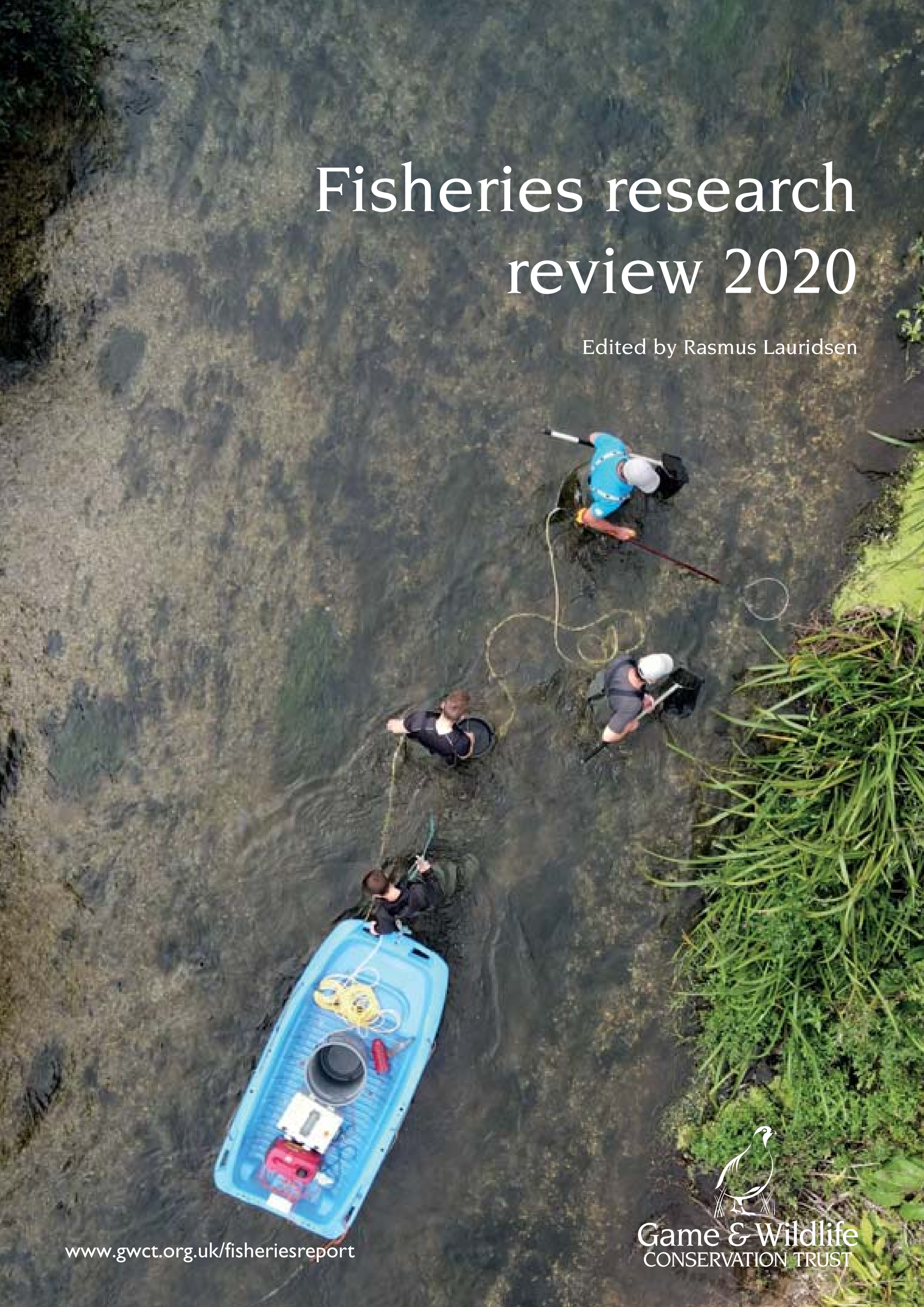
Fisheries research review 2020

Edited by Rasmus Lauridsen



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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.

The GWCT 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, R Needham, D Osmond, D Roberts, L Scott and O Simmons.

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Foreword

David Mayhew

Chairman of the GWCT Fisheries Research steering committee

Well, what a year 2020 has been. Who could have foreseen last January what was to come? Huge credit to the GWCT fisheries team for responding so quickly to the first nationwide lockdown in mid-March. The quick response enabled the team to complete the smolt run assessment, which started in late March and was a testament to the team's dedication. Two people are required on the smolt trap at night-time, but it was immediately clear to the team that they could not use students along with staff members as normal or even mix staff members. Therefore, staff and their partners picked up the mantle to man the trap from mid-March to early May with covid-secure cleaning procedures between changeovers. I would also like to thank the Environment Agency for re-opening the operation of its Tamar fish trap at Gunnislake in late May, just in time to recapture our returning sea trout tagged with Data Storage Tags.

Considering all the challenges, the fisheries team did a sterling job in ensuring that all their routine and planned work, including fieldwork, was completed as planned and without a single associated case of Covid-19. The River Frome was probably one of very few rivers to obtain a smolt estimate in 2020 and a full schedule of works. In terms of results, the estimated salmon smolt run was 13,062, which is the highest estimate since 2013.
The count of adult salmon on the River Frome was

David Mayhew (right) with Dylan Roberts.

653, which was a 45% increase on 2019 and close to the 10-year average. This was similar to the results obtained from other monitored rivers in the area.

I am also delighted to report that after some Covid-19 delays Jessica Picken had an online viva in 2020 and as of last October, she is now Dr Picken. Finally, please do enjoy the 2020 report. I am delighted with the range, quality and depth of the work by the GWCT team at the Salmon & Trout Research Centre.

Aerial image of the Bio-Acoustic Fish Fence diverting the smolts down the Millstream immediately upstream of the floating PIT-tag antennae and fish counter on the main river.

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 Figure 2). 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.

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 latent 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 this knowledge that can inform us how best to manage the river catchment to optimise the output of smolts.

KEY FINDINGS

- Good teamwork and lots of help enabled the fisheries team to continue their data collection in a challenging 2020.
- The 2020 salmon smolt estimate was 40% higher than the 10-year average and the mean size of the 2020 smolts was large, boding well for their marine return rate.
- The juvenile life stage was the only one with disappointing results in 2020. Poor recruitment, particularly in the upper part of the River Frome catchment from last winter's spawning, resulted in fewer juvenile salmon than normal available for tagging.
- A good number of spawners was recorded in 2020, which is promising for the recruitment of juvenile salmon in 2021.

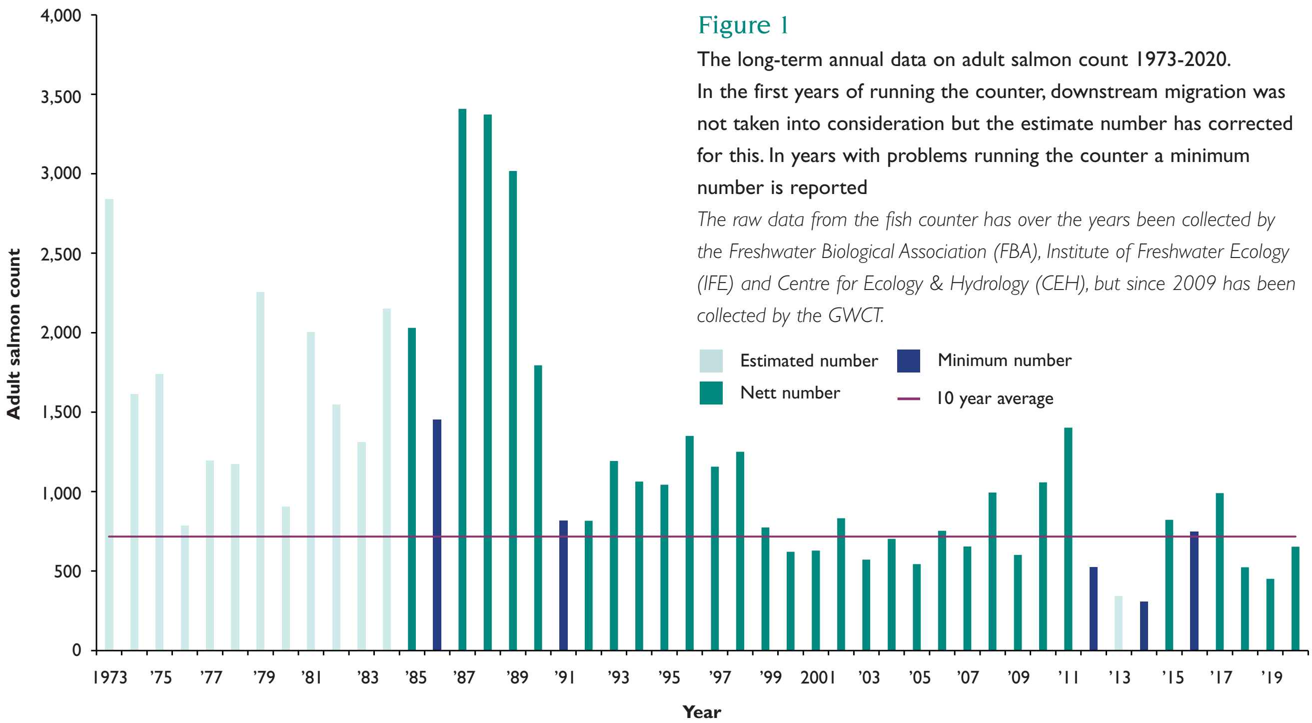


Figure 1

The long-term annual data on adult salmon count 1973-2020. In the first years of running the counter, downstream migration was not taken into consideration but the estimate 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.

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 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.

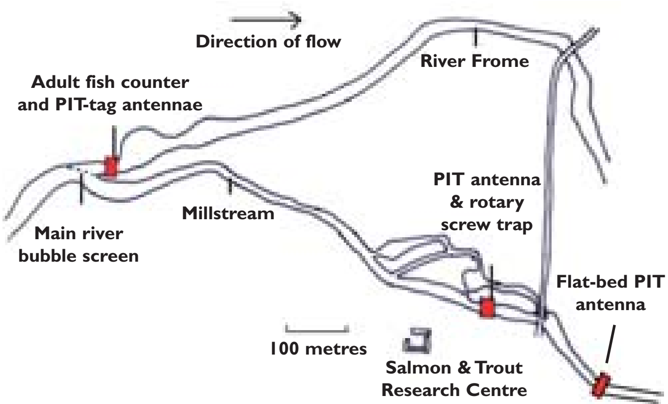


Figure 2

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

With the help of our SAMARCH project, our fish counter at East Stoke had a new fibreglass base with new electrodes installed at the bottom of the river in 2019. We were due to update the electronics decoding the signal from the electrodes in 2020, but this was delayed due to Covid-19. Despite this, the new base improved the electronic signal and provided better contrast for the video images.

The run of adult salmon in Figure 3 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.

As is the case in most years the bulk of the adult salmon moved past our fish counter in late autumn. From the fish counter we estimated that 653 adult salmon returned to the river in 2020, which is considerably better than the two previous years and close to the 10-year average (see Figure 3). We had a decent run of 1SW salmon (individuals that have spent one year at sea before returning) and a surprisingly good run of 2SW salmon. The 2SW fish originated from the 2018 smolt cohort from which we had a poor return in 2019 as 1SW fish; more PIT-tagged salmon from the 2018 smolt cohort were recorded returning as 2SW in 2020 than as 1SW in 2019. Provided egg survival is reasonable, the 2020 run of spawners should result in good numbers of juvenile salmon in 2021.

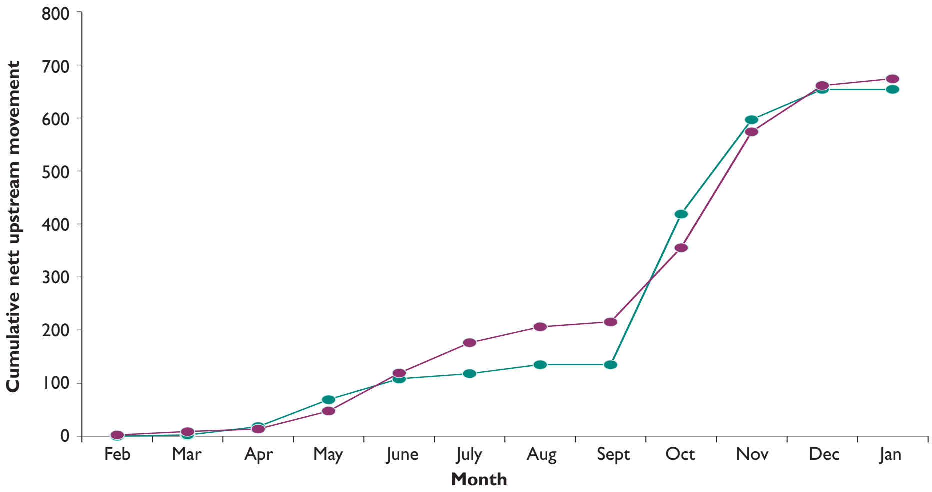


Figure 3

Cumulative nett upstream adult count for 2020 recorded by the resistivity counter at East Stoke

Cumulative 2020

10-year average

** As a result of intermittent technical issues with the resistivity counter, prior to its refurbishment, we have used estimates for total run reported in Figure 1 for some years. This results in a small difference in the 10-year average reported in this figure with the one reported in Figure 1 (717).*

MONTH	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	TOTAL
2020	0	2	16	51	39	10	17	0	284	178	57	0	654
10-year average	2	6	5	34	71	57	30	9	140	218	87	13	672*

Smolt estimate

We have estimated the number of smolts emigrating from the River Frome 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 install a device called a Bio-Acoustic Fish Fence (BAFF) consisting of bubbles with sound entrained, to divert the fish into the Millstream at East Stoke (see Figure 2 and photo on page 4). However, in 2020 heavy rain in March and April resulted in high flows during the smolt run. Consequently, for the third 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 deflection system consisting of bubbles only, which deflects smolts albeit less efficiently. In the Millstream, a proportion of the deflected fish are trapped using a rotary screw trap.

Monitoring salmon smolts is hard work. Starting in March each year, we spend six to seven weeks checking our rotary screw trap every 30 minutes day and night. A challenging task in any year, but the 2020 smolt run came just as the nation found itself in lockdown. Despite the restrictions we managed to operate, but only thanks to the support of partners. The fieldwork was divided across research staff and a PhD student, each joined by their partners who volunteered to help during night shifts to reduce potential risk. An estimated 13,062 (95% CI ±1875) salmon smolts left the River Frome, 40% up on the 10-year average (9,345, see Figure 4). This is the highest number of emigrating smolts recorded since 2013 and they were also on average large smolts. Our previous research has shown that larger smolts are three times

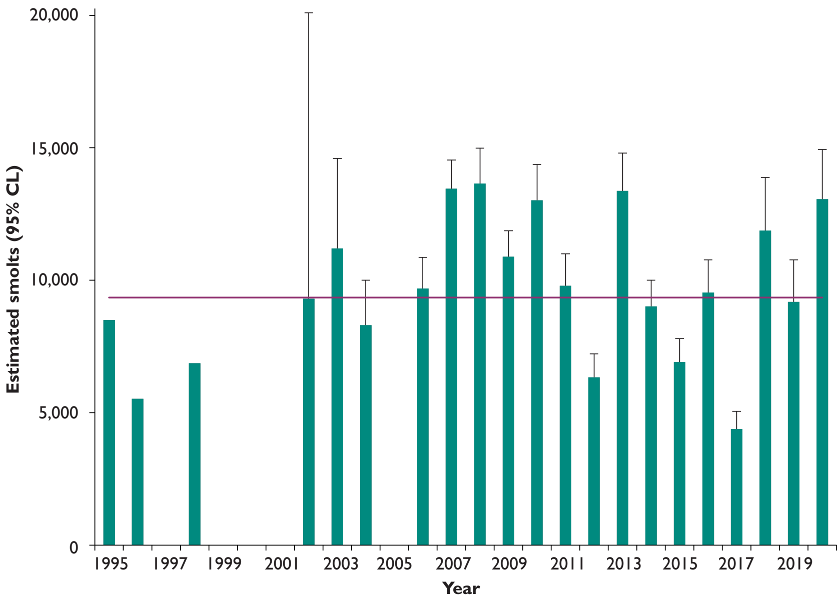


Figure 4

Estimated spring smolt population with 95% confidence intervals 1995-2020

10 year average

more likely to return from the sea than smaller ones. It is more than 10 years since we have observed this number of large smolts leave the river and, given the relationship between return rate and smolt size, we are hopeful that good numbers of adult salmon from the 2020 smolt cohort will return in 2021 and 2022.

Estimate of juvenile salmon

In September each year since 2005, we have electric-fished and marked 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.

Ensuring that all team members stayed safe during our late summer parr-tagging campaign in 2020 provided challenges, but with the help of dedicated volunteers staying for weeks on end we managed to visit all our regular monitoring sites in the River Frome catchment. We easily reached our target of 3,000 tagged young-of-the-year juvenile trout but we encountered fewer juvenile salmon than normal. As a result, we tagged just over 8,000 juvenile salmon, which is somewhat short of our 10,000 target. This was not completely unexpected as the estimated number of returning adult salmon in 2019 was poor. However, salmon recruitment had been particularly poor in the upper part of the catchment. In previous years we have deployed 10-22% of the salmon tags upstream of Lower Bockhampton (see Figure 5 of the River Frome), but in 2020 it was only 1%. We know from the redd survey undertaken the previous winter that there were salmon redds in the upper catchment, but recruitment from these redds had all but completely failed. Please see page 22 where we have analysed our historical dataset to get a better understanding of the drivers of recruitment success from egg to parr in the catchment. These findings from the River Frome, a primarily groundwater-fed river, are compared with our previous findings from rain-fed Welsh rivers.

We 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 2019 was 94,071, which is very close to the 10-year average (93,069, see Figure 6). Hence, the big smolt cohort in 2020 was the result of relative high over-winter survival.

Figure 5

The River Frome catchment highlighting East Stoke, Lower Bockhampton and Maiden Newton which is normally the upstream limit of salmon spawning.

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

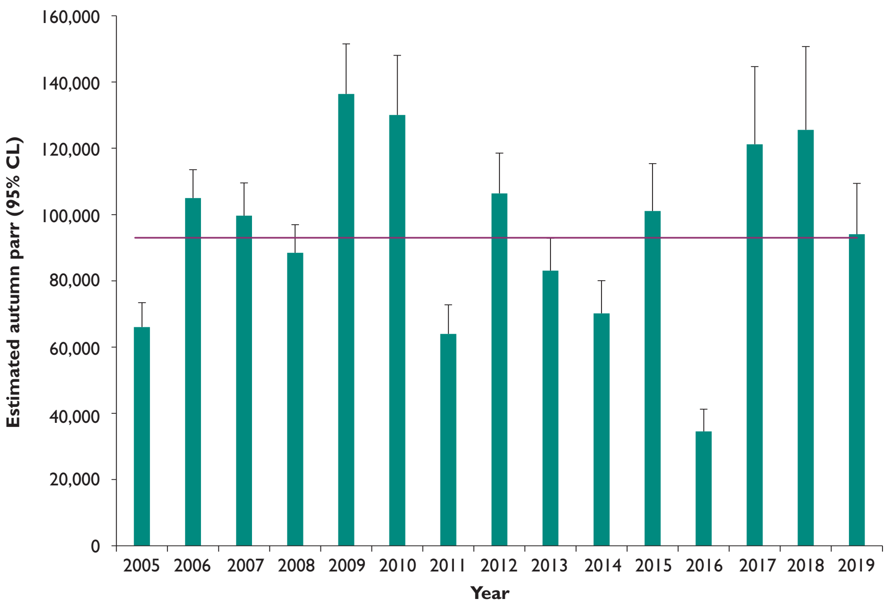


Figure 6

Estimated number of salmon parr in the Frome catchment in September with 95% confidence intervals (2005-2019)

10 year average

Summer morning in the upper Tamar estuary.

Comparing the behaviour of salmon and trout smolts

Atlantic salmon and sea trout are anatomically very similar and only small physical characteristics enable us to distinguish one species from the other. They often co-exist in rivers, inhabiting very similar habitats. Their life cycle is also very similar; they are both anadromous, spawning late autumn/early winter in freshwater where the juvenile hatch the following spring. The juveniles will feed in their native river until they are big enough to smoltify (physiological and anatomical adaptation) and migrate to sea during springtime. As part of SAMARCH we acoustically tracked Atlantic salmon (hereafter salmon) and sea trout smolts during their out-migration in 2018 and 2019 from four rivers discharging into the English Channel. The results from the acoustic tracking highlighted similarities and differences in the migration behaviour of salmon and sea trout smolts.

Smolt length and departure timing

In the four study rivers, salmon and sea trout smolts measured between 9 and 30cm, salmon being generally smaller (mean length 14.5cm) than sea trout smolts (mean length 20cm). Sea trout smolts, in the study rivers, start their downstream migration in mid-March, which is approximately three weeks earlier than the salmon smolts.

KEY FINDINGS

- Trout smolts are generally larger and start their migration to sea earlier in the spring than salmon.
- Trout smolts migrate slower than salmon smolts through estuaries and coastal waters.
- Salmon smolts are more likely than trout smolts to follow the shortest path through estuaries.

Migration speed and duration of estuary crossing

Sea trout smolts displayed a lower migration speed than salmon smolts with average migration speeds of 1.2km h^{-1} and 1.6km h^{-1}, respectively. One notable difference between the species was that whereas the migration speed of sea trout smolts generally slowed down when they entered the marine environment, salmon smolts increased their migration speed. As a result, sea trout smolts stayed much longer than salmon smolts in the estuaries and coastal waters. On average, sea trout were observed for 3.3 days in the estuaries and 4.2 days in coastal waters, whereas salmon smolts were observed for 1.4 days in the estuaries and 0.1 days in coastal waters. Hence salmon smolts spend six days less in the estuaries and coastal waters than sea trout smolts.

Direction during downstream migration

Similar migration behaviour patterns were observed in salmon and sea trout smolts, however, the propensity for particular behaviours varied between species.

Whereas, the vast majority of salmon and sea trout smolts displayed a unidirectional downstream migration to sea, some individuals reversed direction during their migration (oscillation behaviour). Within individual years and rivers, up to 14% of sea trout smolts showed oscillating behaviour whereas up to 81% of salmon smolts displayed this behaviour.

Furthermore, in estuaries where the main channel doesn't follow the shortest route to the sea, 88% of salmon smolts took the shortest route and only 12% followed the main channel, whereas 39% of trout smolts followed the main channel.

All these findings increase our understanding of how salmonids behave during their downstream migration as well as where and when human activities might affect them in estuaries and coastal waters. Due to their longer presence in these environments, sea trout smolts are more likely to be impacted by estuarine or coastal development/activities than salmon smolts. However, sea trout spread out and use the whole environment whereas salmon smolts follow a narrower but direct migration path to sea, increasing their vulnerability to any localised development, activity or pollution. Further research is needed to increase the understanding of smolt migration, not only on a horizontal scale, but also their use of the water column (swimming depth).

A tagged salmon smolt immediately after release.

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).

View of Calstock, the upstream salinity limit of the Tamar estuary.

Salmon growth and its impact on life history strategies

Recent declines in the abundance of anadromous migratory fish, including Atlantic salmon, and changes in their life history strategies might be in response to marine ecosystem changes, such as major changes in the pelagic food web. Decreases in the abundance and energetic quality of prey available to salmon during their marine migration might affect their growth, survival and life-history strategies.

Salmon life history strategies are thought to be phenotypic, or conditional on the interplay between their genetic predisposition and their environmental experiences. Age at maturity is a key phenotypic life history trait and determines whether a salmon matures at sea after one year or stays longer to feed. Since fecundity is highly correlated to body size, especially for females, staying an extra year at sea should result in higher fecundity at the time of spawning, with attendant increased fitness potential. Together, these processes suggest the existence of a sex-specific 'reaction norm' linking maturation with environmental growth conditions at sea. Although such sex-specific reaction norms have been proposed in the scientific literature, the extent to which this mechanism explains variations in age at maturity remains unclear.

Individuals are difficult to track at sea and there is still uncertainty in the routes salmon take during their marine migration, which together restrict our understanding of the underlying ecological and demographic mechanisms. Research on the marine phase of salmon relies on scarce observations from sampling at sea and indirect clues from returning adults. My PhD capitalises on growth data derived from the analysis of historic scale collections from five rivers in the Channel area that provide data on temporal (~30 years) and spatial (five rivers) variability of growth at sea (see Figure 1). In addition, DNA extracted from scales provides sex-specific growth data (molecular sexing).

My recent paper presented the analysis of scales collected over the last 30 years of monitoring on the River Sélune, France. We showed that marine growth has declined during the first summer at sea, especially

KEY FINDINGS

- Scales record seasonal marine growth.
- High-cumulated growth at the end of the first summer at sea correlates with high probability to mature early.
- Females need to achieve higher growth than males for the same probability to mature as 1SW (after one year at sea).
- A recent decrease in growth during the first summer at sea might explain an increase in age and a decrease in length-at-age of salmon returning to south European rivers.

Scale from a returning 2SW salmon.

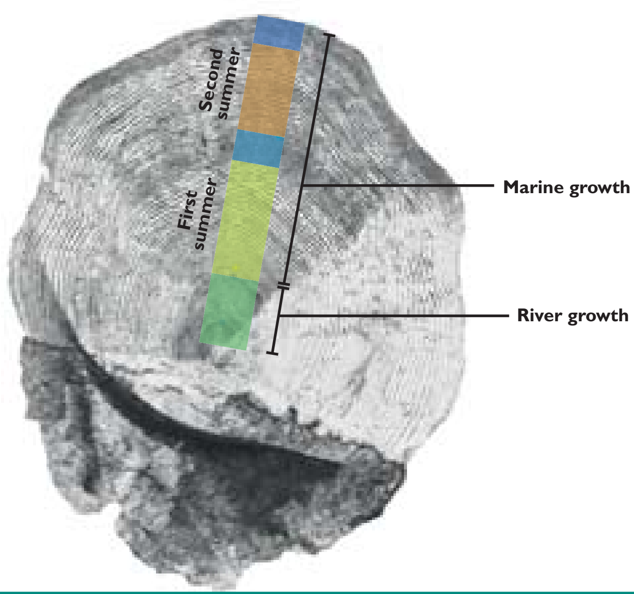


Figure 1

Growth measurements on individual scales:

- Proportional to body growth.
- Periods of fast growth in summer and periods of slow growth in winter.
- Proxy of individual size at different life stages.
- Compare fish returning after one winter (1SW) and two winters at sea (2SW).

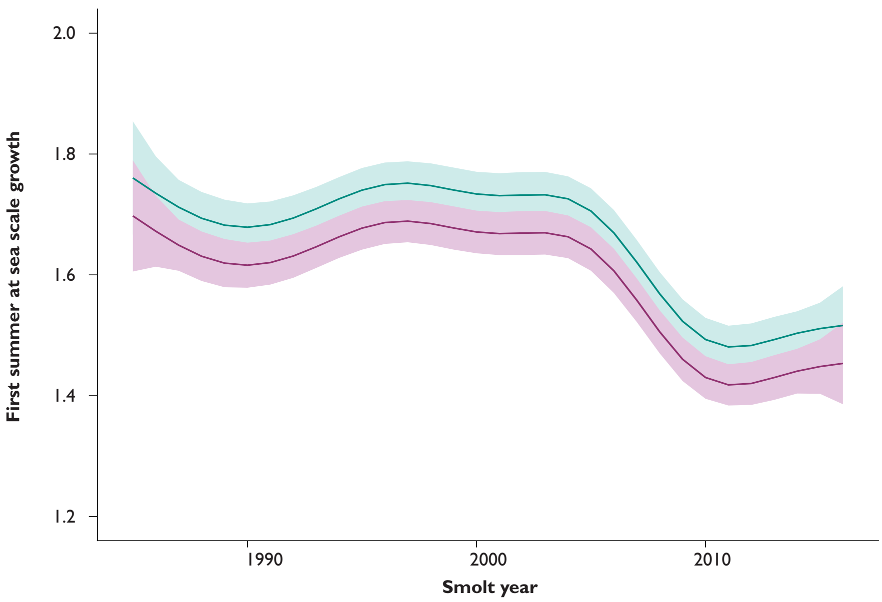


Figure 2

Temporal trends in first summer at sea growth among salmon that return to the River Sélune after one (1SW) or two (2SW) years at sea

1 SW

2 SW

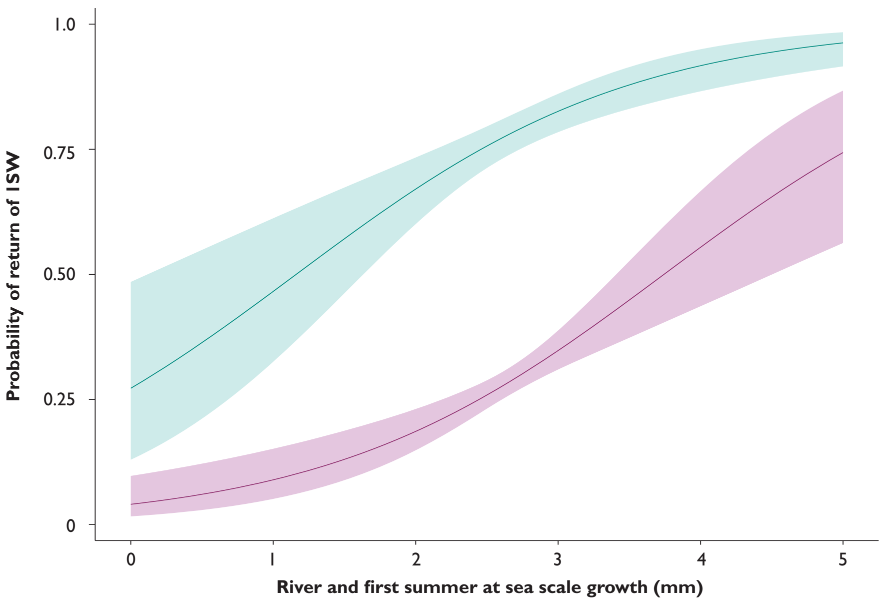


Figure 3

Probabilistic reaction norms showing that male salmon are more likely to return to the River Sélune to spawn after one year at sea compared with females, and that females must achieve higher growth in their first summer at sea to return after one year at sea compared with males

Males

Females

Interreg

France (Channel Manche) England

EUROPEAN UNION

SAMARCH

SAlmonid MAnagement Round the CHannel

European Regional Development Fund

since the 2000s (see Figure 2). My results supported the existence of a sex-specific reaction norm in which individual probability to return after one year at sea increases when growth increases (see Figure 3). It seems that females require higher growth than males to attain their maturation threshold and return after one year at sea. This mechanism could explain temporal variability in sea-age at return at both the individual and population level in the River Sélune salmon population and in many other southern European populations.

Improving our understanding of the drivers and the mechanisms of the spatio-temporal variability of maturation age and marine survival will provide new information, which will improve the models used to manage salmonid stocks.

Cecile Trehin's PhD is part of the SAMARCH project. Cecile strives to test the hypothesis that observed Atlantic salmon population declines and changes in their life history strategies are consequences of altered growing conditions during the marine migration phase.

European grayling. © Rostislav Stefanek

Understanding grayling survival

The European grayling is a member of the family *Salmonidae.* It has received much less research attention compared with its cousins – the Atlantic salmon and trout – and so we know less about its ecology. We do know that it only migrates within fresh water, unlike its cousins that migrate to sea. We also know that it is less tolerant to changes in water quality, including temperature and pollution, and might therefore be an early indicator of environmental changes that will afflict their cousins.

In recent years of the Wylye Grayling and Trout Study (WGTS), grayling numbers appear to have declined and the 2019 survey uncovered some of the lowest numbers on record, particularly among the older age classes. The team also noted changes in the River Wylye environment, including frequent low summer flows and infrequent high

KEY FINDINGS

- Abundances of all age-classes of grayling (age 0+ to 5+) were > 75% lower in 2019, relative to the beginning of the study in 2003.
- Changes to seasonal flow regimes influenced grayling survival.
- Low summer flows negatively impacted sub-adult and mature adult survival and high winter discharge was positively linked to greater juvenile survival.
- Large trout abundance was positively associated with sub-adult grayling survival, suggesting that the two species utilise similar habitat.

Figure 1

Plots showing (A) annual changes in the number of days of summer low flow (days where the flow was equalled or exceeded for 90% of the flow record) and (B) its effect on the probability of sub-adult and mature adult grayling survival (after accounting for other effects) in the River Wylye during the study period

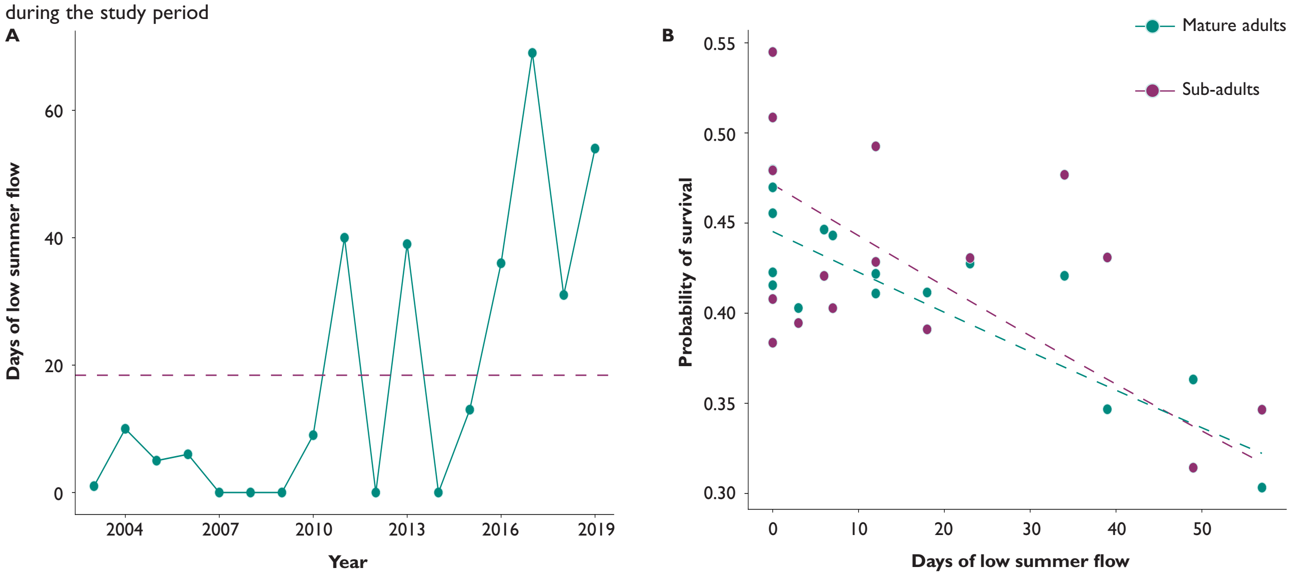
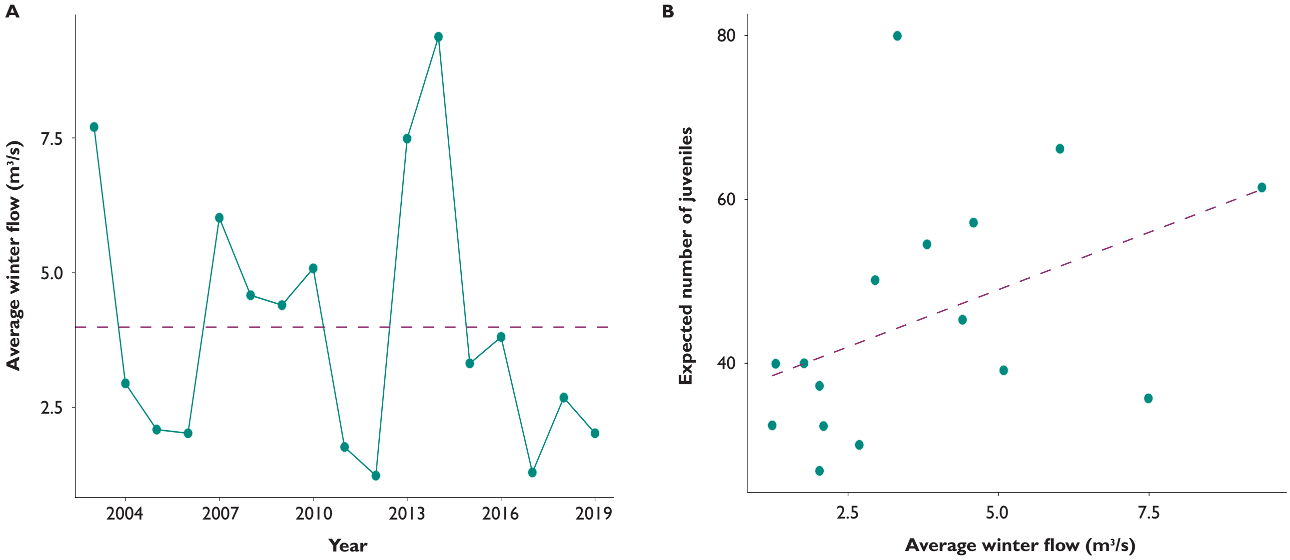


Figure 2

Plots showing (A) annual changes in average winter flow and (B) its effect on the expected number of juvenile grayling surviving from eggs (after accounting for the number of eggs and other effects) in the River Wylye during the study period



winter flow 'recharge' events. These observations were concerning, and motivated funding of a six-month project to explain the observed grayling decline to advance our knowledge on how to reverse this decline. Specifically, the study aimed to compare the possible influences of biological and environmental variables on grayling survival at different life-stages: juvenile (age 0+), sub-adult (age 1+) and mature adults (ages 2+ to 5+).

Building on a previous study by GWCT postdoc Tea Bašić (see *Review of 2018*), we used updated WGTS data from 2003-2019, together with additional in-stream vegetation cover and invertebrate abundance measures, to test our ideas about how these biological and environmental variables might affect grayling survival at each life-stage. For example, low flows can reduce habitat, such as deep pools, that are used by larger grayling and might offer refuge from high summer temperatures. And higher winter flows help clean out silt from spawning gravels, reduce vegetation cover and promote juvenile recruitment.

The results suggested that by 2019, abundances of all grayling age-classes had declined by over 75% from 2003 levels, and that this decline was particularly pronounced in mature adults. The results also suggested that the frequency of summer low flows and average winter flows has been above (see Figure 1A) and below (see Figure 2A) its 16-year average in the last three and five years, respectively. Our analysis found that these recent patterns are negatively associated with survival estimates of different grayling life-stages. Specifically, summer low flows negatively influenced sub-adult and mature adult survival estimates (see Figure 1B), for example reducing probability of sub-adult survival from 47% to 32% (on average) in years with no summer low-flow days compared with years with 50 summer low-flow days. Higher winter flows positively influenced the expected number of juveniles surviving from eggs, from an average of <40 to >60 in years with <2.5 m^3s^{-1} compared with >9 m^3s^{-1} mean winter flow (see Figure 2B). Interestingly, we found no negative impact of large trout abundance on grayling survival estimates, suggesting that the two species are well adapted to co-existing in the same geographic area.

Low flows in summer and winter seem to be becoming more frequent in the River Wylye suggesting that its grayling population might be vulnerable to climate change. This population is situated near the species' southern range limit and might belie future threats to local populations of the grayling's more tolerant cousins, as well as grayling populations at higher latitudes. By using these findings to address River Wylye management strategies, we hope this work will help the River Wylye grayling population now and, in the future, and protect the environment for other socio-economically and ecologically important species.

Jessica Marsh is a postdoctoral fisheries consultant investigating how environmental and biological variables influence population dynamics of European grayling in the River Wylye.

Game & Wildlife Conservation Trust
The Grayling Research Trust
Wessex Water YTL Group
The Piscatorial Society
Cyfoeth Naturiol Cymru
Natural Resources Wales

Migration timing of smolts

Every spring, juvenile Atlantic salmon in the River Frome undergo physical and behavioural changes: they become sleeker, more silver in colour and start to abandon a previously solitary life in favour of joining their conspecifics in small shoals. The time has come for the annual smolt run, where the young salmon get the urge to leave the river that they have resided in since hatching. They head down the River Frome, pass rapidly through Poole Harbour and travel towards their oceanic feeding grounds, where they will feed and mature into adult Atlantic salmon.

This migration is crucial for salmon, as they can access far greater feeding resources at sea than in fresh water, enabling them to grow into mighty adults. It is not, however, without substantial risks. Salmon smolts face environmental conditions novel to them as they enter the estuary for the first time, including saline waters and different temperature regimes. They also face new predators, such as large piscivorous fish and seabirds. Previous research has shown that the timing of the smolt run is crucial for ensuring that smolts entering the estuary have the best chance to survive the journey to their feeding grounds in the North Atlantic. Knowing that the smolt migration bears great rewards to successful returners means that understanding factors that affect the timing of the smolt run is extremely important. As such, we have tested statistically how various environmental and biological variables affect the timing of salmon smolt migrations in the River Frome, and how the effect of some of these variables may alter during the smolt run.

Every autumn since 2005, approximately 10,000 juvenile salmon are marked with a PIT-tag enabling us to detect these individuals as they leave the river as smolts (see page 4). A sample of smolts is recaptured in a rotary screw trap at East Stoke, scanned for tags and measured so that we have a record of their body size. The fish are then gently released back into the Frome to continue their migration.

We hypothesised that water temperature, river discharge, moon phase, smolt body length, schooling behaviour, in-river migration distance and year influenced the timing of the smolt run. We tested statistically how each variable affected the cumulative probability of each smolt migrating on any given day of the smolt run, for 15 smolt runs (from 2006 up to and including 2020). We also divided the number of days in the smolt run into three equal periods (early, middle and late) to assess how the effect of water temperature, discharge and schooling behaviour varied for smolts migrating at different times during the run. Finally, we hypothesised that the effect of smolt body size and schooling behaviour varied depending on whether the smolts were migrating during the daytime or at night, so we tested these interactions as well. These hypotheses are based largely on observations made by staff during the last 15 years.

KEY FINDINGS

- Increases in water temperature and discharge encourage smolts to migrate past our facility at East Stoke.
- Large smolts migrate earlier than small smolts, usually in isolation and not in a school.
- Observations suggest that schooling behaviour changed during the smolt run.

Every autumn since 2005 we have electric-fished and PIT-tagged approximately 10,000 juvenile salmon before releasing them back into the River Frome.

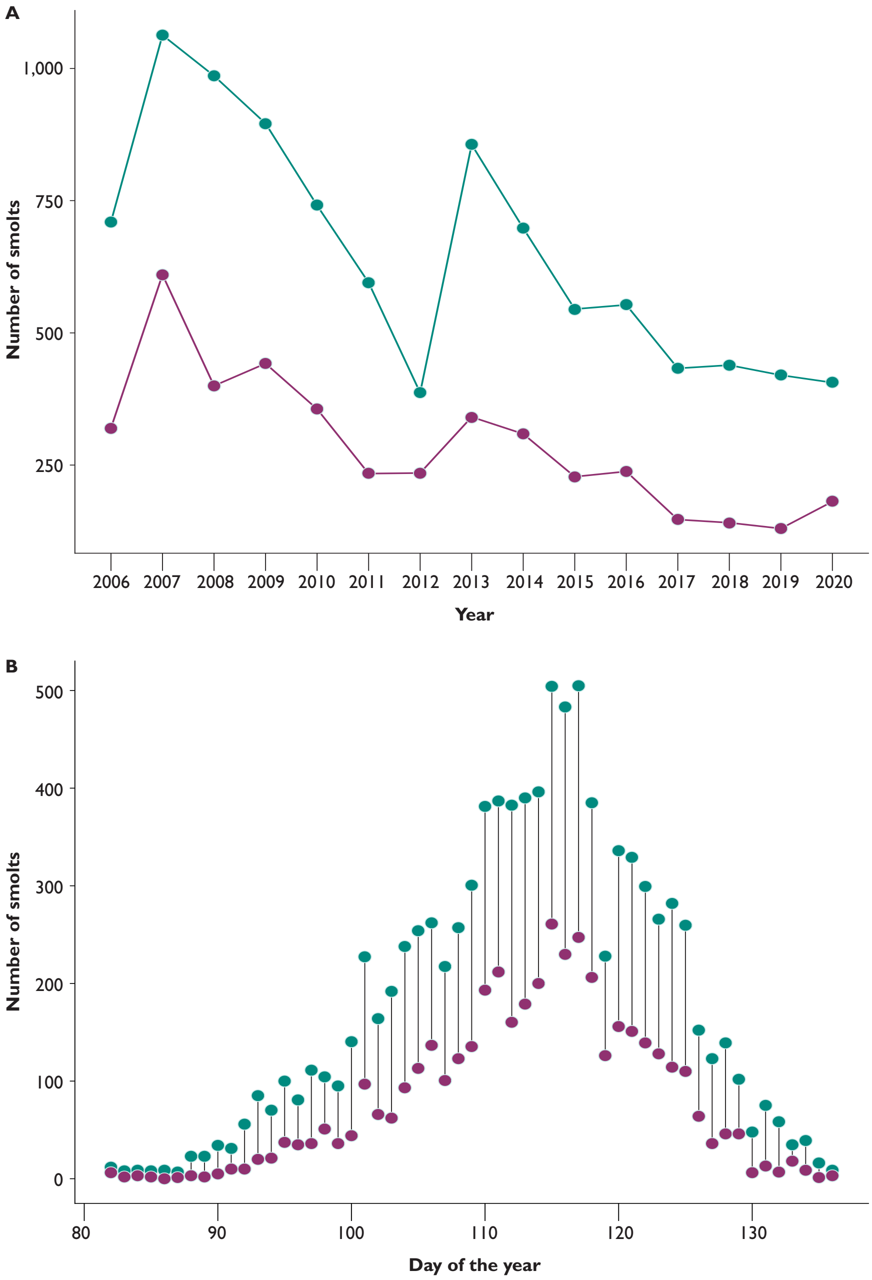


Figure 1
The number of salmon smolts detected by PIT-tag detectors in the Millstream at East Stoke (green) and captured in the rotary screw trap (purple) for each (A) year and (B) the day of year (summed total for all years), where day 80 = 21 March and 130 = 10 May

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Preliminary results suggest that the probability of smolts arriving earlier at East Stoke was elevated following warm winters, and when there were larger positive daily changes in water temperature and discharge during the smolt run. Early migrants were generally large individuals and from sites lower in the catchment. Likewise, later migrants were more likely to migrate in schools, but with schooling behaviour also more likely to occur during daylight than at night. Relative changes in daily water temperature were most important during the early and late run. Relative changes in daily discharge were most influential for the late run, when even relatively small changes in discharge had a strong influence on migration. Further statistical modelling will tease out the nuances of these hypotheses and observations.

Biological and environmental variables are important for the phenology of smolt migrations, and their influence can alter throughout the run. With climate change, predictions of annually increasing river temperatures, more frequent and intense discharge events, and associated shifts to earlier migration, these results imply that such changes in climate are likely to have substantial consequences on the future success of smolt migrations and thereby on future numbers of returning adult spawners.

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

Getting ready to sample a metal polluted Welsh river.

Understanding metal tolerance in brown trout

Brown trout are a ubiquitous species across the British Isles, being present in approximately two-thirds of total river length in England and Wales, and have readily colonised freshwater ecosystems across the globe where introduced. Across this range, trout occupy a broad range of freshwater ecosystems, from the stable, nutrient-rich lowland chalk rivers of southern England and acidic upland moorland streams, to deep glacial lakes. The ability of brown trout to inhabit and thrive in such a range of environments is underpinned by genetic adaptation, with distinct genetic structuring between different populations driven by local adaptation, different sources of recolonisation after the last Ice Age, and genetic drift, with the fidelity of anadromous individuals to their natal rivers maintaining structure.

However, brown trout face a number of anthropogenic stressors in UK rivers, including climate change, acidification, organic pollutants and heavy-metal pollution. The legacy from the metal mining industries causes 9% of rivers in England and Wales to fail to meet chemical and ecological targets. Despite heavy-metal pollution stressors, brown trout have recolonised many mine-impacted catchments across the British Isles, from south-west England, west Wales, south-east Ireland and north-east England. We are seeking to understand the genetic basis of how these recolonising populations are surviving within metal-impacted catchments and how this has affected the wider genetic health and structure of these apparently metal-tolerant populations. Specifically:

- Which regions of the trout genome are responsible for the adaption of brown trout to heavy-metal pollution?
- Do mixtures of different metals drive different responses to adaption?
- How does existing genetic structure of populations interact with metal-impact and adaption?

KEY PROGRESS AREAS

- Successful 2020 field season collecting samples from metal-impacted catchments in Wales.
- Full genome re-sequencing of five brown trout collected during sampling in Wales, with genome assemblies and initial analysis begun.
- Optimisation of computational tools to aid analysis when full sample-set has been collected in 2021.

We began the collection of tissue samples from trout in the metal-polluted catchments of west Wales during the summer of 2020. Catchments were targeted to represent areas with a long history of significant metal pollution, with earliest records of metal extraction in the area extending back as far as the early Bronze Age. We also sought to sample rivers in this area with different 'cocktails' of metals (see Figure 1).

Despite delays and restrictions to travelling for fieldwork arising from the Covid-19 pandemic, we were able to safely sample all of our seven target catchments within Wales during summer 2020 (see Figure 2). Within each catchment, 'clean' sites upstream of significant point sources of metal pollution were sampled, along with sites downstream of the point sources, to give a comparison both within and between catchments in a paired study design. Fish of 1+ years were targeted to reduce the potential bias that can arise from sampling sibling fry. At each site we measured the length and took adipose fin clips from 12 fish before releasing them back to the river. An additional two individuals were sacrificed at each site to provide enough tissue for whole genome re-sequencing (see box on page 17). During field sampling, we found brown trout to be persisting in even the most heavily metal-impacted areas

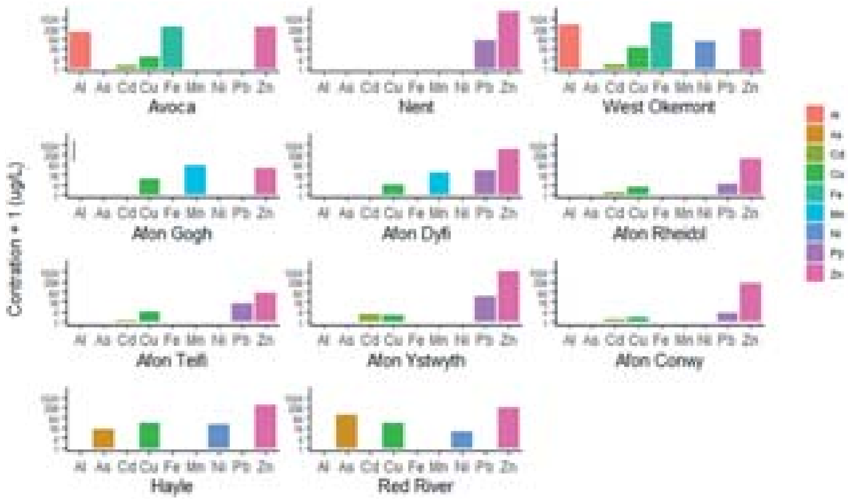

Figure 1
Concentrations of dissolved metals within the target sampling rivers. Chemistry data obtained from peer-reviewed articles, the Environment Agency and Natural Resources Wales, from the maximum toxicity where trout are thought to be present. The Y-axis has been log (x+1) transformed for clarity

where they had previously been reported absent – the hardiness of these fish is quite remarkable.

We have started the genomic analysis with five representative samples from Wales by extracting their DNA and re-sequenced their whole genomes at high coverage, giving us accurate data to begin searching for variable regions across their genomes that could be involved in metal adaptation. These data will also allow us to examine the history of these populations. A previous, study on metal-impacted trout in Cornwall reported significant declines in historical population sizes of brown trout around periods of peak metal extraction during the Industrial Revolution. We will complete fieldwork during 2021, collecting samples from metal-impacted trout populations from catchments in the north-east of England and south-east Ireland. The subsequent data analysis of all fin clips and tissues collected in 2020 and 2021 will be aided by utilising computational tools that we are currently optimising using our initial five high resolution Welsh samples.

What is whole genome re-sequencing?

The full sequence of genetic material for an individual consists of genes, regulatory regions, and 'neutral' regions, that are responsible for biological function. Whole genomes are too long to sequence in a single chain, so many short fragments are read and then assembled together. High coverage improves the accuracy of this assembly and allows true variation to be distinguished from errors in sequencing.

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We measured the length of each trout and took adipose fin clips from 12 fish from each site.

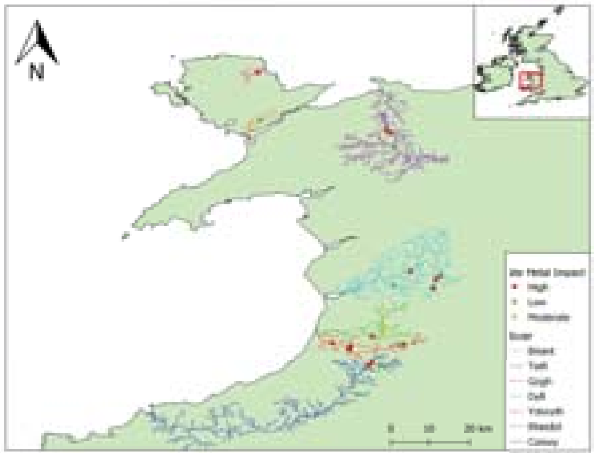
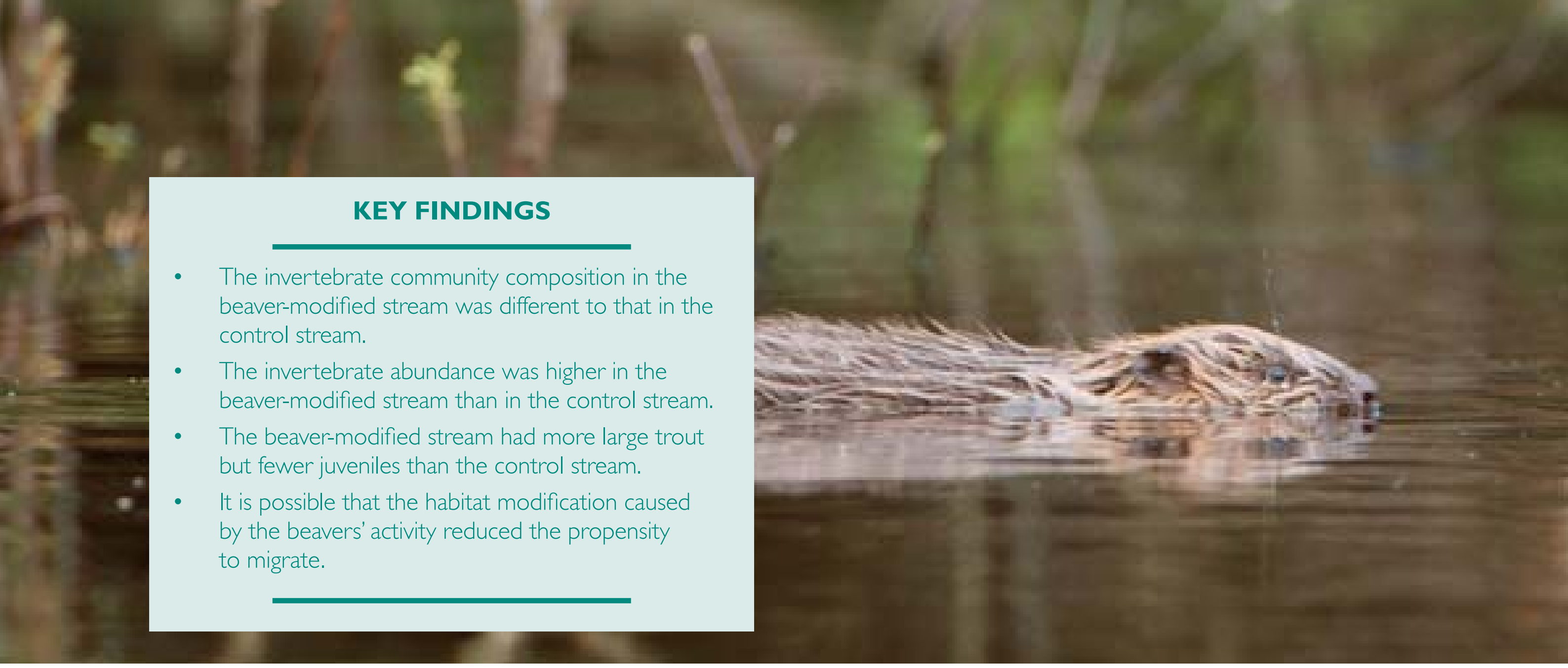


Figure 2
Sampling sites from the seven Welsh catchments visited during 2020 are denoted by circles, where the colour of the circles denotes the relative level heavy-metal pollution.

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



KEY FINDINGS

- The invertebrate community composition in the beaver-modified stream was different to that in the control stream.
- The invertebrate abundance was higher in the beaver-modified stream than in the control stream.
- The beaver-modified stream had more large trout but fewer juveniles than the control stream.
- It is possible that the habitat modification caused by the beavers' activity reduced the propensity to migrate.

Scottish beaver. © Rob Needham

Do beavers affect brown trout?

As part of an ongoing study attempting to answer questions relating to the interactions between beavers and fish, particularly economically important salmonids, this study attempted to quantify the possible impact of beaver habitat modification on the invertebrate community and the brown trout population. The study site, in northern Scotland, comprises of two streams that feed the same freshwater loch, one stream was modified by beaver activity while the other was unaltered (see Figure 1).

The invertebrate community was sampled by collecting 23 kick samples from each of the two streams in October 2016. This method involves agitating the sediment for one minute directly upstream of a net. Electric-fishing was used to survey the trout population in both streams during spring, summer and autumn 2016. Trout were divided into two age groups; 1. Young of the Year (YOY), (Fork length (FL) ≤60 mm) and 2. Older (>60 mm).

During 2016, when considering all age groups, mean abundance varied significantly with season, being greatest in spring and lowest in autumn. There was no difference between spring and summer or between summer and autumn. There was no statistical difference in total abundance of trout between the streams (see Figure 2A). However, the abundance of Older trout was significantly higher in the beaver modified stream (see Figure 2B), whereas the abundance of YOY trout was significantly higher in the control stream (see Figure 2C).

The mass of YOY trout in the beaver-modified stream was statistically greater during the summer compared with the control, although there was no statistical difference in YOY mass during the autumn and spring. Hence growth of surviving YOY trout was similar in the two streams.

The distribution of invertebrates in the beaver-modified stream was more variable than in the control stream but the mean invertebrate abundance was significantly greater in the beaver modified stream than in the control stream (see Figure 3). Not only was there between-stream variation in the abundance of invertebrates but the invertebrate community structures also differed significantly between the two streams. Ordination analysis revealed

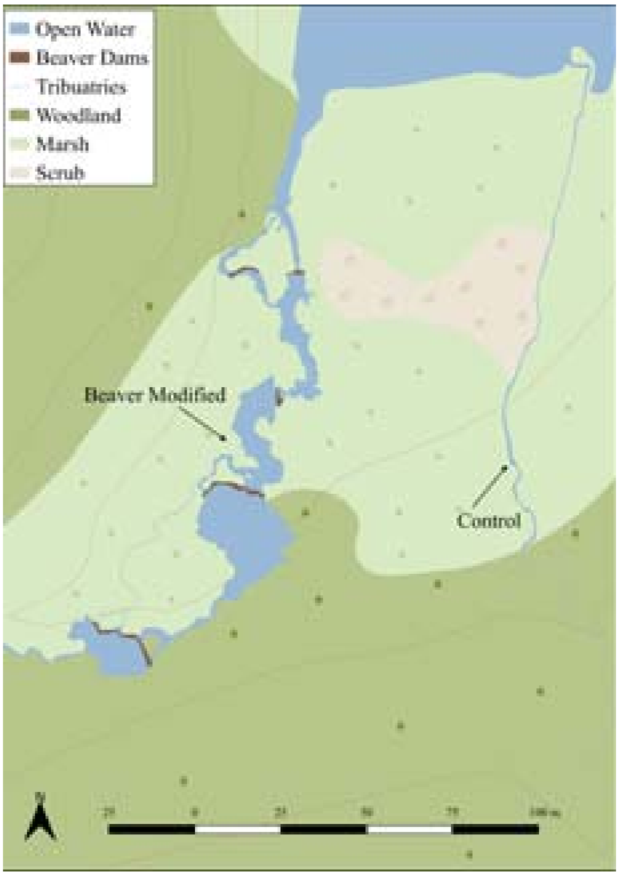


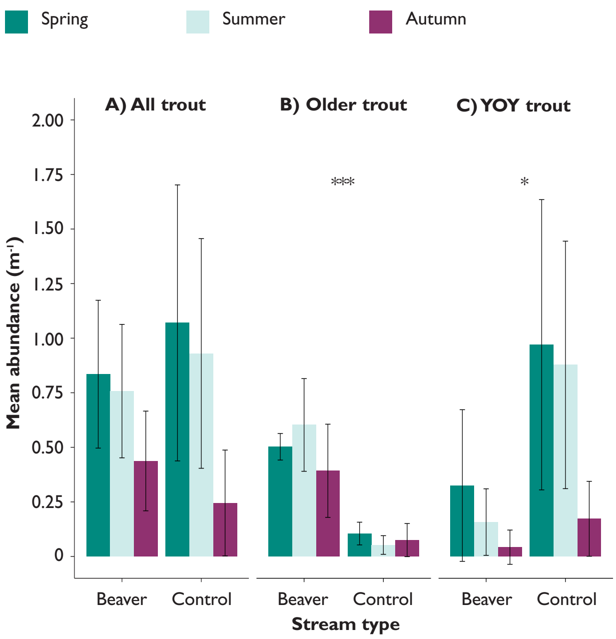
Figure 1

Study site in which the response of a population of brown trout to fluvial landscape modification by beavers was investigated. The map illustrates the study area post-beaver modification, as of July 2016 and the surrounding landscape and habitat types that Chironomidae, Sphaeriidae, Glossiphoniidae, Sialidae, Physidae and Dytiscidae, all associated with slow-flowing water, were most associated with the beaver-modified stream whereas Philopotamidae, Thaumaleidae, Capniidae, Simuliidae, Planorbidae and Perlodidae, mainly families associated with fast-flowing water, were most associated with the control stream (see Figure 4).

Habitat modifications caused by beaver activity resulted in significant changes in the invertebrate community as well as the size distribution of trout. Beaver activity promoted a higher density of invertebrates as well as changing the community composition to one dominated by species associated with slow-flowing water. Beaver activity also promoted deeper habitat suitable for Older trout whereas the beaver-modified habitat proved less favourable for recruitment of YOY trout, though there was no apparent change in the growth of YOY trout. The trout populations in these streams are partially migratory with some individuals migrating to the freshwater loch that the streams discharge into and it is possible that the habitat modification caused by beaver activity reduced the propensity for individuals to migrate to the loch. The study also collected data on trout passage of beaver dams and this analysis is ongoing.

Figure 2

Mean ± standard deviation brown trout abundance (trout m^{-1}) during spring, summer and autumn 2016 in the beaver modified and control streams for A) All trout; B) Older trout (FL >60 mm); C) YOY trout (FL ≤60 mm). Significant difference between Beaver and Control site is indicated with: * $p < 0.05$; ** $p < 0.01$ and *** $p < 0.001$



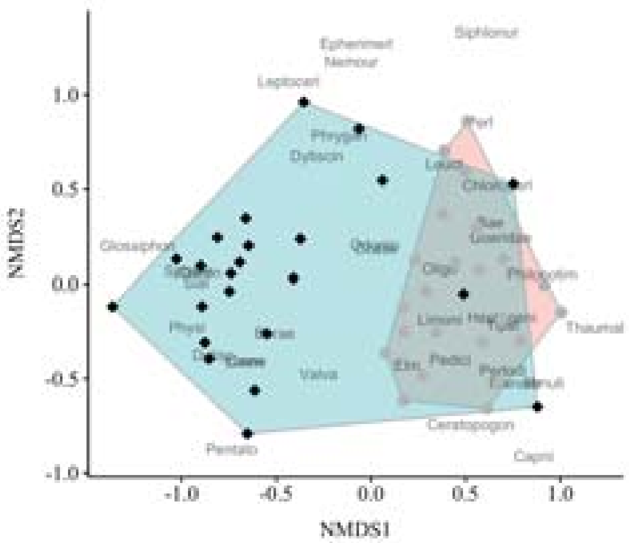


Figure 3

Mean invertebrate abundance of the beaver modified stream and the control stream (error bars show the standard deviation). Significant difference between Beaver and Control site is indicated with: * $p<0.05$; ** $p<0.01$ and *** $p<0.001$

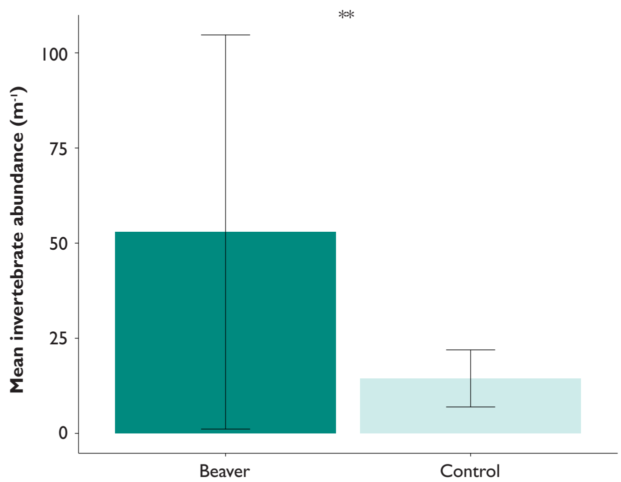


Figure 4

NMDS ordination plot of invertebrate community composition between the beaver-modified (black diamonds and blue polygon) and control streams (grey circle and red polygon)

Rob Needham is a PhD student working with the GWCT and Southampton University studying the effects of beaver activity on trout migration and population dynamics.

A pair of pink salmon in spawning colours. © John R McMillan NOAA/NWFSC

Pink salmon carcasses

In recent years, increasing numbers of non-native Pacific pink salmon, *Oncorhynchus gorbuscha*, have been confirmed in rivers around the UK, having been deliberately introduced into rivers in the White Sea region by the former Soviet Union. Like many Pacific salmonids, pink (or humpback) salmon are known for mass spawning events after which they die and their carcasses decompose in the streams. Yet, the impact of these decaying carcasses on our native aquatic environments remains largely unknown. To determine the impact on macroinvertebrate communities, a manipulation experiment was conducted in experimental channels at East Stoke, Dorset (see Figure 1), where different loads of disease-free, pink salmon carcasses were added to eight of the 12 channels (four were controls).

KEY FINDINGS

- Pink salmon carcasses attract aquatic macroinvertebrates.
- The energy from carcasses increases macroinvertebrate recruitment.

Study design

- Twelve experimental channels were set up each 0.3m wide, 12m long and 0.3m deep with a mesh bag (0.3 × 0.3m) at the upstream end.
- The mesh bags were loaded with three levels of carcass: Control = $0 kg/m^2$; Low = $0.05 kg/m^2$; High = $0.15 kg/m^2$. Each treatment was replicated in four channels.
- Macroinvertebrates were collected using a 25x25cm Surber sampler (300 μm mesh) on days 0, 30, 45 and 60 of the study.

Preliminary results indicate that changes in abundance of macroinvertebrates depended on the distance from the carcass. The abundance was greatest close to the carcasses in treatments containing the highest load of pink salmon carcass (see Figure 2). This suggests that decomposing pink salmon carcasses provide a food source for aquatic invertebrates. Over the first 60 days of the experiment, macroinvertebrate abundance gradually increased in samples collected close to the carcass compared with control channels (see Figure 2). After 60 days, macroinvertebrate densities varied according to the distance from the carcass and the amount of carcass added. This suggests that macroinvertebrate densities decreased as the carcasses were depleted, achieving virtual parity with abundance levels in the control channels further downstream from the carcasses. Interestingly, an increased number of young macroinvertebrates ($<0.1 mg$) was observed in the channels where carcasses were added, suggesting that the food carcasses provide leads to an increase in macroinvertebrate recruitment. A range of species fed opportunistically on the carcasses, including snails *(Radix balthica)*, which are normally herbivorous. This study has provided new evidence that pink salmon carcasses can provide marine-derived resources for native stream macroinvertebrates.

Figure 1

One of four sets of three experimental channels at East Stoke used to study the impact of pink salmon carcasses

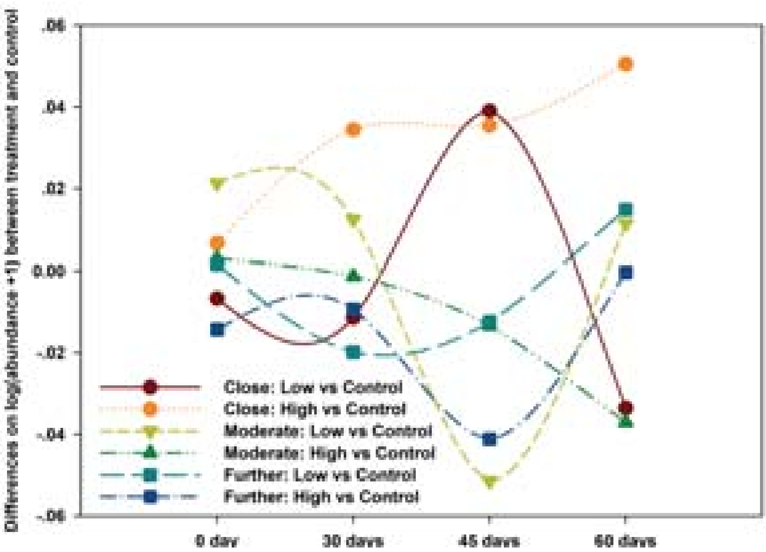


Figure 2

The abundance of macroinvertebrates in the treatment streams relative to the control streams according to their proximity (close, moderate and further distance downstream) to pink salmon carcasses in the experimental channels at days 0, 30, 45 and 60

中国水产科学研究院

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Dr Hui Wei was a visiting researcher from Pearl River Fisheries Research Institute of the Chinese Academy of Fishery Sciences (at Guangzhou), where her research focuses on the invasion biology of non-native freshwater fish. Hui was hosted by QMUL, Cefas and GWCT.

The River Cerne, a tributary to the River Frome. © Peter Thompson

Warm winters and cool springs

In 2016, juvenile salmon numbers in England and Wales were among the lowest on record. It was speculated that this was caused by an unusually warm winter and wet spring. We recently published an article suggesting that winter and spring temperatures as well as high discharge were associated with this '2016 recruitment crash' in seven rain-fed rivers throughout Wales (see *Fisheries Review of 2019*). We observed similarly low juvenile abundance in 2016 on the River Frome, a primarily groundwater-fed chalk stream in southern England characterised by relatively benign temperature and discharge regimes. We wanted to know whether the findings from the Welsh rivers were transferable to this chalk stream.

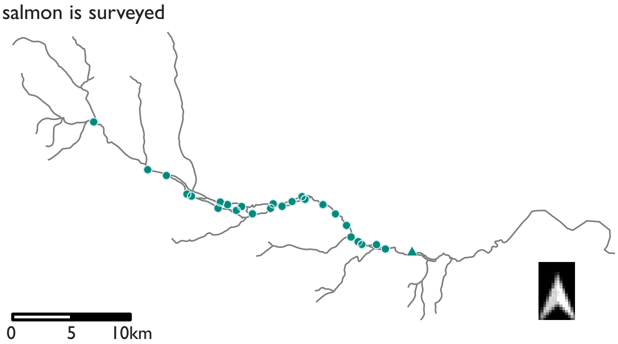
Specifically, did temperature and discharge during spawning through to emergence influence juvenile population numbers between 2015-2020? Interestingly, this study period included the year 2020 for which we also recorded low juvenile abundance on the River Frome, where monitoring efforts were unaffected by the Covid-19 pandemic.

KEY FINDINGS

- Warm winters and cold springs appear to reduce salmon recruitment in the River Frome, a groundwater-fed chalk stream.
- The effects of temperature on salmon recruitment in the River Frome were very similar to what we found in a study of rainwater-fed Welsh rivers. This highlights how similar freshwater conditions in contrasting river-types significantly affect salmon productivity.

Figure 1

Sites in the River Frome catchment where abundance of juvenile salmon is surveyed



Since 2015, 0+ juvenile salmon abundance has been surveyed at multiple sites across the catchment (see Figure 1) using depletion electric-fishing surveys in August and September.

To test the influence of winter and spring temperature and discharge on juvenile abundance, we calculated explanatory variables such as temperature during spawning and emergence, as well as flood events during pre-emergence and emergence periods.

We also used annual catchment-level estimates of egg deposition to look at the relationship between juvenile abundance and number of deposited eggs.

The abundance estimates of juvenile salmon varied annually, with the lowest number estimated in 2016 and these site-specific estimates appeared to successfully capture trends in catchment-level abundance estimates (see Figure 2).

Similarly to the study of the Welsh rivers, high spawning temperatures and low emergence temperatures negatively influenced juvenile salmon abundance (see Figure 3A). Although chalk stream temperatures are relatively stable compared with rain-fed rivers, our findings suggest that changes in seasonal temperatures – even in chalk streams – have a detrimental influence on juvenile salmon recruitment. Indeed, effects of temperature are relative to local conditions and salmonid eggs are highly susceptible to increases in temperature. Relatively warm temperatures during spawning might also inhibit ovulation and affect gamete viability. Cold temperatures during emergence might reduce feeding opportunities, negatively influencing growth and survival.

Although the mean estimated effect of pre-emergence and emergence floods was negative, corresponding with findings from Wales and elsewhere in the UK, its influence on juvenile abundance in the current investigation was negligible (see Figure 3B). This suggests that flood events in the River Frome, and perhaps chalk streams generally, are less influential in salmon recruitment relative to rain-fed rivers. Chalk streams typically have a low gradient with flood events unlikely to mobilise the redd substratum and cause egg washout or displace fry.

There was no clear and simple association between egg deposition and juvenile abundance in these data (see Figure 3C), suggesting that the temperature and flow effects were sufficient to explain the inter-annual pattern in estimated juvenile numbers for these years.

As in the rain-fed rivers of Wales, temperatures particularly influenced the recruitment of juvenile salmon in a groundwater-fed southern English chalk stream. These results highlight how similar freshwater conditions in contrasting river-types have potential to significantly affect juvenile salmon productivity and their subsequent population dynamics.

Figure 2

Mean site-specific juvenile salmon abundance and 95% credible intervals and mean catchment estimates of juvenile abundance and 95% confidence intervals (as smolt data is required for this estimate, data for 2020 parr could not be included)

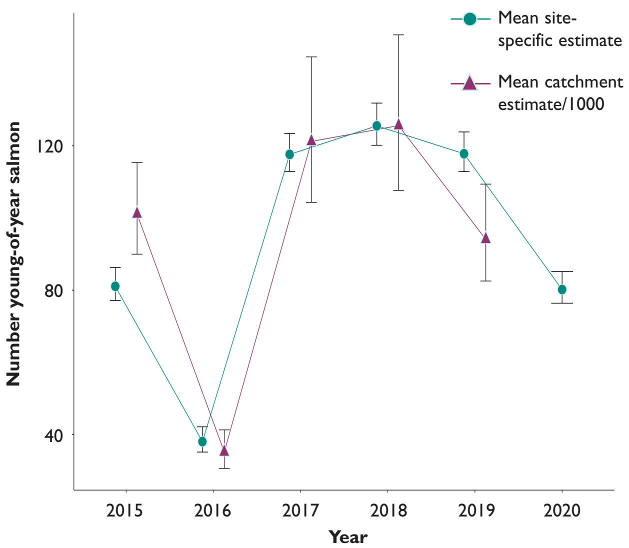
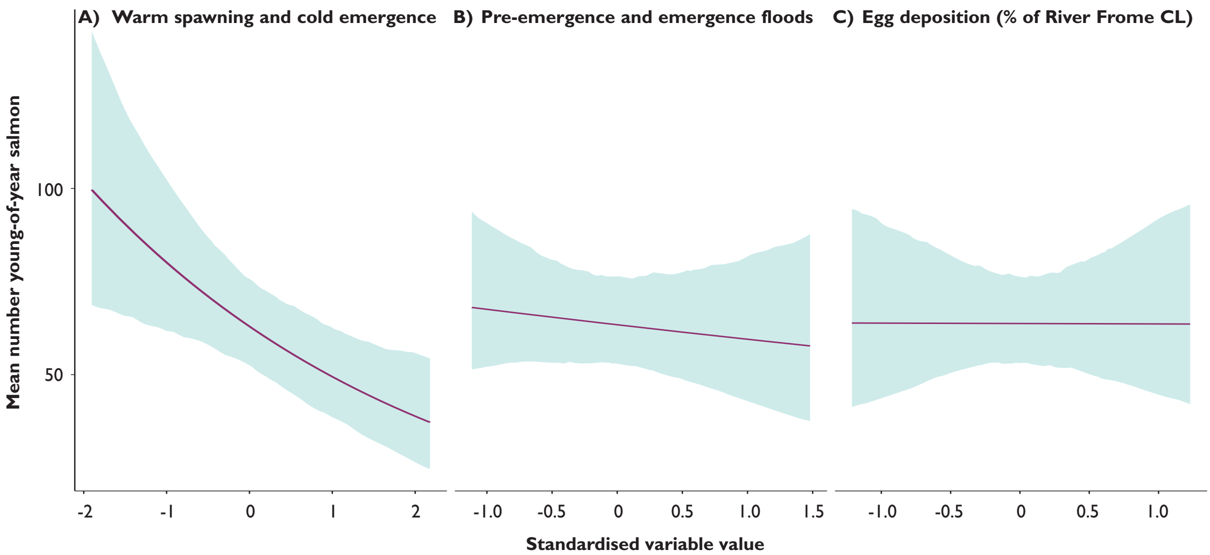


Figure 3

Effects of: A) warm spawning and cold emergence, B) pre-emergence and emergence floods, and C) egg deposition on juvenile salmon abundance (after accounting for other effects). The line represents the mean effect and the green shaded area shows 95% credible intervals



Jessica Marsh is a postdoctoral fisheries consultant investigating how environmental and biological variables influence population dynamics.

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Returning adult Atlantic salmon. © The Atlantic Salmon Trust

The Likely Suspects Framework

Estimates of Atlantic salmon abundance for stocks across the Atlantic Ocean show remarkable similarities in declines through time, and it is estimated that multi-sea winter salmon have declined in abundance by 88% and one-sea winter (grilse) by 66% (see Figure 1).

Big problems require big responses, but salmon management is frequently impeded by poor access to information or evidence to support changing historical approaches. In response to these declines and to improve management efficiencies, the Missing Salmon Alliance (MSA) (www.missingsalmonalliance.org) is developing a programme known as 'The Likely Suspects Framework'.

The Likely Suspect Framework focuses on improving our understanding of what drives the reduced survival trends in salmon, providing salmon managers with new tools to support their future decisions to help stabilise or reverse salmon declines. We are taking on this huge challenge by:

- Collectively focusing attention on mobilising data from across the salmon's range, providing a new data structure to link resources to address key scientific questions and help improve the way knowledge flows to salmon managers (see Figure 2).
- Promoting future salmon management through a process of recognising the salmon's role as an integral species within a wider ecosystem.

Moving from a historical single-species management approach to one that recognises the importance of a wider suite of interacting ecological and physical processes, provides many benefits when determining the fate of salmon. These 'ecosystem-based' approaches allow the consideration of wide sets of existing environmental and biological data and aquatic management initiatives, focused through the lens of the salmon life cycle. This identifies new indicators and ecological linkages that could help us not only understand where and why salmon are not surviving, but can also direct us to places, times and actions where management changes can be made to improve conditions for salmon.

KEY AIMS FOR 2021

- Production of data management system to organise and mobilise knowledge on salmon mortality
- Supporting the delivery of an ICES-funded Workshop on salmon mortality.
- Developing nearshore and offshore salmon research programmes with Strathclyde and Essex Universities
- Establish an international PIT-tag database to help evaluate bycatch of Atlantic salmon.
- Roll out Phase 1 of the salmon management support tool.

Progress so far

Progress for the Likely Suspects Framework programme has been rapid in 2020 and focused on five areas:

1. **Building the team:** A core Likely Suspects Framework team was established, consisting of a principal investigator, data specialist and research assistant. The MSA's Technical Steering Group expanded to include a group of external participants with a diverse range of expertise to help with the revision and direction of the project.
2. **Forging links in the international salmon community:** The team is regularly making representations at international science and salmon management meetings and workshops.
3. **Devising the way ahead for the programme:** In May, 2020, we hosted an international workshop, establishing the route for programme delivery and an appropriate design for the data mobilisation

framework. Over the past months the team has been leading on an initiative to identify and prioritise the most important science questions to address, to help explain recent salmon declines. This work will assist international collaborations linking data resources needed to test key hypotheses.

4. **Database development and getting information to managers:** An ambitious data management system is under development, collating biological, physical and salmon specific information from freshwater and marine environments located around the North Atlantic. By working with other international data mobilisation initiatives, the scope to collate potential information widens, increasing the data available for assessment methods and hypothesis testing. This will improve realism and the capacity to provide better scenario-testing capacity for managers.
5. **Knowledge and understanding of the 'levers':** Understanding where changes in the environment and ecosystem are linked to responses in salmon abundance, will be critical. These 'levers' will be used to influence the design of a new user-friendly interface currently being designed to help salmon managers. Phase 1 of this 'Decision Support Tool' is under development in collaboration with a group of ecologists and academics and should be rolled out in 2021.

Track the progress of the Likely Suspects Framework programme here: **missingsalmonalliance.org/likely-suspects-framework.**

Colin Bull is the principal investigator for the Likely Suspects Framework, the flagship project of the Missing Salmon Alliance.

Figure 1

Estimates of Atlantic salmon abundance in the sea. The Pre-fishery Abundance (PFA) are estimated for two Continental Stock Units: Non-maturing (MSW) (purple) and maturing (1SW) salmon (green line). Abundance estimates for the entire cohort (MSW+1SW) is shown in yellow. Data from ICES Working Group on North Atlantic salmon

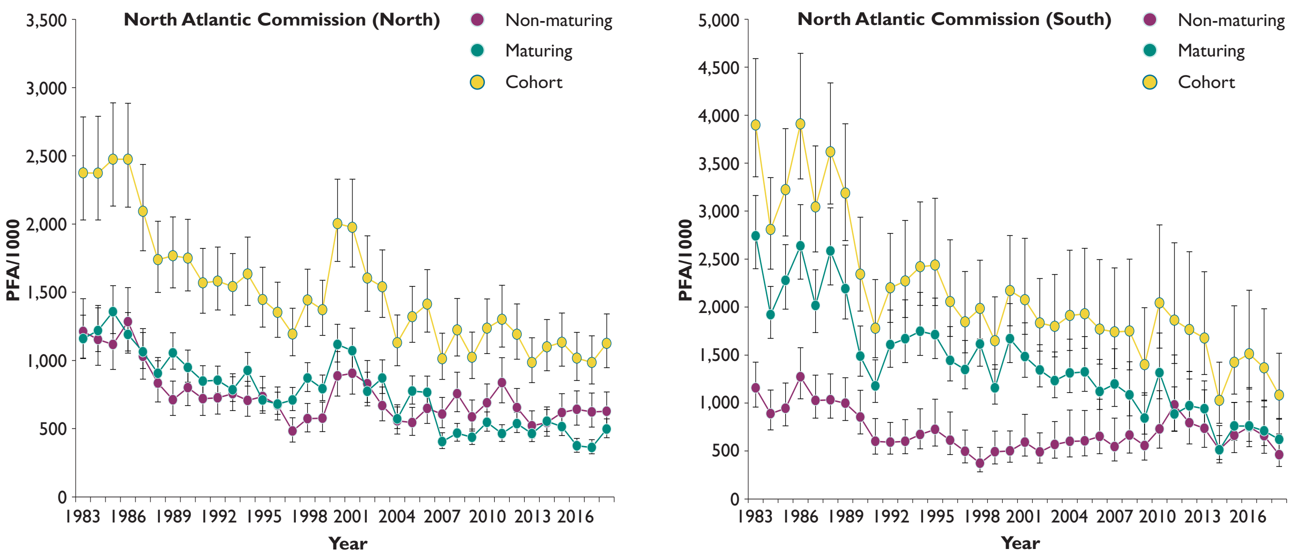
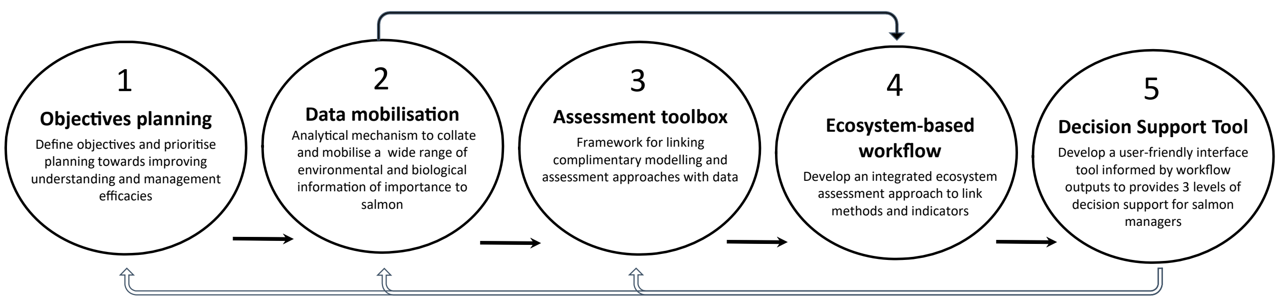


Figure 2

An illustration of the various stages in the Likely Suspects Framework's workflow to build a tool helping salmon managers in their future decisions



Electric-fishing the River Frome for parr.

Scientific publications

2020

Gillson, JP, Maxwell, DL, **Gregory, SD,** Posen, PE, Riley, WD, **Picken, JL** & Assunção, MGL (2020) Can aspects of the discharge regime associated with juvenile Atlantic salmon *(Salmo salar L.)* and trout *(S. trutta L.)* densities be identified using historical monitoring data from five UK rivers? *Fisheries Management and Ecology*, **27**, 567-579. DOI: 10.1111/fme.12456.

Gregory, SD, Bewes, V, Davey, AJH, **Roberts, DE,** Gough, P & Davidson, IC (2020) Environmental conditions modify density-dependent salmonid recruitment: insights into the 2016 recruitment crash in Wales. *Freshwater Biology,* **65**, 2135-2153. DOI: 10.1111/fwb.13609.

Höjesjö, J & Walker, A (ed.) (19 authors), **Lauridsen, R,** (17 authors) (2020) Working group to develop and test assessment methods for sea trout populations (WGTRUTTA). *ICES Scientific Reports.* 2:59. DOI: 10.17895/ices.pub.7431.

ICES (2020). NASCO Workshop for North Atlantic Salmon At-Sea Mortality (WKSalmon, outputs from 2019 meeting). *ICES Scientific Reports.* 2:69. 175 pp. DOI: 10.17895/ices.pub.5979.

ICES (2020). Working Group on North Atlantic Salmon (WGNAS). *ICES Scientific Reports.* 2:21. 358 pp. DOI: 10.17895/ices.pub.5973.

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SALMON & TROUT RESEARCH CENTRE
East Stoke, Wareham,
Dorset, BH20 6BB
Email: fisheries@gwct.org.uk
Tel: 01929 401894l

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