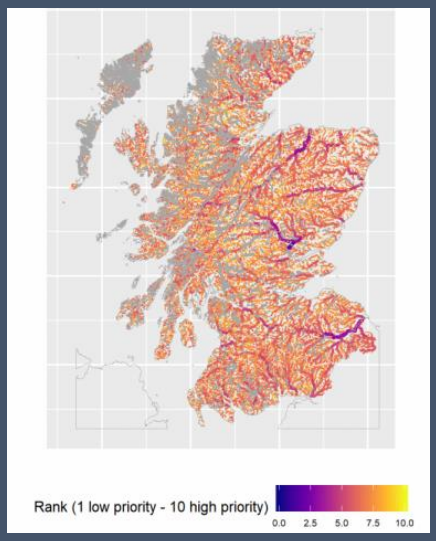

Warm Water Angling Protocols

Approaches taken elsewhere and recommendations for the Spey

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Contents

Cover image from https://marine.gov.scot/information/scotland-river-temperature-monitoring-network-srtmn-tree-planting-prioritisation-shading

1. Introduction

River temperatures are rising and climate change predictions indicate that they will continue to rise. Concern has been expressed about the impact of angling on salmon survival during warm water conditions. Studies have shown that there is a relationship between river temperatures and mortality rates amongst catch and release salmon. Van Leeuwen et al.,(2020), using modelling, concluded that catch & release mortality at cool water temperatures (0 and 12 °C) would be low (mean = 3%), increasing to a mean of 8% at temperatures 12 and 18 °C. At temperatures between 18 and 20 °C, mortalities ranged from 7 to 33% (mean = 16%), and at 20 to 25 °C mortalities range from 14 to 61% (mean = 35%). These are modelled values but a recent study investigating mortality over a period up to 300days, post release, using actual, and realistic, angling conditions found similar results (Keefe et al., 2021). They showed that at cool to moderate water temperatures (10 to 18 °C) angling related mortality ranged from 2 to 4% up to 30 days post release. Mortality rates increased at higher river temperatures, and although the number of salmon hooked and released at temperatures above 21 °C was low, the mortality rate amongst that group increased from 31% after one day, to 57% after 30 days.

Warm river temperatures also have sub-lethal population level impacts. This will be discussed further below.

High quality river temperature is available on the Spey through the Marine Scotland Science network of river temperature loggers. This network was established in 2013 across a range of catchments in Scotland, including the River Spey. Spey Fishery Board staff maintain and download nine of the lower Spey catchment loggers for Marine Scotland. Five of these loggers are located in the mainstem, from Carron Bridge to near the Garmouth viaduct.

The aims of this paper are:

1. Investigate approaches adopted nationally and internationally to manage or regulate salmon fisheries during warm water conditions.
2. To report on summer temperatures from the Spey mainstem
3. Make recommendations for the management of the fishery during warm water events.

2. Temperature tolerance of Atlantic salmon

Atlantic salmon are more tolerant of high temperatures than brown trout with the lethal temperature (that which can be tolerated for a short period only (less than one day)) for salmon parr in the range 30-33^{o}C. For brown trout the lethal temperature is 3^{o}C less. For both species acclimatization will influence the ultimate tolerance. Lethal temperatures for adult salmon are less well understood but will be lower than for juveniles. For Atlantic salmon juveniles, the incipient lethal temperature, defined as the temperature which the fish can tolerate for a long period (usually taken as seven days), is 27.8^{o}C (Elliott 1991). Thermal sensitivity is size-related with adult salmonids preferring lower temperatures and are less tolerant of high temperatures than juveniles (Fowler et al. 2009). The incipient lethal temperature, and ultimate lethal temperature, for adults is expected to be lower than for juveniles. The incipient lethal temperature for adult salmon is likely to be around 25°C.

Salmonids, both juveniles and adults, have been observed to move to avoid high temperatures and seek lower temperatures and/or higher oxygen levels. In that regard thermal refugia, where fish can

avoid peak temperatures are important for survival of stocks when under stress. Thermal refugia could be inflowing cooler tributaries, deep water, or ground water upwellings.

Thermal stress can have sub-lethal impacts with reduced fecundity, egg size and survival noted in experimental conditions (King et al, 2003). Other aspects of elevated temperatures on reproduction, such as ovulation, and critical upper temperature thresholds, for spawning have been reported (Taranger and Hansen (1993).

The presence and well-being of populations of salmonids depends on more subtle factors than a simple absence of directly lethal conditions. Various authors reported temperatures in the range 19 – 22°C as being the upper temperatures during the warmest part of the year for salmonids to thrive (Solomon & Lightfoot, 2008). Clearly, salmon populations exist, for short period at least, when maximum temperatures exceed these values but the concept of a physiological thermal tolerance zone helps define the optimum temperature regime. Elliot (1991) classes Atlantic salmon and brown trout as cold-water species with physiological thermal tolerance zones of 7 - 21.9°C for Atlantic salmon and 4 - 19°c for brown trout. Webb and Walsh (2004) modelled the effect of increased river temperatures, based upon predicted climate change scenarios, on fish populations in 27 rivers in the UK. Under a high emissions scenario, 12 of the 27 UK rivers studied would become uninhabitable by Atlantic salmon by 2080. All 27 rivers were considered to have favourable thermal conditions for Atlantic salmon at present. Both Scottish rivers, the Dee and Halladale were considered to remain favourable for salmon by 2080, although the Dee site selected was at over 300m altitude. The impacts of climate change are likely to be experience, first, at lower altitude.

Despite the apparent greater tolerance of salmon to high temperatures they have declined to a greater extent in the southern limits of its range than brown trout have. It may be that higher marine and/or estuarine temperatures are limiting anadromous species such as salmon. Any increase in the temperature regime of the Spey is likely to have a detrimental impact on the salmon population, although the considerable area of high-altitude habitat utilised by Spey salmon will provide a buffer.

3. National, and international, warm water angling protocols

In Scotland the issue of warm-water angling is a relatively recent concern, with increasing awareness of rising temperatures, but also due to the availability of high-quality temperature data. The establishment of a national stream temperature monitoring network by Marine Scotland Science has provided the infrastructure and communication channels required to understand real-time and trends in river temperatures. The Spey was one of the original network rivers which involved the installation of 25 temperature loggers, including several in the lower mainstem and across a range of tributaries.

Evidence from long-term river temperature data sets have recorded increasing river temperatures in the order of 0.2°C per decade since the 1960s (Pohle et., 2019) with increasing air temperatures and reduced snow coverage implicated. That particular study did not consider high temperatures to be a present threat, although the data used was collected by fishing beats, presumably in the morning, when river temperatures are at their lowest.

Guidance concerning regulation of salmon angling during warm water periods has been implemented on a limited number of Scottish salmon rivers. On the Oykel, salmon angling is restricted when the river temperature gets above 18oC (Steven Mackenzie, pers.comm.). It is understood that other District Salmon Fishery Board have considered issuing guidance to avoid

angling when the river reaches the same 18oC threshold. The issue has been discussed by other fishery boards with no action taken, primarily as this was considered to be a matter for the angling beats.

On spate rivers, such as the Oykel, the issue of angling restrictions during warm-water periods is largely self-regulating, as such periods are invariably accompanied by low flows, with angling at a virtual standstill anyway. This applies less so to rivers such as the Spey, where flows conducive to angling are almost always available.

Internationally, the country where warm-water angling protocols are most advanced is Canada, specifically regarding the rivers in the province of New Brunswick. In Norway there is currently no state regulation of angling during warm-water conditions (Eva Thorstad, NINA., pers., comm), although individual fishery/river closures have been implemented by owners.

River temperatures in New Brunswick typically exceed those recorded in Scottish rivers and significant mortalities of adult have been recorded. Daily maximum temperatures >23oC are routinely recorded in some New Brunswick rivers and in 1999 this daily maximum was exceeded on over 60 days on the Little Southwest Miramichi. It should be noted that over the same period river temperatures in the adjacent Restigouche rarely exceeded the same threshold. Angling in Canada is managed by the federal authorities through Fisheries and Oceans Canada (DFO) an organisation with oversight over recreational angling in public and private angling waters. Warm water angling protocols are highly developed by the DFO and stakeholders. The metric used to determine fishery closures is the minimum daily temperature (T_{min}). If T_{min} exceeds 20^{o}C for two consecutive days fishery limitations or closures are implemented. The regulations include limitations on the hours when angling is permitted (usually early morning to midday) or full fishery closures. The scientific justification for the adoption of T_{min} as a management threshold is that fish can recover from periods of high temperature if they are exposed to more optimal (lower) temperatures at some point during the day. At temperatures in excess of 24oC exercise to exhaustion results in anaerobic metabolism. In order to recover, rest periods at lower temperatures are required, so that potentially harmful by-products of anaerobic metabolism can be assimilated.

Further north in Canada, in Newfoundland and Labrador province similar regulations apply with rivers that permit salmon retention closed to angling during the day when water temperature is >20°C across 2–3 days. In rivers where only catch and release angling is permitted, lower river closure temperature thresholds apply (closures occur during the day when water temperature is >18 °C across 2–3 days) (Van Leeuwen et al., 2020).

DFO have authority over all recreational fisheries and the regulations are well observed (Robyn McCallum, pers. Comm.). The regulations are well-communicated and enforced by federal and provincial agents. Stakeholder engagement is high and awareness of the stress experienced by salmon during warm-water conditions has been widely promoted.

It is important to note that the likelihood of individual rivers reaching critical temperatures varies, as may the tolerance of fish within catchments.

4. River Spey temperatures

SFB staff maintain and download the Marine Scotland downstream temperature loggers in the Spey catchment (downstream of Carron Bridge). A summary of the peak summer temperatures in 2018 & 2021 (two hot summers) are provided in the tables below. Peak river temperatures, and the

duration of warm water conditions (+20°C), were higher, and longer, respectively in 2018 than in 2021.

The 2018 data from the Carron Bridge logger was not used as it had been air exposed during low flow periods. At these five mainstem loggers the highest peak temperatures were recorded at the Arndilly logger in both years. This logger is located at the downstream end of a long, shallow, riffle where there is high potential for air/water heat exchange. The peak temperatures recorded at loggers further downstream, and at lower altitude, were not as high as at Arndilly. The peak temperature at the Garmouth Viaduct (Spey_Scot97.1) was the lowest of the loggers in both 2018 and 2021. This highlights the importance of the local character of the river in facilitating heat exchange with the atmosphere and determining maximum temperatures reached.

Table 1: River temperatures and thresholds reached at lower Spey mainstem loggers, summer 2018.

2018	Spey_Scot88 - Carron Bridge	Spey_Scot90 Arndilly	Spey_Scot95 Brae Grilse	Spey_Scot95 A96	Spey_Scot97 .1 Viaduct	Average T°C
Daily Max T°C	Logger exposed	25	24.2	23.4	23.3	23.98
Daily Min T°C		18.9	19.7	19.8	19.9	19.58
Days >20°C		30	26	20	19	23.75
Nights min > 20°C		0	2	1	0	0.75
Mean T°C		20.1	20.9	20.6	20.7	20.58

Table 2: River temperatures and thresholds reached at lower Spey mainstem loggers, summer 2021.

2021	Spey_Scot88 - Carron Bridge	Spey_Scot90 Arndilly	Spey_Scot95 Brae Grilse	Spey_Scot95 A96	Spey_Scot97 .1 Viaduct	Average T°C
Daily Max T°C	22.1	23.6	23.3	22.7	21.9	22.72
Daily Min T°C	19.2	19.2	19.5	19.5	19.5	19.38
Days >20°C	11	12	13	11	10	11.4
Nights min > 20°C	0	0	0	0	0	0
Mean T°C	19.7	20.3	20.1	19.9	19.5	19.9

The Arndilly logger (Spey_Scot90) is located on the right bank, in the run into Cobble Pot. The river temperature profile for summer 2018 at this logger is shown in Figure 1. In 2018 the peak daily maximum was 25oC and there were 30 days when the peak temperature exceeded 20oC (Table 1). However, there were no 24-hour periods when T_{min} was greater than 20°C. In the same summer, T_{min} above 20oC were recorded on 2 & 1 nights respectively at the Brae Water Grilse Pool logger and at the logger located a short distance upstream of the A96.

Figure 2 shows the temperature profile from the Arndilly temperature logger over the warmest 13-day period of summer 2018. It can be seen that although the maximum temperature peaked at 25oC there were no nights when T_{min} exceeded 20oC. It can be seen that the peak temperatures occur in the afternoon with the lowest temperatures during the diurnal cycle in the early morning.

In 2018, in the same 13-day period as shown in Figure 2, the maximum temperatures recorded in the Fochabers Burn, and in the middle reaches of the Mulben Burn logger were 16.7 and 19.6°C respectively, with minimum temperatures of 9.5 and 11°C. Both of these burns are well-wooded (notably the Fochabers Burn) and the maximum temperatures recorded were significantly lower than in the mainstem. These burns are low altitude but this highlights the potential that exists to mitigate future climate changes. There is extensive scope for riparian tree planting on middle and

upper Spey tributaries. Marine Scotland have produced guidance on priority areas for tree planting across Scotland.

The impact of upper river abstraction on flows in the lower Spey will also have a significant impact of heat exchange and peak temperatures. The natural mean flow in the Spey is currently reduced by 17% - 24% at Boat o' Brig (Envirocentre, 2021). This reduction in natural flow reduces the resilience of the river during low flow conditions and will inevitably results in higher peak temperatures during low flow periods. Restoration of a more natural flow regime in the Spey catchment is a high priority of the SFB. If accomplished this could greatly improve river resilience, including mitigating against future water temperature rises.

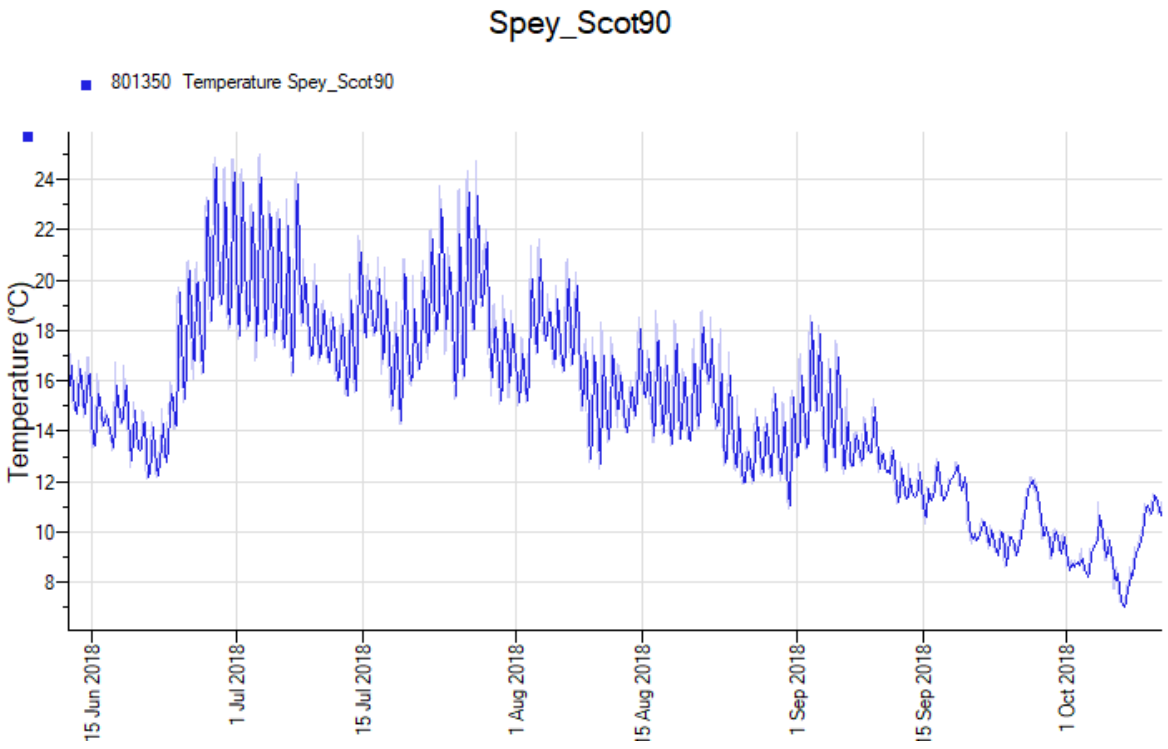

Figure 1: River Spey, Arndilly logger, river temperature profile summer 2018

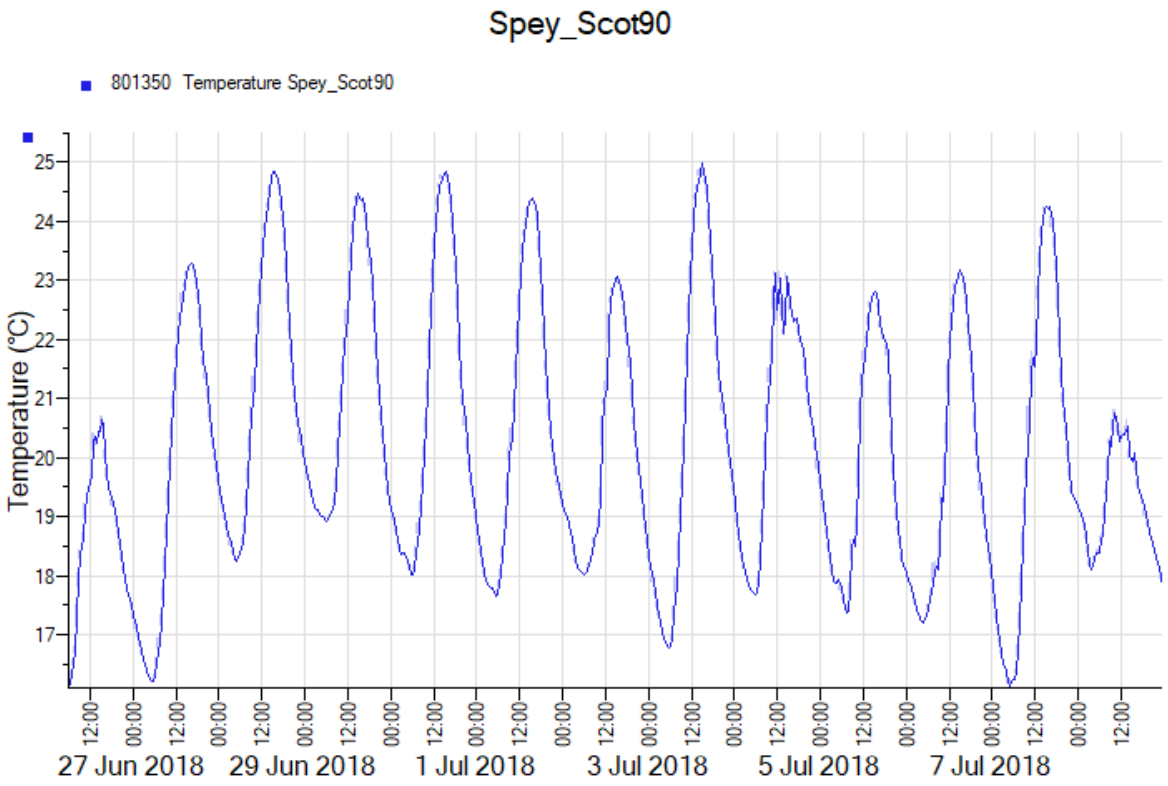

Figure 2: River Spey, Arndilly logger, river temperature 27th June to 8th July 2018. There were no occasions when T_{min} exceeded 20°C for the full 24hours

5. Population Level Impacts of Warm Water

Various authors have noted that the presence of viable populations of brown trout and salmon appears to be limited by temperatures well below those considered to be directly lethal (Solomon & Lightfoot, 2008).

The upper lethal limit for salmon and trout are well defined, but there are sub-lethal effects, which are much less well understood (Elliot, J.M., 1981). These impacts include reduced egg size, fecundity & survival, and mis-matches between spawning and emergence. The cumulative effect of these sub-lethal can affect the status of the population as a whole, even in the absence of temperatures approaching lethal levels. Overall, it appears that occurrence of temperatures within the upper critical temperature range (i.e. above 19.5°C for brown trout and 22.5°C for Atlantic salmon) represents a stress that may affect the long-term well-being of the population. This factor probably accounts for the northwards shift of salmon populations, rather than the loss of fish through direct thermal mortality.

It is also likely that populations will adapt to changing environmental conditions including rising temperatures. One response could be earlier run timing. The remnant salmon populations in the Iberian Peninsula run the rivers early and reach the cooler headwater locations before the peak summer temperatures. However, ecological responses such as these occur over many generations, and the pre-adaption phase are likely to feature significant population declines (Carlson et al., 2014).

6. Warm Water Angling Recommendations

If the Miramichi protocols had been adopted on the Spey there would have been no occasions in recent years when fishery closure would have been warranted (based on the temperature data

collected from the River Spey over two recent hot weather summers (2018 and 2021)). However, climate change predictions suggest that will change in the decades to come.

Studies have shown that mortality amongst catch and release salmon increases with temperature although there appears to be little direct evidence for excess warm water mortality arising from catch and release angling in the Spey. Mortalities following catch and release are occasionally seen, and reported on the Spey, but not necessarily correlated with high temperature events. Mortalities are often seasonal with May the month when mortalities are most likely. This does not mean that no mortalities occur. Stressed fish may be more susceptible to predation, e.g. by otters, and cause of death may be wrongly attributed.

The question of how many fish are actually caught during warm water conditions also arises. Van Leeuwan et al (2020) predicted the proportion of the total run to die following C&R angling, in a selection of Newfoundland and Labrador rivers, as ranging from 0 to 7.6%.

Studies investigating the impact of catch and release angling, during warm water conditions (+23^{o}C) have recorded mortality rates of up to 40%, with no mortality in control fish held in the same conditions (Wilkie et al (1997)). Other papers have demonstrated sub-lethal impacts of "air-exposure" on subsequent spawning and reproduction success (Richard et al., 2013).

The week of the highest temperatures on the Spey in 2021 was the week commencing the 19th July. Fish were still caught that week, in reasonable numbers on some beats (https://www.speyfisheryboard.com/week-commencing-19th-july/) but it is significant that most of the fish pictured were caught when there was cloud cover in the morning. During the course of that week, it was typically 11am before the river temperature climbed above 20oC. The number of fish caught when temperatures were above 20oC in that week is likely to be measured in the tens, rather than the hundreds, but some fish are caught in temperatures above 20oC. Further research is required to establish the numbers of salmon caught by angling during warm water events. This is essential to understand the magnitude of the issue.

Any actions that could be taken to limit increases in the river water temperature should be implemented. These actions could include tree planting, identification and protection of cold water refugia, and mitigation against sources of thermal pollution. The Spey supports the greatest density of distillers in Scotland and one of the most significant environmental impacts of that industry is thermal pollution.

Regulation of fisheries is different in Scotland than in Canada, and the Spey Fishery Board have no powers to implement fishery closures. However, significant changes in attitudes, and actions, have been delivered through voluntary approaches supported with robust science and guidance, for example the adoption of catch and release as a conservation measure. It is likely that attitudes to angling during warm water events could also be influenced through awareness raising and consultation. At present critical temperatures in the Spey angling zone are not yet being reached; mitigation measures, such as outlined below, will help safeguard against the requirement for fishery closures.

The best way to maintain and protect Spey salmon is to ensure that the survival chances and reproductive success of wild adult salmon returning to the river are maximised. The following recommendation are suggested:

1. River Spey temperatures are monitored so that trends, and the onset of critical temperature thresholds, are understood.

2. An assessment of the number of salmon caught during warm water events (+20°C) should be undertaken to quantify any potential threat to the salmon population.
3. Mitigation measures to limit the impacts of increasing temperatures are implemented on a catchment scale. Most obviously, this includes tree planting to provide shade along riparian habitat.
4. Restoration of more natural flows (removal of upper river abstractions) would increase the resilience of the river, buy time, and mitigate against climate change environmental stresses, such as high river temperatures.
5. Collaborative projects are developed to mitigate the thermal footprint of the distilling industry.
6. Cold water refugia are identified and protected to maximise range and effectiveness.
7. Awareness of the threats posed by high water temperatures, including sub-lethal effects, are promoted amongst the angling community.
8. High standards in catch and release are promoted across the angling community, including minimisation of handling and air exposure, particularly when temperatures are elevated.
9. Guidance on Warm Water angling protocols are produced in consultation with fisheries, anglers and other stakeholders, and implemented when required in order to protect the Spey wild salmon stock.

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