Elucidate how the common stressor of metal pollution differentially impacts populations with different phylogenetic history and genetic origin.
- Compare effects of different metal mixtures upon population genetic structuring.

This PhD project seeks to address some of the questions raised by the Hayle study. After the last ice age 10,000 years ago, trout recolonised the UK from a number of European refugia during the last glacial maximum. Does the existing genetic structure, in terms of genetic origin and local adaptation, produce different adaptive pathways to adaptation to metal toxicity or do all trout populations adapt in the same way to a common metal pollutant stressor? With a number of different metals (and mixtures of metals) being responsible for metal pollution, and with toxicity being known to vary dependent on the ratio of relative concentrations within each river, how do these different 'cocktails' of metal pollution affect adaption within trout populations.

To answer these questions, field sampling will commenced in summer 2020, taking tissue samples from metal impacted trout from a range of rivers around the UK, including: Wales, south-east Ireland and north-east England to complement existing samples from Cornwall (see Figure 1). Within these regions, sampling will be carried out within metal-impacted rivers and nearby paired rivers with no or minimal metal impact, with sites chosen specifically to examine effects of similar metal chemistry on population genetics. Tissue samples from these sites will be analysed, making use of ever-decreasing DNA sequencing costs and the recently published brown trout genome, using a mixture of full genome resequencing and restriction site sequencing, targeted at genetic regions of interest. Of particular interest is the identification of single nucleotide polymorphisms (see glossary) within regions of DNA relevant metal regulation in trout, eg. the metal binding protein group metallothioneins. This will highlight particular pathways likely to be responsible for adaption to metal pollution within different populations and will allow the development of a rapid, low-cost fluorimetric assay to characterise potential impacts of metals on the population structure of trout from across the UK.

Against a backdrop of rapid environmental change in freshwaters due to a number of different stressors, this project aims to elucidate how a cosmopolitan species, well-documented for adaption, is capable of adapting to one such stressor and how this will impact population genetic diversity and ability to adapt to such stressors in the future.

Dan Osmond is a PhD student working with the GWCT, University of Exeter and Cardiff University, studying evolutionary adaptation of trout to metal pollution.

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Nucleotide: An individual base component of DNA of which there are four variants: A, T, C and G. The sequence of these variants encodes the structure of proteins within an organism.

Microsatellite markers: A repeated sequence of a small number of nucleotides, eg. TATATATATA. These do not encode proteins and therefore the number of repeats varies freely between populations.

Single Nucleotide Polymorphism (SNP): A variation in DNA sequence by just an individual nucleotide. Such a variation might change the protein product and thereby affect the organism's survival.

Figure 1 Preliminary map of sampling sites.

Remains from historic mining activity.

Stream affected by metal input.

THE MISSING SALMON ALLIANCE

The number of salmon returning to their spawning grounds has fallen dramatically since the 1970s and wild Atlantic salmon could be lost from many of our rivers within our lifetime if we do not act now. This is not a localised issue, the decline in wild salmon stocks has occurred across the north-east Atlantic.

Based on Pre Fisheries Abundance (an estimate of returning salmon), the multi-sea-winter salmon have declined between 54% and 88% while grilse have declined between 40% and 66%. Saving the wild Atlantic salmon will take a co-ordinated effort. That is why the GWCT has joined up with other leading UK salmon conservation organisations – Atlantic Salmon Trust and the Angling Trust with Fish Legal – to form the Missing Salmon Alliance. The alliance was launched at an event with 150 delegates last November at Fishmongers' Hall, who kindly sponsored the event.

Salmon face a number of pressures throughout their lives in freshwater and in the marine environment and at the heart of the Missing Salmon Alliance is the Likely Suspects Framework project (LSF). The LSF is the overarching framework that will guide the Missing Salmon Alliance's strategic thinking, identifying the key pressures on the salmon's life cycle in collaboration with international scientists. The GWCT's SAMARCH project and our core salmon Index river work will form a key part of this work, providing information on how salmon use estuaries and coastal waters and how salmon survival at sea is impacted by their early juvenile stages in the river. The findings from LSF will direct action where it is urgently needed in terms of policy and management to arrest and reverse the declines in wild salmon populations. To deliver this ambitious plan, the Missing Salmon Alliance has employed Collin Bull to lead on implementing the LSF.

BY WORKING TOGETHER WE WILL

- Share information, agree priorities, avoid duplication of effort, present co-ordinated arguments, and take co-ordinated action to halt and reverse the decline.
- Increase the scale of funding available and make efficient use of resources by being more focused and more accountable.
- With the Likely Suspects Framework, we aim to build an evidence-base to influence national decision-makers to regulate activities that adversely impact wild salmon.

Scientific publications

2019

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