	Council **Development of evidence-based management strategies to protect salmon populations from the effects of high river temperatures under climate change through targeted riparian tree planting; case studies from Scotland and England**	**CNL(23)58** **Agenda item: 7a)**

Development of evidence-based management strategies to protect salmon populations from the effects of high river temperatures under climate change through targeted riparian tree planting; case studies from Scotland and England

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Introduction

River temperature is a key control on freshwater ecosystems, influencing species survival, distribution, abundance and growth. Across the UK many native freshwater species, including Atlantic salmon, are adapted to live in cool clean water habitats. During the summer of 2018, it is estimated that around 70% of Scotland's rivers experienced temperatures that exceeded the threshold for thermal stress in juvenile Atlantic salmon (Jackson *et al.,* 2020). UK climate change projections provided by the MET Office (UKCP18) indicate that summers like 2018 could occur every other year by 2050, with increasingly high air temperatures (Ta) and low summer flows. There are thus increasing concerns over the potential impacts of rising river temperature under climate change. In recognition of these challenges, and within the broader context of national climate adaptation programmes and associated resources (see for example Natural England and RSPB, 2019), management strategies that seek to improve the climate resilience of rivers are a key component of efforts to protect and recover salmon populations across the UK (see Scottish Wild Salmon Strategy, England's Salmon 5 Point Approach and the Welsh Salmon and Sea Trout Plan of Action).

Alongside the management of flows and abstractions, riparian tree planting provides one of very few management options available to reduce river temperature. Riparian trees can shade river channels, reducing the amount of solar radiation reaching the water surface, thereby reducing temperatures. In addition, shading can help mitigate the negative effects of other pressures, expected to be exacerbated by climate change, such as eutrophication and algal blooms.

Increasing amounts of river restoration are being undertaken in the UK, which often includes riparian tree planting. Financial support comes from a variety of sources, including government grant schemes and local charitable fundraising. Commitments, such as in Scottish Forestry's Implementation Plan (2022-2025) to develop 'an integrated approach to riparian management to improve the climate resilience of rivers, water quality, river morphology, and the availability of habitat networks', also aspire to support further expansion of riparian woodlands.

There is considerable potential in the UK to increase riparian woodland. Due to the time taken to plan and implement appropriate tree planting, and for trees to reach heights where they provide meaningful shading, it is important that efforts are made to increase the spatial extent of riparian woodland as a matter of urgency. However, given constrained resources, it is also important to prioritise planting to river reaches where trees can deliver the greatest benefits in terms of temperature moderation.

Substantial technological and statistical developments have enabled significant advances in large-scale river temperature monitoring and modelling, in addition to the availability of large-scale shading models. This provides a strong scientific evidence base on which to build climate adaptation strategies. This presentation provides an overview of two case studies from different parts of the UK.

Scotland Case Study

The Scotland River Temperature Monitoring Network (SRTMN) was established in 2013 as a collaboration between the Scottish Government directorate Marine Scotland, fisheries managers and the University of Birmingham. It includes (1) a strategically designed monitoring network (Jackson *et al.,* 2016) supported by quality controlled data collection and database storage, (2) spatio-temporal statistical models to identify which rivers are hottest and most sensitive to climate change (Jackson *et al* 2017; 2018), (3) simplified process-based shading models to identify where rivers can be most effectively cooled by riparian woodland (Jackson *et al.,* 2021) and (4) national scale mapping tools to prioritise management to areas where riparian tree planting will have the greatest overall benefits in terms of protecting Scotland's rivers from the adverse effects of high summer river temperatures under climate change (SRTMN, 2023).

To our knowledge, SRTMN was the first strategically designed, quality controlled national river temperature monitoring network in the world. It was designed to cover the environmental range of river characteristics that previous studies showed to be good predictors of temperature in near-natural rivers (Jackson *et al.,* 2016). This approach minimises site redundancy and maximises statistical power to make predictions to unmonitored locations. Data collection is undertaken through collaboration with local fisheries managers. Since its initial deployment in 2014/15 the core network of 223 sites, has been expanded to include short-term deployments (~ 1 year) in unmonitored catchments, and monitoring of catchments influenced by natural and modified standing waters where predictions are less accurate.

Data from SRTMN have supported the development of spatio-temporal statistical river temperature models (see Jackson *et al.,* 2018 for details). These can be used to understand and predict river temperature across the country. In brief, maximum daily river temperature was modelled as a function of air temperature, time of year and landscape characteristics (elevation, channel orientation and riparian woodland). Spatial correlation (non-independence of sites close to each other) was encompassed at river network and regional scales. Temporal correlation (the non-independence of observations over time) was addressed through an autoregressive (AR1) error structure. The resulting models allowed prediction of maximum river temperature and climate sensitivity across Scotland.

The effects of riparian woodland on channel shading depend on complex interactions between channel width, orientation, aspect, gradient, tree height and solar geometry. The subsequent effects on river temperature are influenced by water volume and residence time. By combining the results of a simplified process-based shading model with information on water volume and residence time the effects of solar radiation on river temperature can be modelled. By comparing scenarios with and without trees it is possible to identify rivers that can be effectively cooled by riparian woodland (Jackson *et al.,* 2021). When the outputs of the statistical and process-based models are combined it is possible to identify priority river reaches for management, specifically, where rivers are hottest, most sensitive to climate change and where planting is likely to be most effective in reducing temperatures.

Data and analyses from SRTMN have been disseminated through a variety of media tailored to different audiences interested in the management of river temperature under climate change.

This includes peer reviewed publications, R Shiny Applications, web pages, spatial data layers (e.g. online GIS, web based mapping services) and non-technical documents (e.g. end user friendly leaflets).

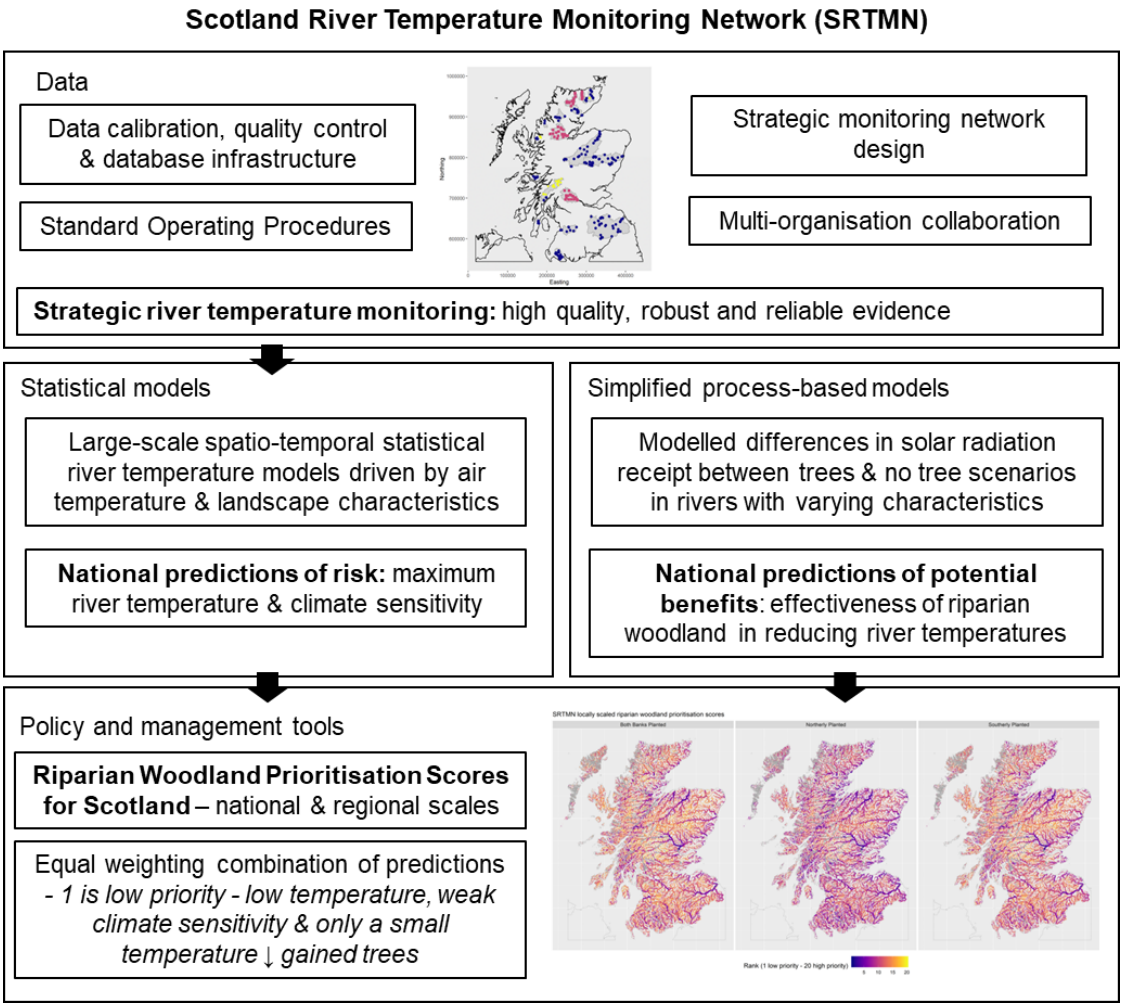

***Figure 1**: Schematic of Scotland River Temperature Monitoring Network.*

England Case Study - Keeping Rivers Cool

The Keeping Rivers Cool (KRC) project is a nationwide initiative. It aims to increase the resilience of sensitive ecosystems and freshwater wildlife, particularly salmon and trout, to the impacts of climate-change-induced temperature increases by using riparian shading to cool rivers.

KRC provides practical support to encourage landowners and conservation managers to increase riparian shading, by providing (1) Riparian shade maps, which can be used by land managers to target areas in a catchment which are exposed most to sunlight. Shade maps grade the river on a spectrum from red (low shading) to blue (high shading) to indicate the degree of relative shading (2) Best practice guidance, which is now administrated by The Woodland Trust and (3) A direct link to funding, including via the England Woodland Creation Offer, which is focussed on rivers less than seven metres wide.

In the initial demonstration projects on the Ribble, Hampshire Avon, Wye, and Tyne river catchments, 55,000 trees were planted and 37 km of fencing erected between 2012–2016. Since then, KRC has expanded exponentially with, for example, the Rivers Trust planting 277,520 trees in 2021.

During 2021-22, 68Ha were planted to Keep Rivers Cool with funding from a number of government tree planting schemes. For example, in the Mid-Ribble catchment (Bier Beck, Savick Brook, Showley Brook, Porters Brook, West Clough, Greystonely Brook, Hodder) funding was provided via SITA Trust's Enriching Nature Programme, Defra Catchment Restoration Fund and the Woodland Trust's MOREwoods. Planting was further supported by 36 volunteer days. Combined this resulted in installation of 10 km of fencing across 13 sites and 10,000 trees planted, improving over 9 hectares of riparian habitat.

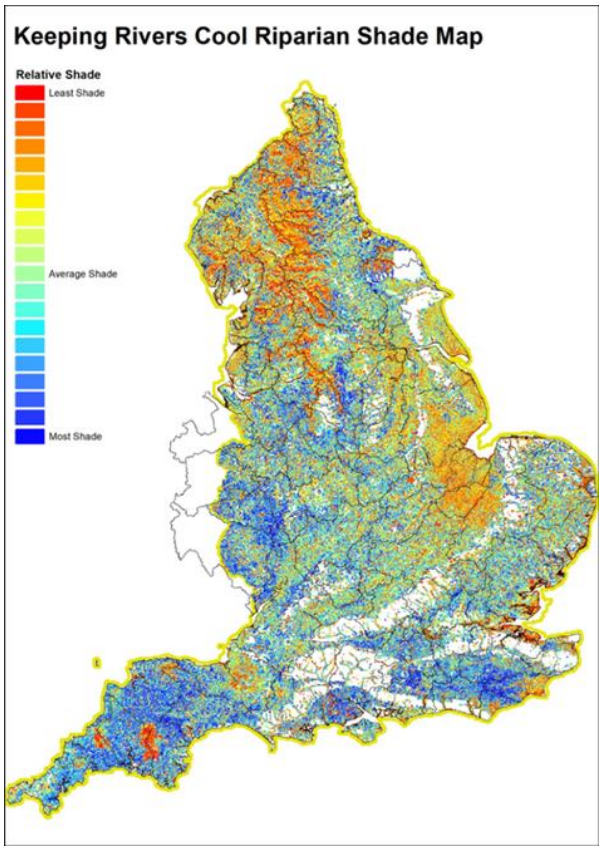

***Figure 2**: England Riparian Shade Map*

To provide an up to date and more accurate riparian shade map, an England-wide detailed (1m resolution) lidar survey was undertaken between 2017-2022 to map the vegetation and a first-return Digital Surface Model (DSM) was employed to give a more accurate depiction of vegetation height. Multi-directional sun-shading was then applied to a Digital Terrain Model (DTM) and first-return Digital Surface Model (DSM), based on sun-angles throughout the day over the summer months, to determine the degree of shading. The 2nd generation KRC riparian shade map and accompanying Vegetation Object Model are now available directly from the Environment Agency and by late 2023 will be available to download via the government's Open Data portal (Environment Agency, 2021).

Conclusions and future look

Appropriate monitoring approaches provide reliable and unbiased quantitative data on river temperature variability. As timeseries of quality controlled data build, they also provide valuable information on trends and the efficacy of management. When combined with appropriate statistical and process-based models these data can be used to guide policy and target management action. Where river temperature data and associated modelling are not available shading potential maps can be used to target resources. However, as they only provide sunlight exposure, alone they may not identify the highest temperature locations or locations where trees can reduce temperatures most. Depending on data availability, priorities and resources, there is potential to extend river temperature modelling approaches to explore future river temperatures using climate change projections (UKCP18), support other environmental assessment methods and explore opportunities for 'real-time' monitoring and management (e.g. within season close times for angling as seen in other countries such as Canada; Breau 2012).

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