River temperature, climate change and the potential of bankside tree planting to mitigate high temperatures

The Scottish Government
Riaghaltas na h-Alba

http://www.gov.scot/Topics/marine/Salmon-Trout-Coarse/Freshwater/Monitoring/temperature

Northern Rivers Institute
University of Aberdeen
University of Birmingham
University of Nottingham UK | CHINA | MALAYSIA
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Outline

- Background and context
- Processes controlling Tw
- SRTMN: Using statistical models to understand and predict where river temperatures are hottest and most sensitive to climate change
- Using process-based models to understand where riparian shading most effective in reducing Tw?
- Combining outputs from statistical and process models to prioritise tree planting
- Future directions

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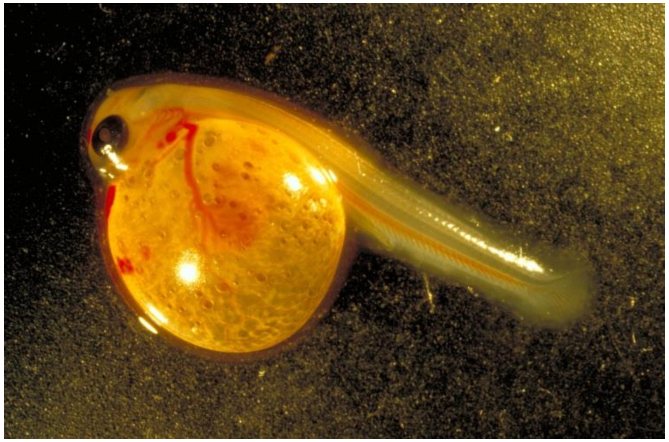
Temperature and salmonids

- **Influences:**
  - spawning location and timing
  - Embryo development and timing of hatch and emergence
  - Feeding and growth
  - Productivity
  - Size at age
  - Population demographics (age at smolting, lifetime mortality)
  - Survival at temperature extremes



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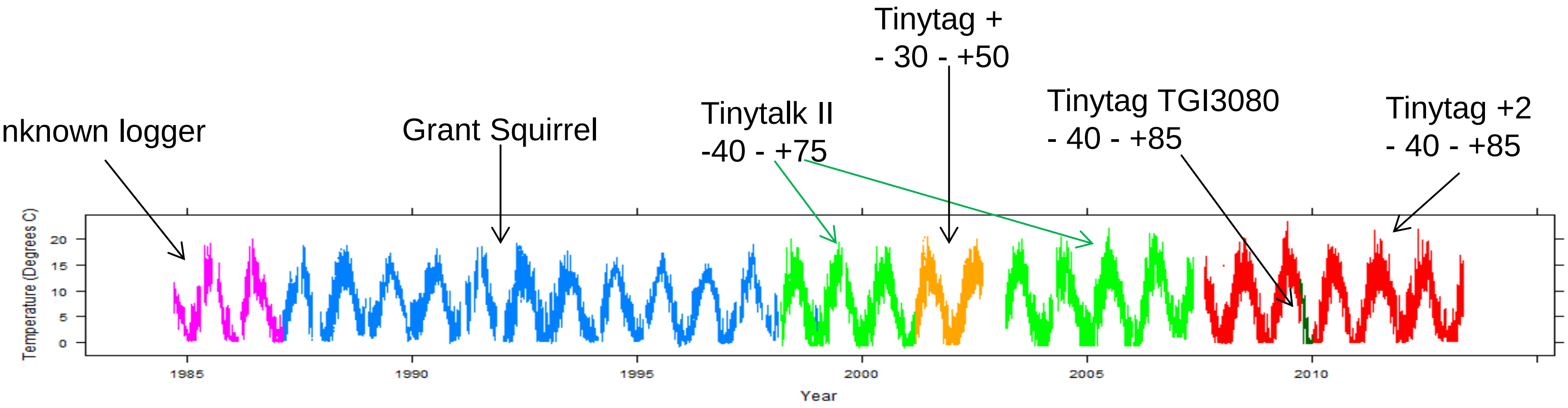
Temporal trends

- Very few continuous high resolution records > 2 decades in Scotland
- Especially sites independent of significant land use change
- MSS data from Girnock Burn
- First 30 years published by Langan *et al*., 2001, reported 1966-2006 Ca. 0.6 degree increase in mean T



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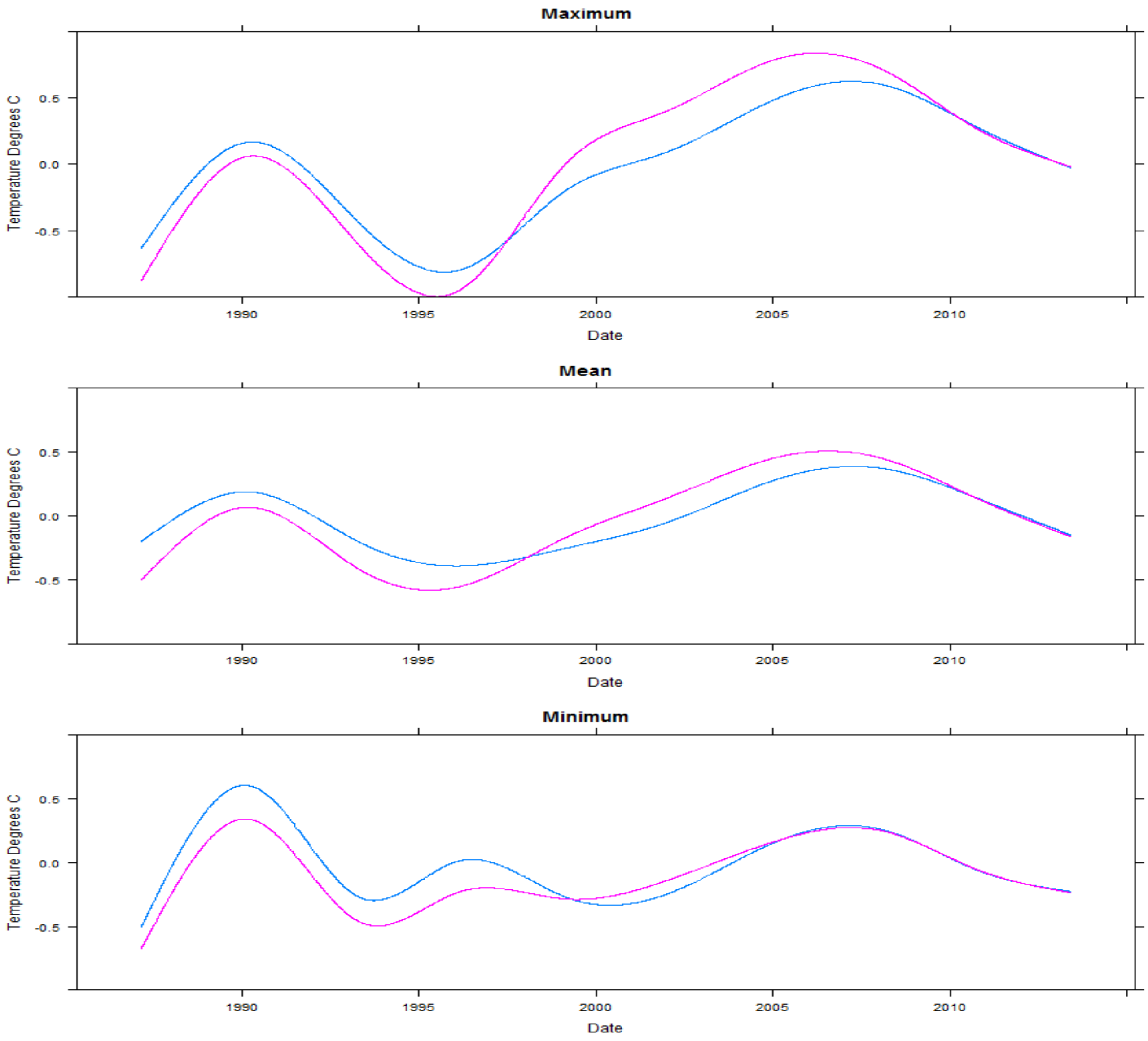
Significant long-term trends, punctuated by decadal variability. QC is critical

Raw
Corrected

- Significant long-term temporal trends
- Long-term trends did not vary with DoY (seasonally)
- Corrected trends accentuated, but could have been reduced or eliminated depending on logger order



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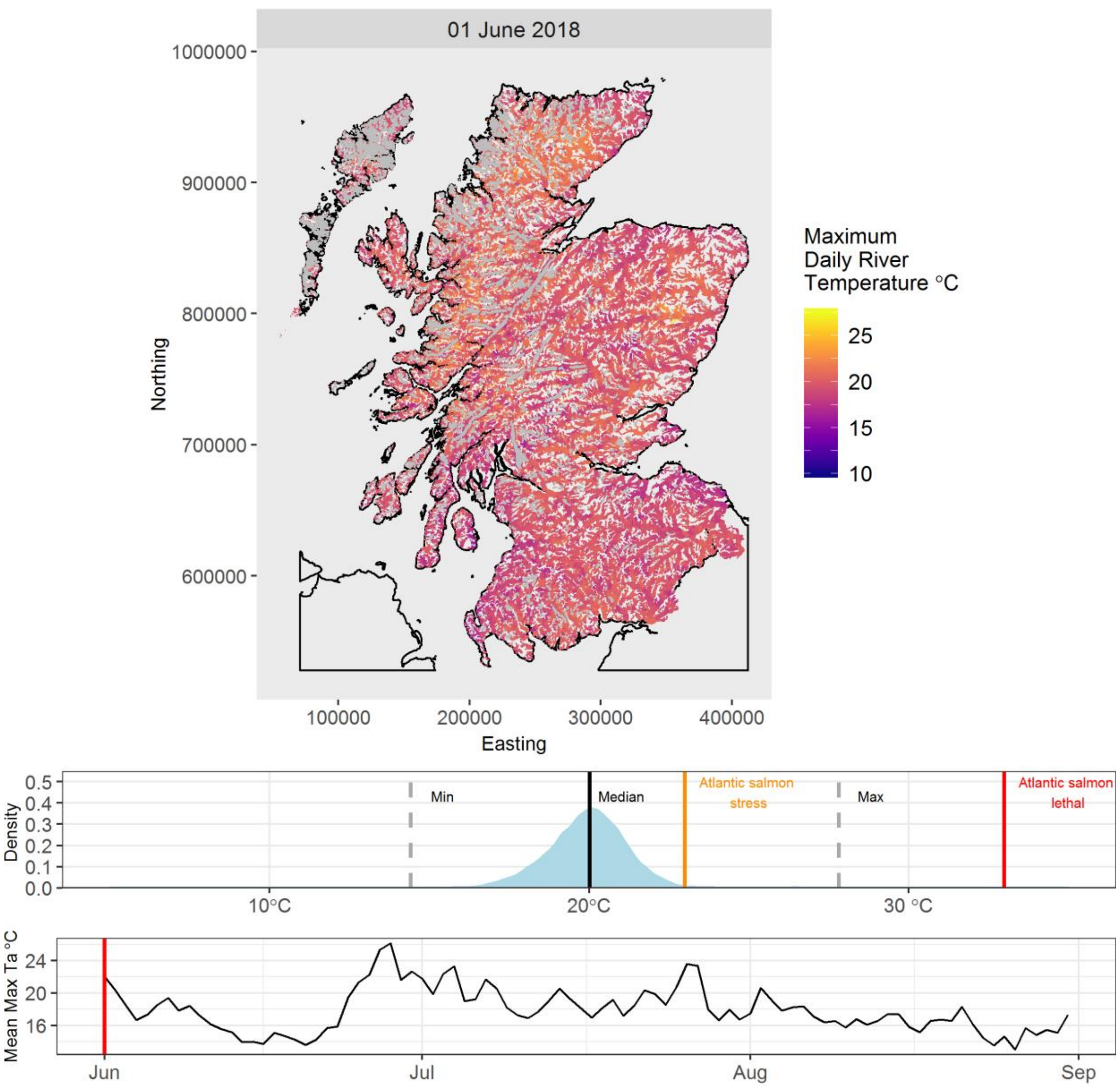
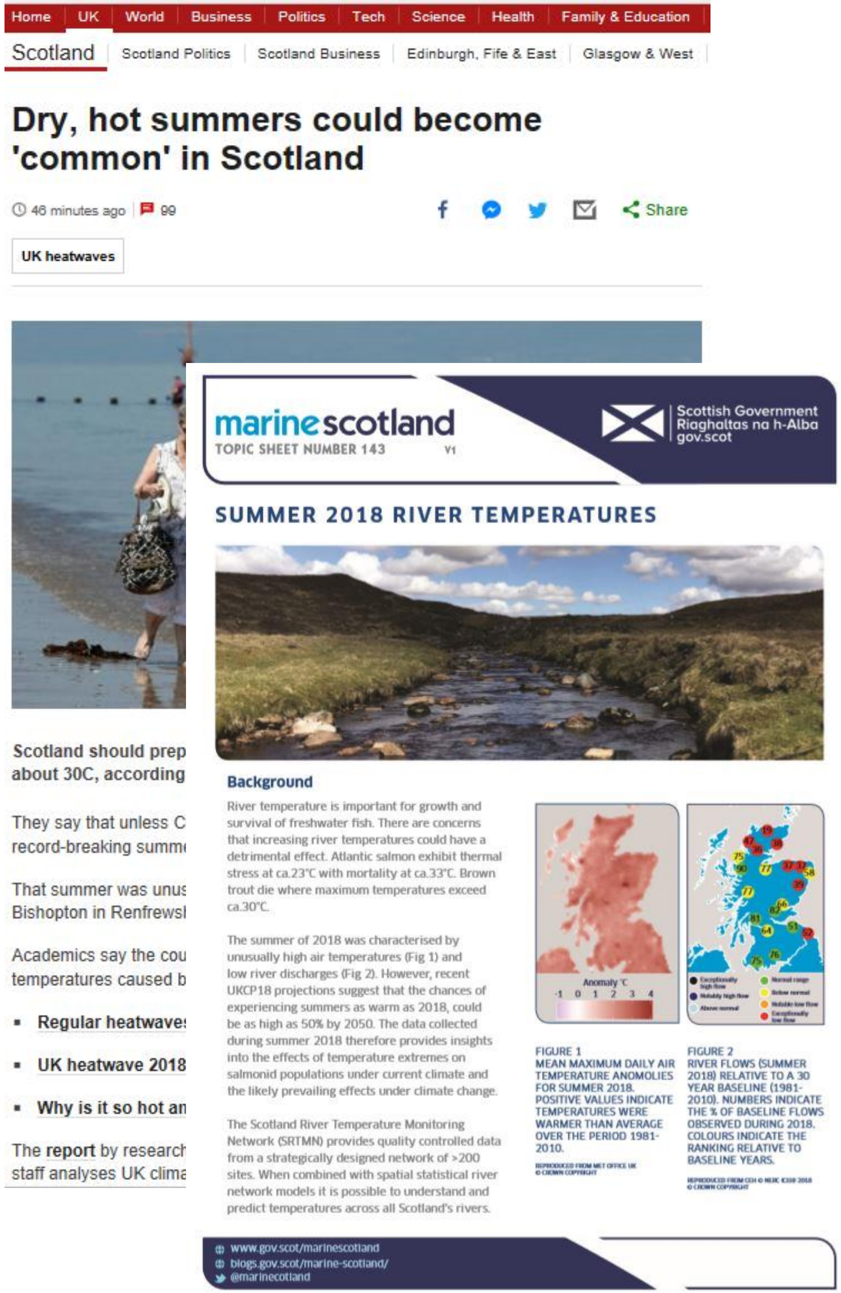
Summer 2018; an indication of things to come?

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Dry, hot summers could become 'common' in Scotland

46 minutes ago | 99

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UK heatwaves

Scotland should prep
about 30C, according

They say that unless C
record-breaking summ

That summer was unus
Bishopton in Renfrews

Academics say the cou
temperatures caused b

- Regular heatwave
- UK heatwave 2018
- Why is it so hot an

The report by researc
staff analyses UK clima

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TOPIC SHEET NUMBER 143 V1

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SUMMER 2018 RIVER TEMPERATURES

Background

River temperature is important for growth and survival of freshwater fish. There are concerns that increasing river temperatures could have a detrimental effect. Atlantic salmon exhibit thermal stress at ca.23°C with mortality at ca.33°C. Brown trout die where maximum temperatures exceed ca.30°C.

The summer of 2018 was characterised by unusually high air temperatures (Fig 1) and low river discharges (Fig 2). However, recent UKCP18 projections suggest that the chances of experiencing summers as warm as 2018, could be as high as 50% by 2050. The data collected during summer 2018 therefore provides insights into the effects of temperature extremes on salmonid populations under current climate and the likely prevailing effects under climate change.

The Scottish River Temperature Monitoring Network (SRTMN) provides quality controlled data from a strategically designed network of >200 sites. When combined with spatial statistical river network models it is possible to understand and predict temperatures across all Scotland's rivers.

FIGURE 1
MEAN MAXIMUM DAILY AIR TEMPERATURE ANOMOLIES FOR SUMMER 2018. POSITIVE VALUES INDICATE TEMPERATURES WERE WARMER THAN AVERAGE OVER THE PERIOD 1981-2010.

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FIGURE 2
RIVER FLOWS (SUMMER 2018) RELATIVE TO A 30 YEAR BASELINE (1981-2010). NUMBERS INDICATE THE % OF BASELINE FLOWS OBSERVED DURING 2018. COLOURS INDICATE THE RANKING RELATIVE TO BASELINE YEARS.

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Mitigation: riparian tree cover

- **Riparian woodland can reduce high temperature extremes**
- **Strategically target effort:**
  - Where are rivers hottest (SRTMN)
  - Where are rivers most sensitive to effects of climate change (SRTMN)
  - Where does riparian tree planting have the greatest effect on river temperature (process based models)
  - Management tools that combine above

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TOPIC SHEET NUMBER 91 V2

Scottish Government
Riaghaltas na h-Alba
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WHERE SHOULD WE PLANT TREES TO PROTECT RIVERS FROM HIGH WATER TEMPERATURES?

Background

River temperature (Tw) influences the feeding, growth and productivity of freshwater fish and extreme high Tw (e.g. >29°C and >32°C for trout and salmon juveniles) can kill fish in as little as 10 minutes. Under climate change Tw is expected to rise, with potential consequences for Scotland's valuable salmon and trout populations.

Bankside trees can reduce Tw, however, their effect varies depending on the characteristics of the rivers (such as width, channel orientation, speed) and their surrounding landscapes (such as tree density, landscape shading).

Fisheries and river managers are increasingly interested in planting bankside trees to protect rivers from high water temperatures. However, they often lack the necessary information to determine where planting would deliver the greatest benefits.

Can models help inform tree planting strategies?

Marine Scotland and the University of Birmingham have recently developed tools and advice to help river managers decide where to plant trees to reduce maximum daily river temperatures and mitigate the effects of climate change.

These tools include two types of complimentary models which are applied depending on the spatial scale at which decisions are being made:

1. Statistical models describe large scale (>km) Tw variability and climate sensitivity
2. Deterministic models identify the processes controlling Tw and the effects of management actions (including shading by trees) at finer spatial scales (metres to kilometres).

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Controls on River Temperature

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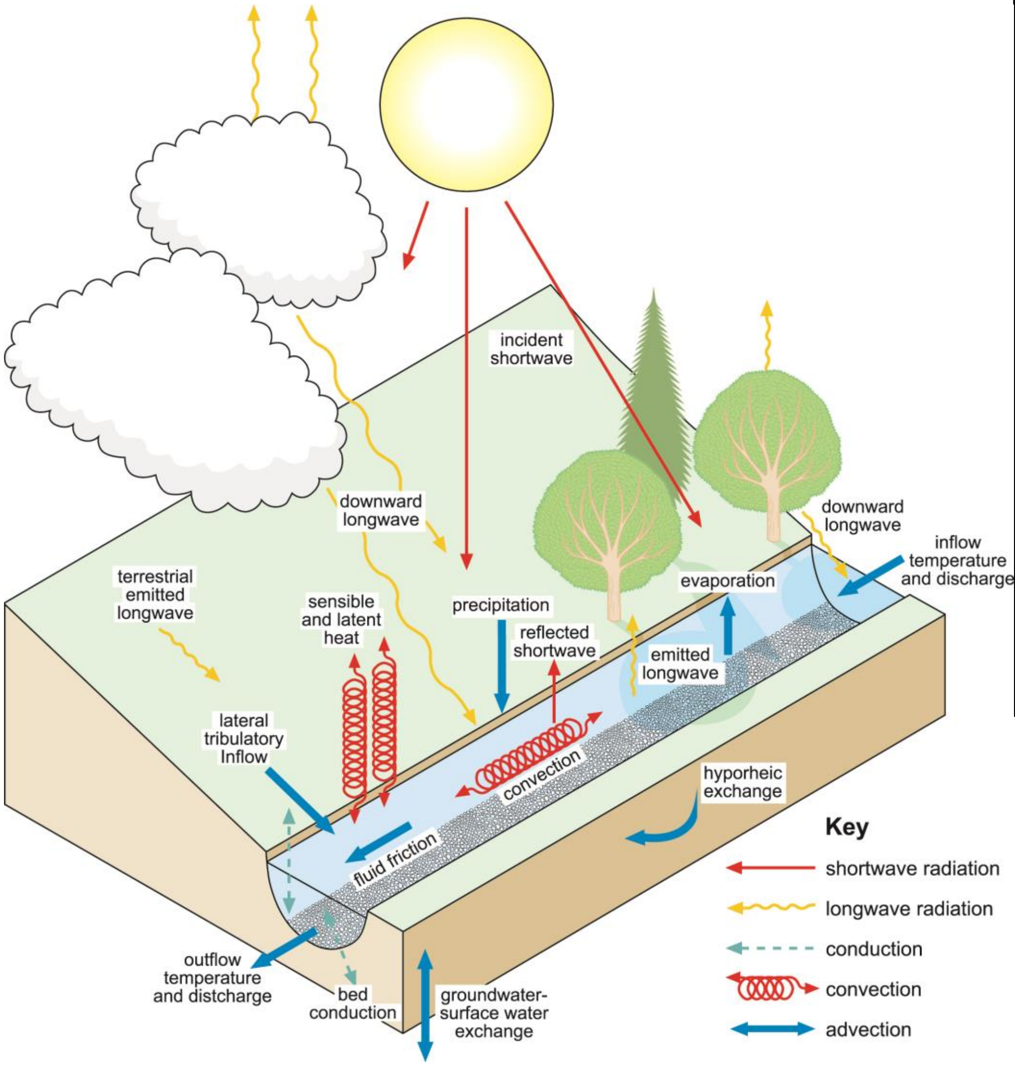
Processes controlling Tw



A comparison of forest and moorland stream microclimate, heat exchanges and thermal dynamics

David M. Hannah, Iain A. Malcolm, Chris Soulsby and Alan F. Youngson

HYDROLOGICAL PROCESSES

Inter-annual variability in the effects of riparian woodland on micro-climate, energy exchanges and water temperature of an upland Scottish stream

Hydrol. Earth Syst. Sci., 18, 5361–5376, 2014

Hydrology and Earth System Sciences

What causes cooling water temperature gradients in a forested stream reach?

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Stream temperature under contrasting riparian forest cover: Understanding thermal dynamics and heat exchange processes

Stephen J. Dugdale, Iain A. Malcolm, Kaisa Kantola, David M. Hannah

HIGHLIGHTS

GRAPHICAL ABSTRACT

ARTICLE INFO

ABSTRACT

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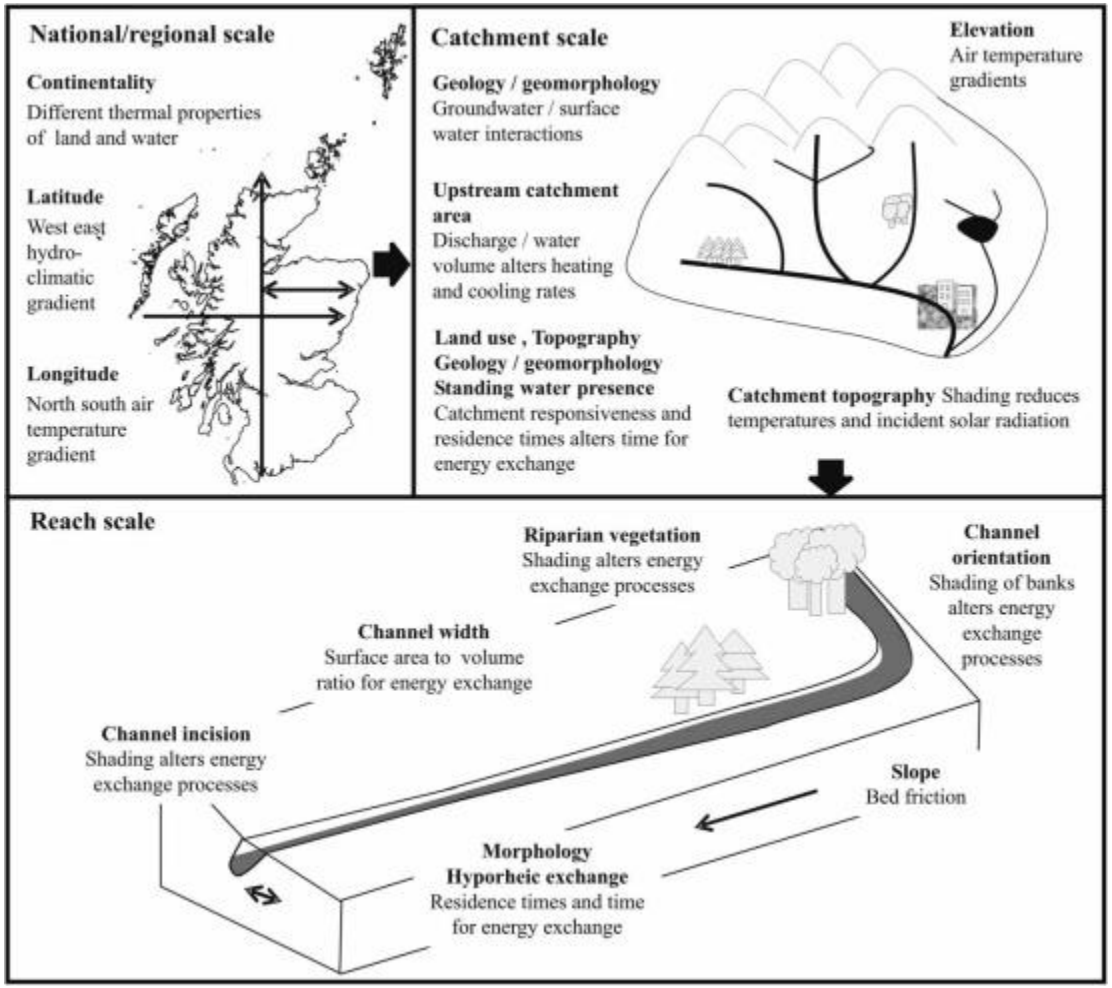
Consider how landscape affects processes



  Hydrology Research | 47.3 | 2016

A novel approach for designing large-scale river temperature monitoring networks

F. L. Jackson, I. A. Malcolm and David M. Hannah

ABSTRACT

Water temperature is an important control on processes in aquatic systems and particularly for freshwater fish, affecting growth, survival and demographic characteristics. In recognition of this importance, the Scottish Government has prioritised developing a robust national river temperature monitoring network. Advances in geographical information systems, spatial statistics and field data loggers make large-scale river temperature monitoring increasingly possible. However, duplication of environmental and thermal characteristics among monitoring sites means many networks have lower than expected statistical power. This paper describes a novel methodology for network design, illustrated by the development of the Scotland River Temperature Monitoring Network. A literature review identified processes controlling stream temperature and associated landscape controls. Metrics indicative of these landscape controls were calculated for points every 500 m along the river network. From these points, sites were chosen to cover the full range of observed environmental gradients and combinations of controlling variables. The resulting network contains sites with unique characteristics covering the range of relevant environmental characteristics observed in Scottish salmon rivers. The network will thus have minimal redundancy, often not seen in large networks, and high statistical power to separate the relative importance of predictor variables thereby allowing large-scale water temperature predictions.

Key words | large-scale monitoring, network design, river temperature, Scotland

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INTRODUCTION: CURRENT STATUS AND LIMITATIONS OF LARGE-SCALE RIVER TEMPERATURE NETWORKS

Rising water temperatures (*Tw*) have the potential to alter the thermal suitability of rivers for freshwater fish, which are frequently the focus of management (Mohseni *et al.* 2003; Isaak *et al.* 2010, 2012). Cold water fish such as salmonids are highly sensitive to river temperature which affects growth, metabolism, performance, survival and demographic characteristics (Elliott 1994; Gurney *et al.* 2008). Atlantic salmon (*Salmo* salar) and, to a lesser extent, brown trout (*Salmo trutta*) have a high economic (Radford *et al.* 2004), recreational and conservation value (Anon 2009). Consequently, there are strong socio-economic drivers for understanding the spatio-temporal dynamics of thermal regimes, their sensitivity to drivers of change and opportunities for management or mitigation of thermal extremes (Malcolm *et al.* 2008; Hrachowitz *et al.* 2010). In recognition of the importance of these issues, CAMERAS (Coordinated Agenda for Marine, Environment and Rural Affairs Science), an umbrella group of Scottish Government departments and agencies, prioritised the development of a strategic national water temperature network in their recent freshwater monitoring action plan.

doi: 10.2166/nh.2015.106

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SRTMN: Using statistical models to understand and predict where river temperatures are hottest and most sensitive to climate change

Objectives of SRTMN

1. Characterise river T across Scotland

2. Identify areas susceptible to climate change

3. Improve understanding of controls on T

4. Develop models to predict T change

5. Determine optimum areas for riparian tree planting

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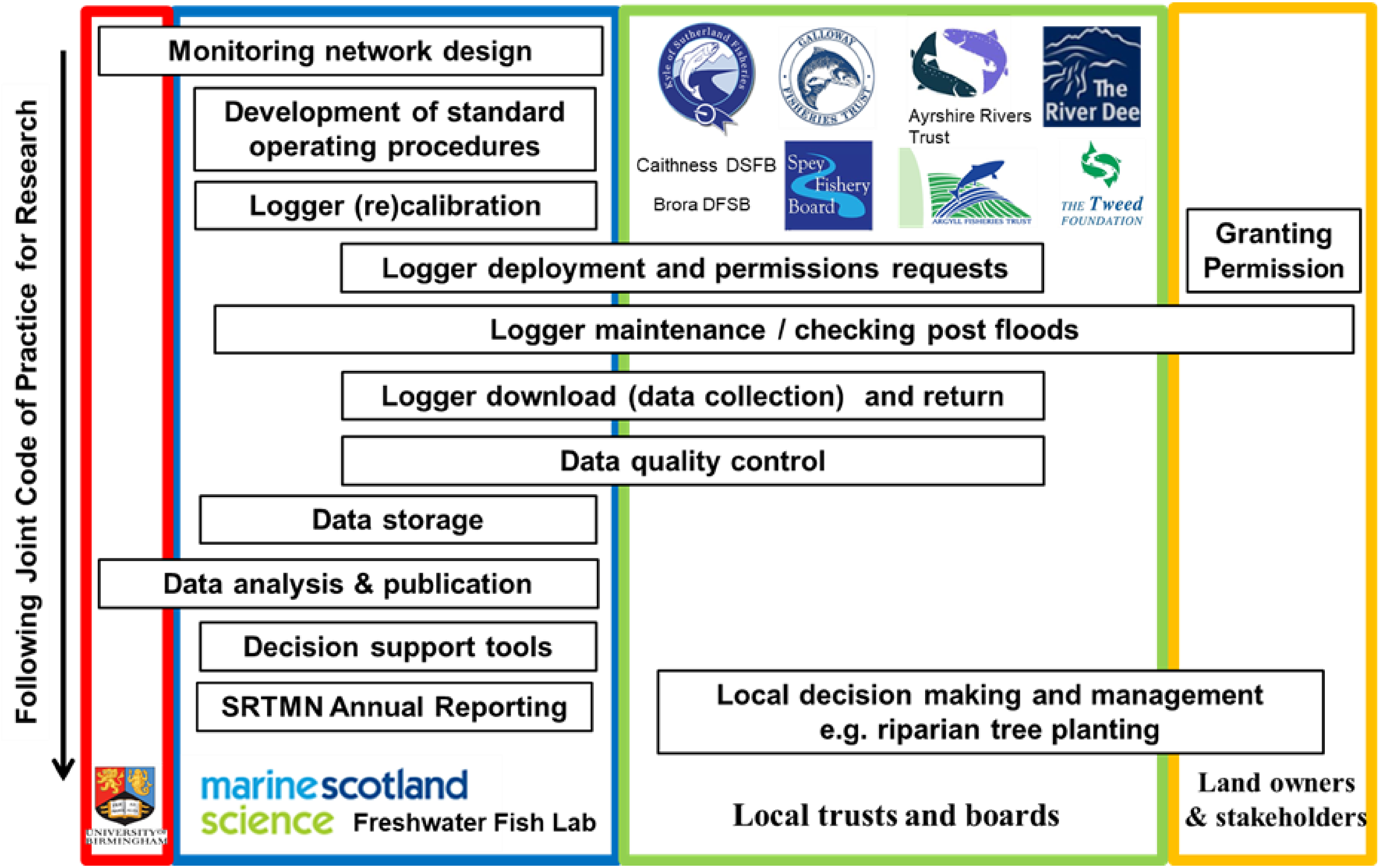
NERC SCIENCE OF THE ENVIRONMENT

SRTMN



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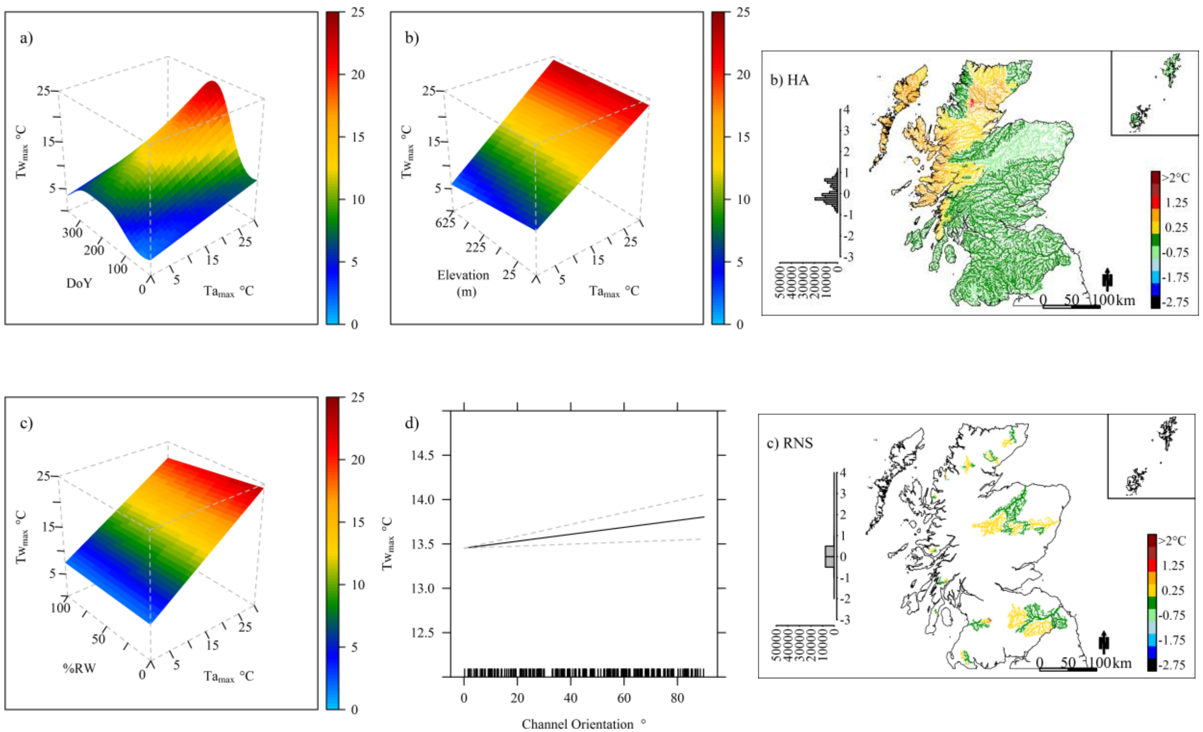
Use models to predict river temperature in unmonitored locations

Large-scale spatio-temporal statistical models

$$Tw_{max} \sim Ta_{max} + s(DoY) + s(DoY) \times Ta_{max} + Elevation + Elevation \times Ta_{max} + \%RW + \%RW \times Ta_{max} + Orientation + HAS + HAS{:}Ta_{max} + RNS{:}Catchment + RE(Site) + RE(Site){:}Ta_{max}$$



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A spatio-temporal statistical model of maximum daily river temperatures to inform the management of Scotland's Atlantic salmon rivers under climate change

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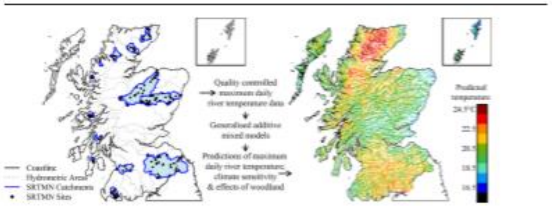
[b] School of Geography, Earth and Environmental Science, University of Birmingham, Birmingham B15 2TT, England, UK
[c] Marine Scotland Science, Scottish Government, Marine Laboratory, 375 Victoria Road, Aberdeen AB11 9DB, Scotland, UK

HIGHLIGHTS

- Data collected from strategic river temperature monitoring network
- Novel spatio-temporal model of maximum daily river temperature developed
- Models include air temperature, location, day and landscape characteristics
- Model predictions show spatial temperature variability and climate sensitivity.
- Maps provide tools for fisheries and river managers.

GRAPHICAL ABSTRACT



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Generalized additive mixed model
Climate sensitivity
Fisheries management

ABSTRACT

The thermal suitability of riverine habitats for cold water adapted species may be reduced under climate change. Riparian tree planting is a practical climate change mitigation measure, but it is often unclear where to focus effort for maximum benefit. Recent developments in data collection, monitoring and statistical methods have facilitated the development of increasingly sophisticated river temperature models capable of predicting spatial variability at large scales appropriate to management. In parallel, improvements in temporal river temperature models have increased the accuracy of temperature predictions at individual sites. This study developed a novel large scale spatio-temporal model of maximum daily river temperature (Tw_{max}) for Scotland that predicts variability in both river temperature and climate sensitivity. Tw_{max} was modelled as a linear function of maximum daily air temperature (Ta_{max}), with the slope and intercept allowed to vary as a smooth function of day of the year (DoY) and further modified by landscape covariates including elevation, channel orientation and riparian woodland. Spatial correlation in Tw_{max} was modelled at two scales; (1) river network (2) regional. Temporal correlation was addressed through an autoregressive (AR1) error structure for observations within sites. Additional site level variability was modelled with random effects. The resulting model was used to map (1) spatial variability in predicted Tw_{max} under current (but extreme) climate conditions (2) the sensitivity of rivers to climate variability and (3) the effects of riparian tree planting. These visualisations provide innovative tools for informing fisheries and land-use management under current and future climate.

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http://dx.doi.org/10.1016/j.scitotenv.2017.09.010

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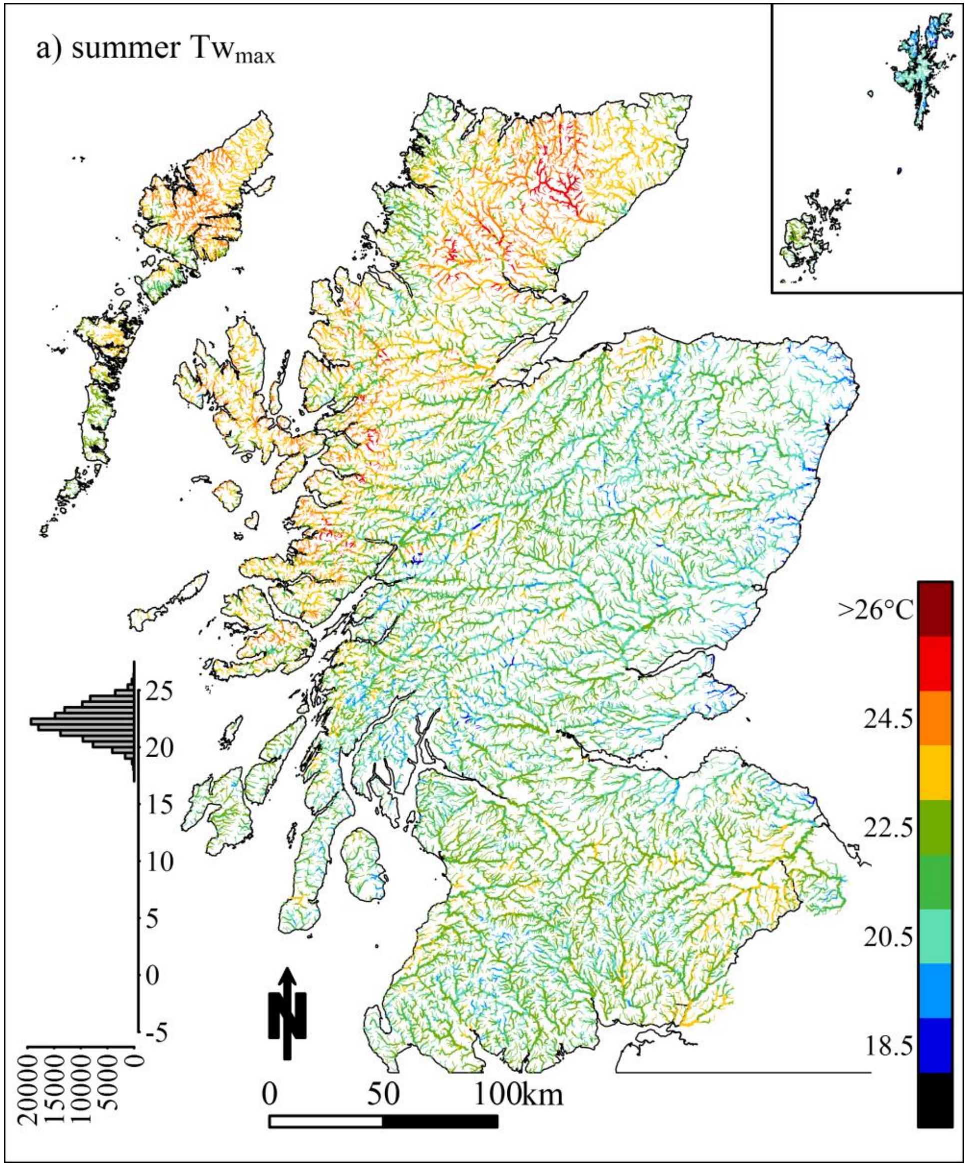
Predictions of daily maximum river temperatures under 'extreme' conditions (highest Ta observed in 2003)

Results:

Spatial patterns reflect Ta, landscape covariates, HA and RNS

Warmest temperatures are in low altitude (high Ta) unshaded rivers, particularly in North.



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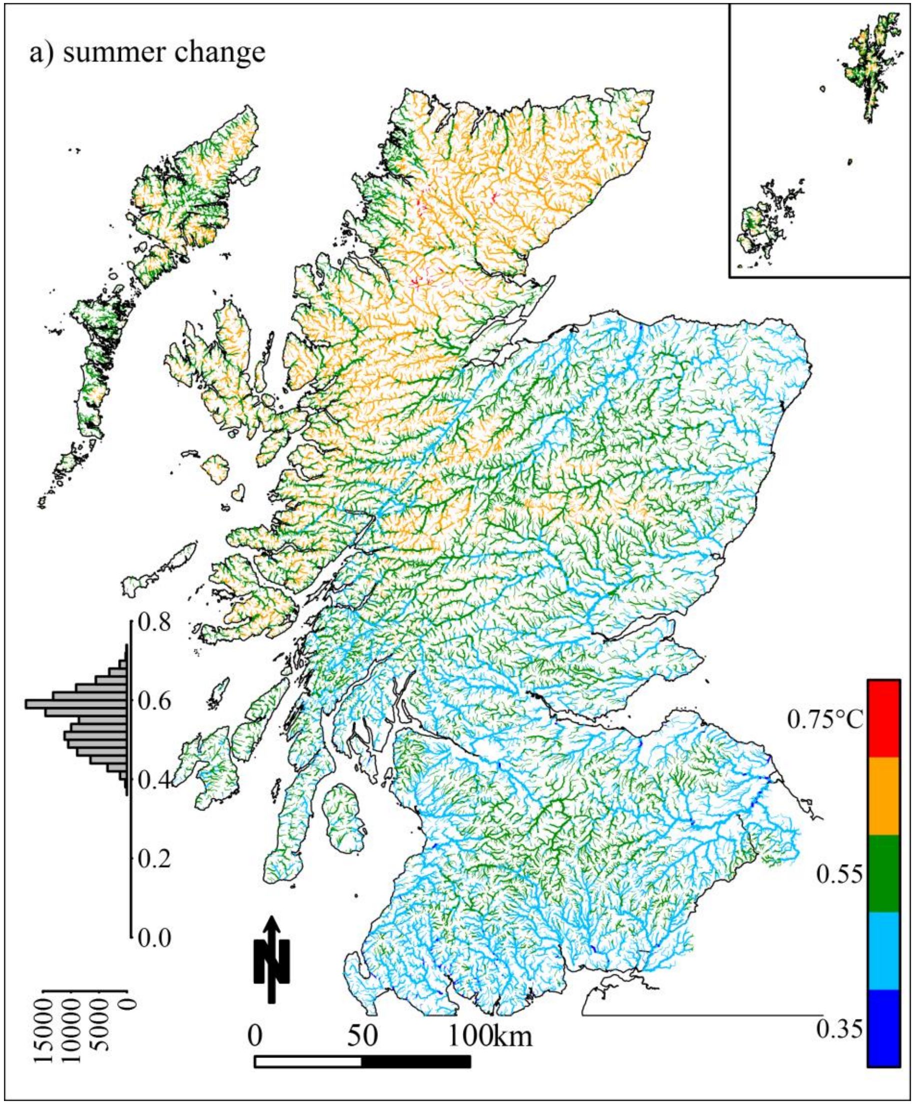
Predictions of climate sensitivity

How much Tw_{max} will change for a 1 degree C change in Ta_{max}

Results:

Biggest changes are seen in northern rivers and in the Cairngorms



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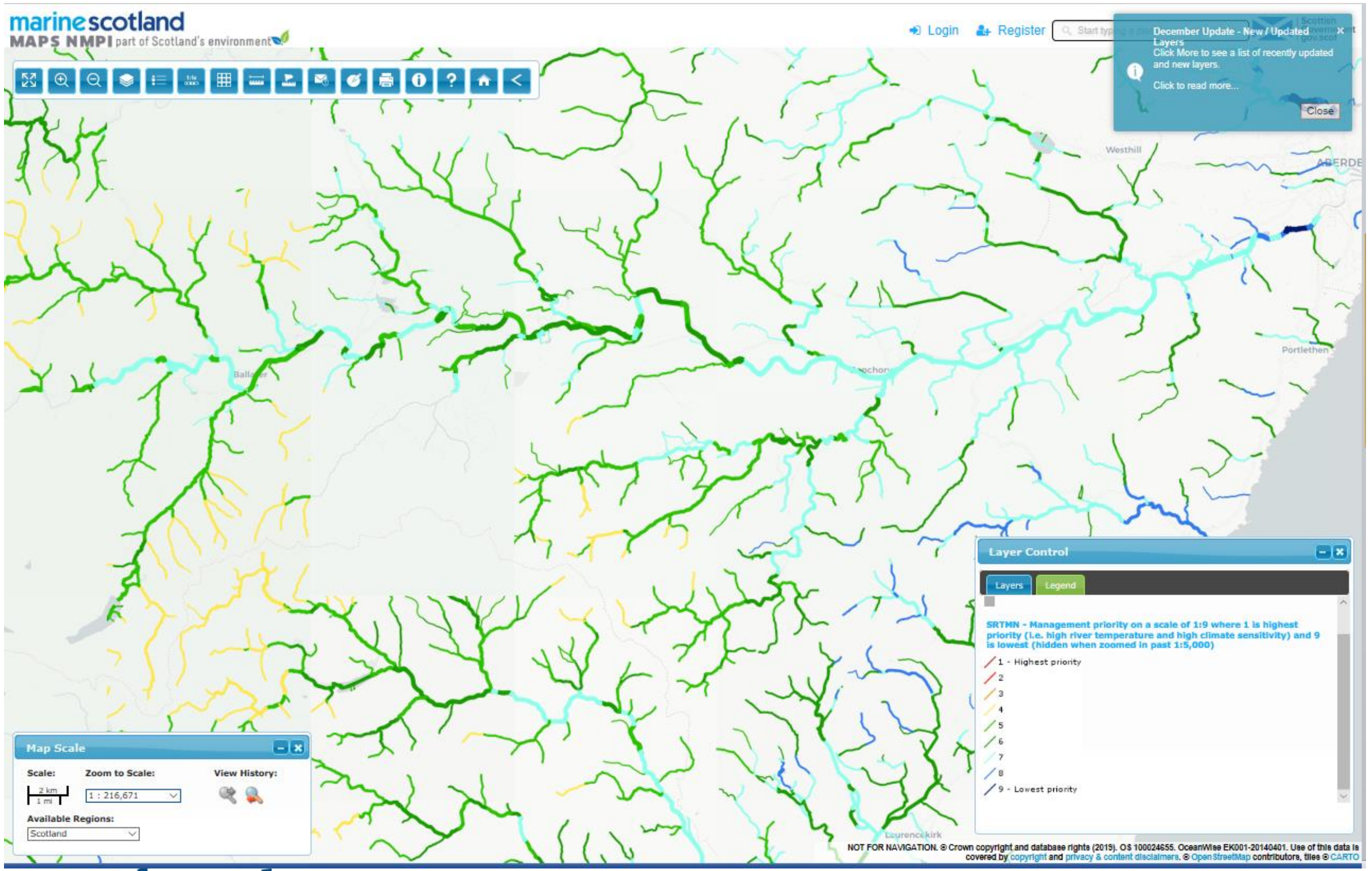
Current Prioritisation layer (s)

Combine “maximum temperatures” and “climate sensitivity”

Considers two metrics to be equal importance: 1 are the highest priority for management (i.e. high river temperature and high climate sensitivity) and 9 the lowest



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Using process-based models to understand where riparian shading most effective in reducing Tw

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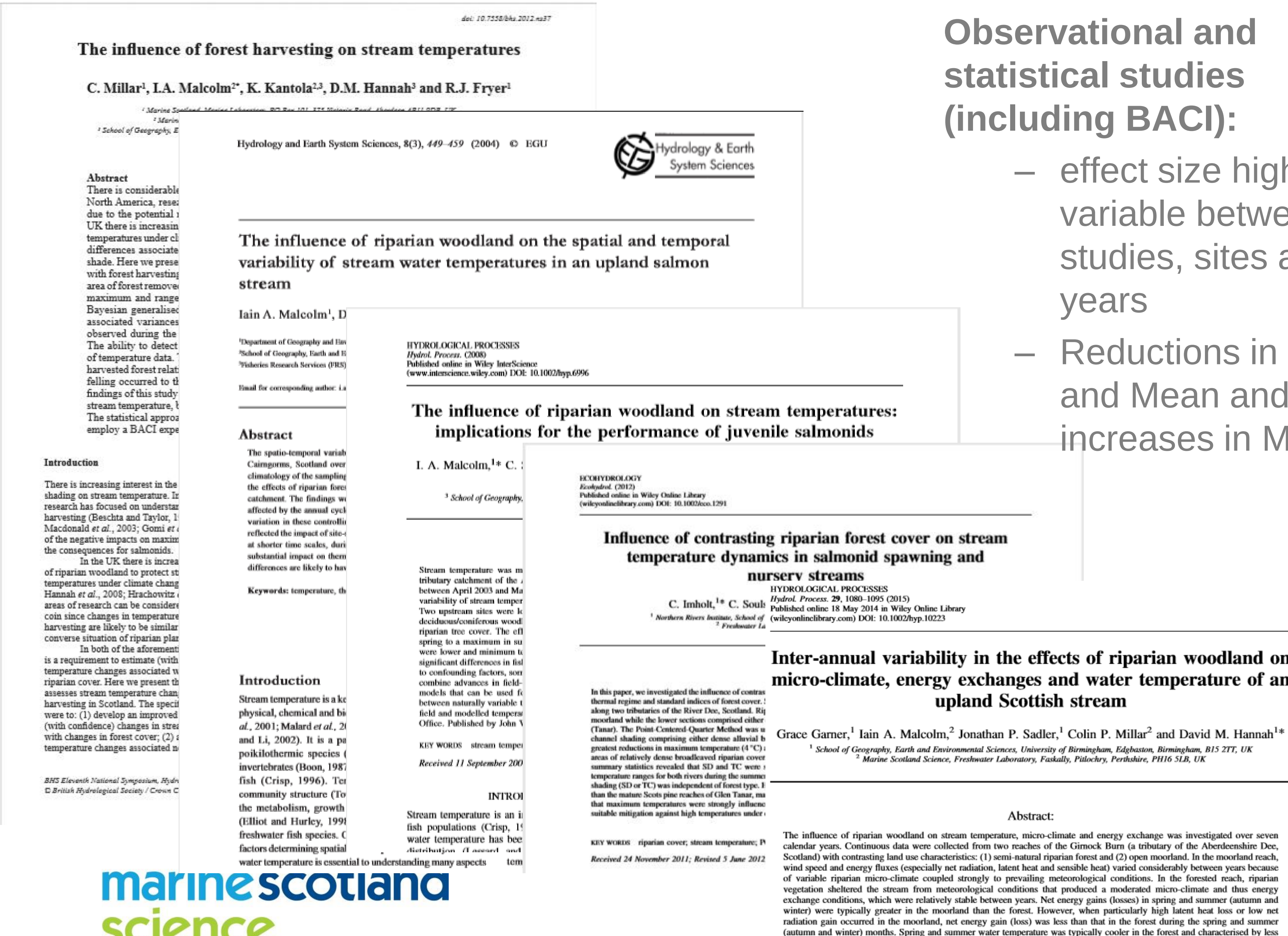
"Woodland effects"



doi: 10.7558/bhs.2012.ns37

The influence of forest harvesting on stream temperatures

C. Millar[1], I.A. Malcolm[2*], K. Kantola[2,3], D.M. Hannah[3] and R.J. Fryer[1]

Hydrology and Earth System Sciences, 8(3), 449–459 (2004) © EGU

Hydrology & Earth System Sciences

The influence of riparian woodland on the spatial and temporal variability of stream water temperatures in an upland salmon stream

HYDROLOGICAL PROCESSES
Hydrol. Process. (2008)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/hyp.6996

The influence of riparian woodland on stream temperatures: implications for the performance of juvenile salmonids

ECOHYDROLOGY
Ecohydrol. (2012)
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/eco.1291

Influence of contrasting riparian forest cover on stream temperature dynamics in salmonid spawning and nursery streams

HYDROLOGICAL PROCESSES
Hydrol. Process. 29, 1080–1095 (2015)
Published online 18 May 2014 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.10223

Inter-annual variability in the effects of riparian woodland on micro-climate, energy exchanges and water temperature of an upland Scottish stream

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Abstract:

The influence of riparian woodland on stream temperature, micro-climate and energy exchange was investigated over seven calendar years. Continuous data were collected from two reaches of the Girnock Burn (a tributary of the Aberdeenshire Dee, Scotland) with contrasting land use characteristics: (1) semi-natural riparian forest and (2) open moorland. In the moorland reach, wind speed and energy fluxes (especially net radiation, latent heat and sensible heat) varied considerably between years because of variable riparian micro-climate coupled strongly to prevailing meteorological conditions. In the forested reach, riparian vegetation sheltered the stream from meteorological conditions that produced a moderated micro-climate and thus energy exchange conditions, which were relatively stable between years. Net energy gains (losses) in spring and summer (autumn and winter) were typically greater in the moorland than the forest. However, when particularly high latent heat loss or low net radiation gain occurred in the moorland, net energy gain (loss) was less than that in the forest during the spring and summer (autumn and winter) months. Spring and summer water temperature was typically cooler in the forest and characterised by less

Observational and statistical studies (including BACI):

- effect size highly variable between studies, sites and years
- Reductions in Max and Mean and increases in Min T

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How does riparian woodland influence river temperature?

- **Shading can reduce incoming shortwave radiation**
- **However, also reduces heat loss through evaporation & net longwave radiation**

HYDROLOGICAL PROCESSES
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Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/hyp.7003

A comparison of forest and moorland stream microclimate, heat exchanges and thermal dynamics

David M. Hannah,[1]* Iain A. Malcolm,[2] Chris Soulsby[3] and Alan F. Youngson[2]
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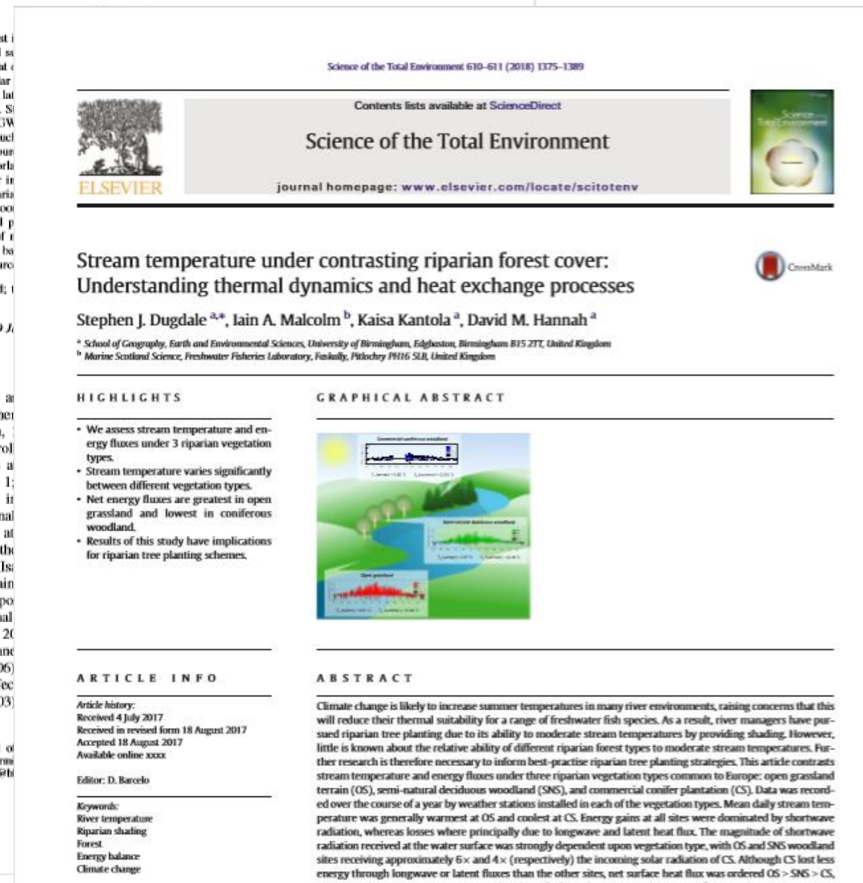
INTRODUCTION



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Stream temperature under contrasting riparian forest cover: Understanding thermal dynamics and heat exchange processes

Stephen J. Dugdale [a,*], Iain A. Malcolm [b], Kaisa Kantola [a], David M. Hannah [a]
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HIGHLIGHTS

- We assess stream temperature and energy fluxes under 3 riparian vegetation types.
- Stream temperature varies significantly between different vegetation types.
- Net energy fluxes are greatest in open grassland and lowest in coniferous woodland.
- Results of this study have implications for riparian tree planting schemes.

GRAPHICAL ABSTRACT

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ABSTRACT

Climate change is likely to increase summer temperatures in many river environments, raising concerns that this will reduce their thermal suitability for a range of freshwater fish species. As a result, river managers have pursued riparian tree planting due to its ability to moderate stream temperatures by providing shading. However, little is known about the relative ability of different riparian forest types to moderate stream temperatures. Further research is therefore necessary to inform best-practise riparian tree planting strategies. This article contrasts stream temperature and energy fluxes under three riparian vegetation types common to Europe: open grassland terrain (OS), semi-natural deciduous woodland (SNS), and commercial conifer plantation (CS). Data was recorded over the course of a year by weather stations installed in each of the vegetation types. Mean daily stream temperature was generally warmest at OS and coolest at CS. Energy gains at all sites were dominated by shortwave radiation, whereas losses where principally due to longwave and latent heat flux. The magnitude of shortwave radiation received at the water surface was strongly dependent upon vegetation type, with OS and SNS woodland sites receiving approximately 6× and 4× (respectively) the incoming solar radiation of CS. Although CS lost less energy through longwave or latent fluxes than the other sites, net surface heat flux was ordered OS > SNS > CS, mirroring the stream temperature results. These findings demonstrate that energy fluxes at the air-water inter-

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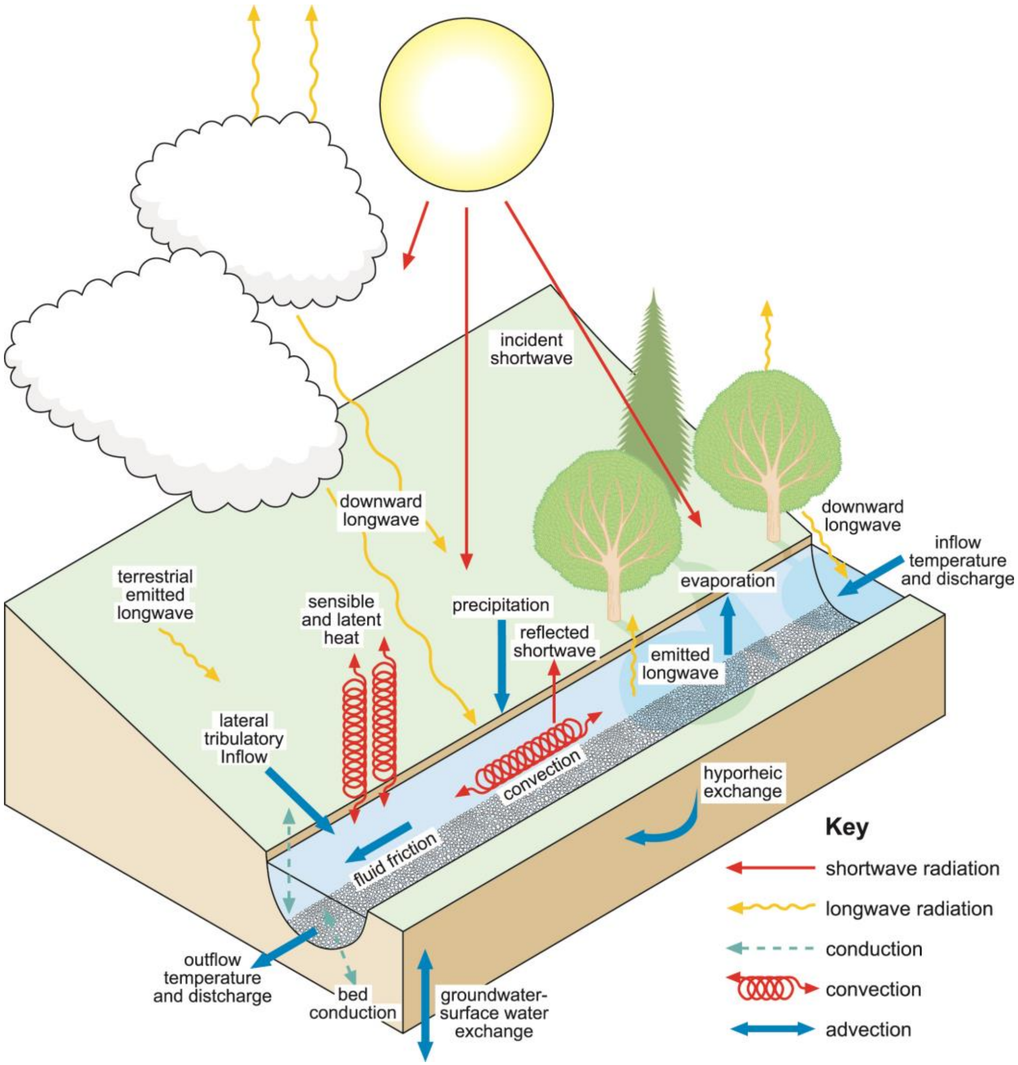
Processes based Tw models



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River temperature modelling: A review of process-based approaches and future directions

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ABSTRACT

River temperature has a major influence on biophysical processes in lotic environments. River temperature is expected to increase due to climate change, with potentially adverse consequences for water quality and ecosystems. Consequently, a better understanding of the drivers of river temperature space-time variability is important for developing adaptation strategies. However, existing river temperature archives are often of low resolution or short timespans, and the analysis of patterns or trends can therefore be difficult. In light of these limitations, researchers have increasingly used models to generate river temperature estimates suitable for addressing fundamental and applied questions in river science. Of these models, process-based approaches are well suited to helping improve knowledge of the mechanisms controlling river temperature, because of their ability to explore the energy (and water) fluxes responsible for temperature patterns. While process-based modelling approaches can often be more data intensive than their statistical counterparts, they offer significant advantages with regard to simulating the impacts of projected land-use or climate change, and can provide valuable insights for informing the development of statistical models at larger scales. However, a wide range of process-based river temperature models exist, and choosing the most appropriate model for a given investigation requires careful consideration. In this paper, we review the foundations of process-based river temperature modelling and critically evaluate the features and functionality of existing models with a view to helping river scientists better understand their utility. In conclusion, we discuss key considerations and limitations of currently available process-based models and advocate directions for future research. We hope that this review will enable river researchers and managers to make informed decisions regarding model selection and spur the continued refinement of process-based temperature models for addressing fundamental and applied questions in the river sciences.

1. Introduction

River temperature is one of the most important river habitat variables (Caissie, 2006; Hannah and Garner, 2015), controlling biogeochemical processes (Durance and Ormerod, 2009; Kaushal et al., 2010), ecosystem dynamics (Durance and Ormerod, 2007; Bärlocher et al., 2008; Dugdale et al., 2016) and water quality (Finlay, 2003; Bloomfield et al., 2006; Delpla et al., 2009). Quantifying river temperature is therefore key for improved understanding of fluvial environments. River temperature regimes in most locations are expected to change as a result of future climate change (van Vliet et al., 2013; Caldwell et al., 2015; Hannah and Garner, 2015; Muñoz-Mas et al., 2016) and other anthropogenic drivers (e.g. abstraction, impoundment, land-use change; Poole and Berman, 2001; Hester and Doyle, 2011). However, shortcomings in several key aspects of river temperature research mean that little is currently known about the complex nature of future temperature variability. River temperature science has in the past been based on data with low spatial and temporal resolution, frequently collected as a side product of water quality and/or ecological sampling. Water temperature data quality is consequently highly variable and elucidating the controls of river temperature remains difficult (Webb et al., 2004; Jonsson and Jonsson, 2009; Watts et al., 2015). Efforts have been made to resolve this using novel temperature logger networks (e.g. Isaak et al., 2010; Jackson et al., 2016; Boyer et al., 2016) or remote sensing techniques (see Dugdale, 2016). While such investigations are fast becoming the new norm, process-based understanding has not always kept pace with methodological development, and the exact mechanisms controlling river temperature heterogeneity remain difficult to isolate (Hannah and Garner, 2015). Further research into river temperature dynamics is consequently of key importance with regard to

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What causes cooling water temperature gradients in a forested stream reach?

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Abstract. Previous studies hav
parian vegetation may reduce
and provide refugia for tempe
isms. Longitudinal cooling g
during the daytime for stream
trees downstream of clear cuts
stream of open moorland. How
energy exchange processes th
cially in semi-natural woodlan
ing cool groundwater inflows.
quantified and modelled vari
and heat fluxes along an uplan
tributary of the Aberdeenshire
land use transitions from open
dominantly deciduous woodl
along a 1050 m reach using a
of 10 water temperature data
stations and 211 hemispheric
to estimate incoming solar r
terised a high-resolution ene
flow routing, which predicted
stream temperature. Variabili
controlled largely by energy
atmosphere interface. Net en
reach, predominantly during
change across the bed–water-c
< 1 % of the net energy budg
net radiation gains were high
between water temperature
streamwise direction; a maxi
of 2.5 °C was observed betwee
and 1050 m downstream. Furt

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Research papers

The role of riparian vegetation density, channel orientation and water velocity in determining river temperature dynamics

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Riparian vegetation
Landuse change

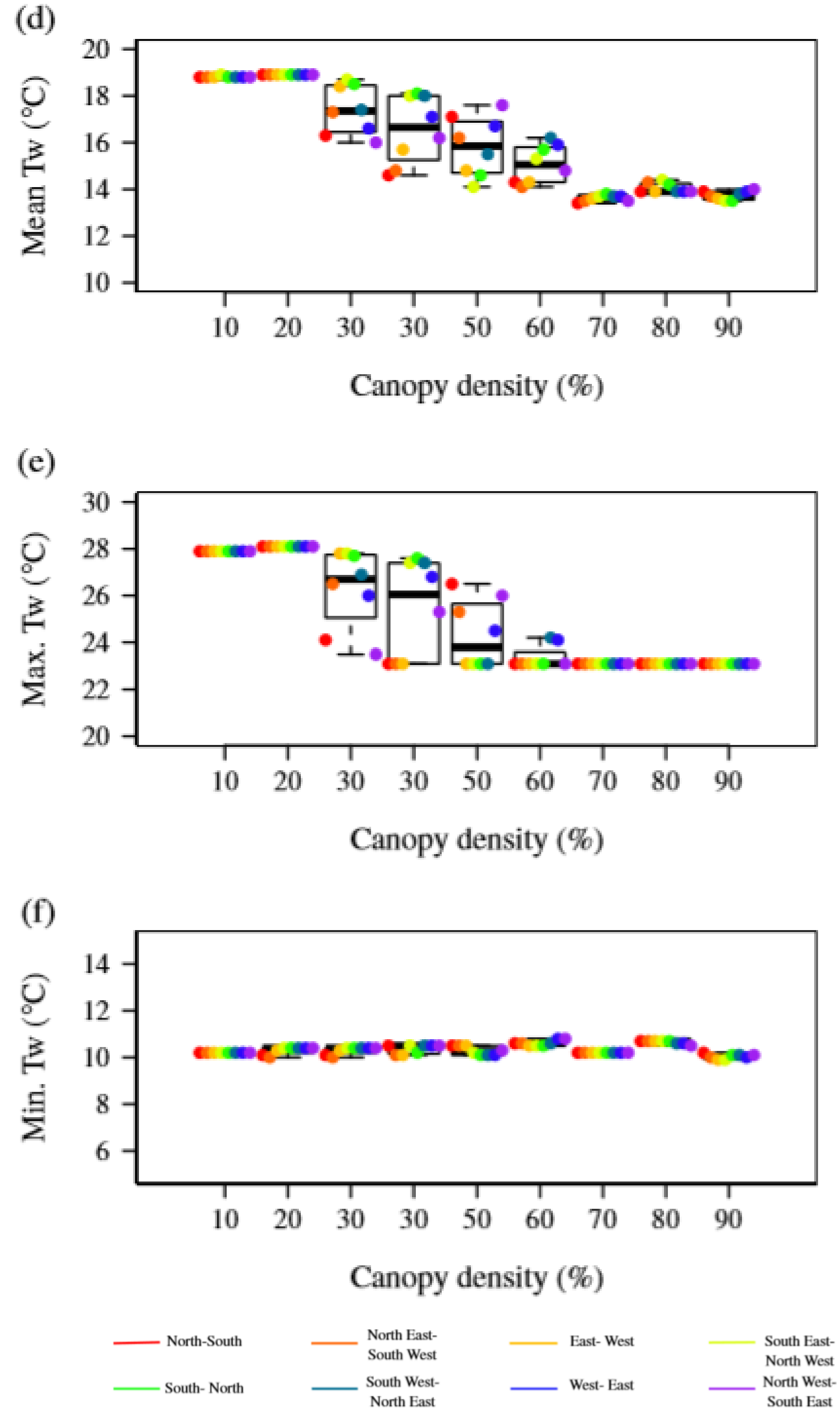
A B S T R A C T

A simulation experiment was used to understand the importance of riparian vegetation density, channel orientation and flow velocity for stream energy budgets and river temperature dynamics. Water temperature and meteorological observations were obtained in addition to hemispherical photographs along a ~1 km reach of the Girnock Burn, a tributary of the Aberdeenshire Dee, Scotland. Data from nine hemispherical images (representing different uniform canopy density scenarios) were used to parameterise a deterministic net radiation model and simulate radiative fluxes. For each vegetation scenario, the effects of eight channel orientations were investigated by changing the position of north at 45° intervals in each hemispheric image. Simulated radiative fluxes and observed turbulent fluxes drove a high-resolution water temperature model of the reach. Simulations were performed under low and high water velocity scenarios. Both velocity scenarios yielded decreases in mean (≥1.6 °C) and maximum (≥3.0 °C) temperature as canopy density increased. Slow-flowing water resided longer within the reach, which enhanced heat accumulation and dissipation, and drove higher maximum and lower minimum temperatures. Intermediate levels of shade produced highly variable energy flux and water temperature dynamics depending on the channel orientation and thus the time of day when the channel was shaded. We demonstrate that in many reaches relatively sparse but strategically located vegetation could produce substantial reductions in maximum temperature and suggest that these criteria are used to inform future river management.

1. Introduction

It is anticipated that a changing climate will alter river temperature regimes. Elevated temperatures relative to historical baselines are expected for most watercourses (e.g. Beechie et al., 2013; van Vliet et al., 2013; MacDonald et al., 2014a; Hannah and Garner, 2015). Such changes, particularly increased maxima, may diminish the spatial and temporal extent of suitable cool-water habitat for temperature sensitive organisms with potential impacts on the composition and productivity of aquatic ecosystems (Wilby et al., 2010; Leach et al., 2012). Consequently, there is substantial interest in adaptation strategies that may ameliorate the effects

ing hyporheic exchange (Beechie et al., 2013; Kurylyk et al., 2014), reducing and retaining urban runoff (e.g. Booth and Leavitt, 1999) and reducing rates of water abstraction (Poole and Berman, 2001). However in upland streams, where catchment hydrology and geomorphology have not been altered significantly by human activities, fewer of these strategies may be implemented to protect aquatic ecosystems from thermal extremes (Beschta, 1997; Poole and Berman, 2001). Observational datasets, frequently in combination with deterministic modelling approaches, have demonstrated that the summer temperature of headwater streams is generally dominated by: (1) advected heat from upstream (2) heat exchange at the air–water column interface (e.g. Westhoff et al., 2011; Leach



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Science of the Total Environment 678 (2019) 326–340

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journal homepage: www.elsevier.com/locate/scitotenv

Drone-based Structure-from-Motion provides accurate forest canopy data to assess shading effects in river temperature models

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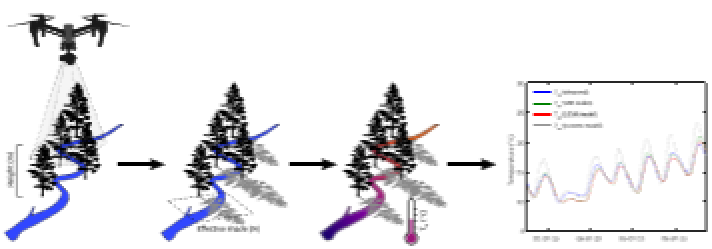
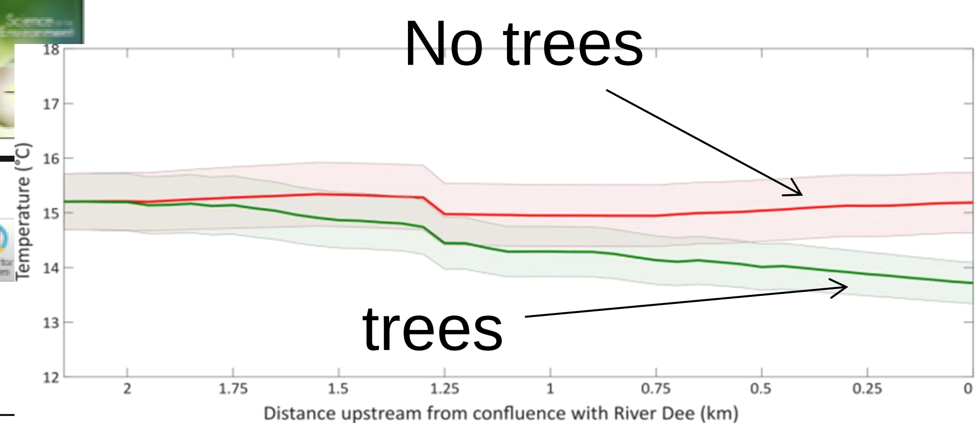
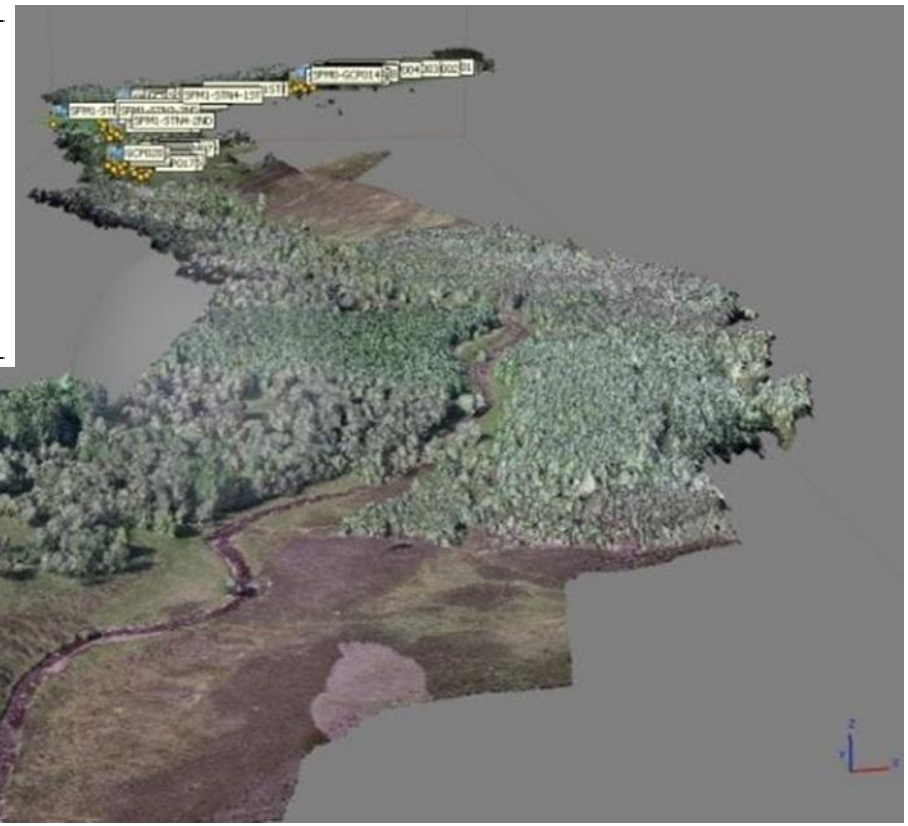
HIGHLIGHTS

- Riparian shading can moderate river temperature extremes, but data needed to model this effect can be difficult to obtain
- We combine Structure-from-Motion (SfM) photogrammetry with river temperature modelling to simulate the effect of tree shading
- Our approach simulates river temperature with a high degree of accuracy and can help better understand thermal processes in rivers

GRAPHICAL ABSTRACT







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RESEARCH ARTICLE

WILEY

Integrating process-based flow and temperature models to assess riparian forests and temperature amelioration in salmon streams

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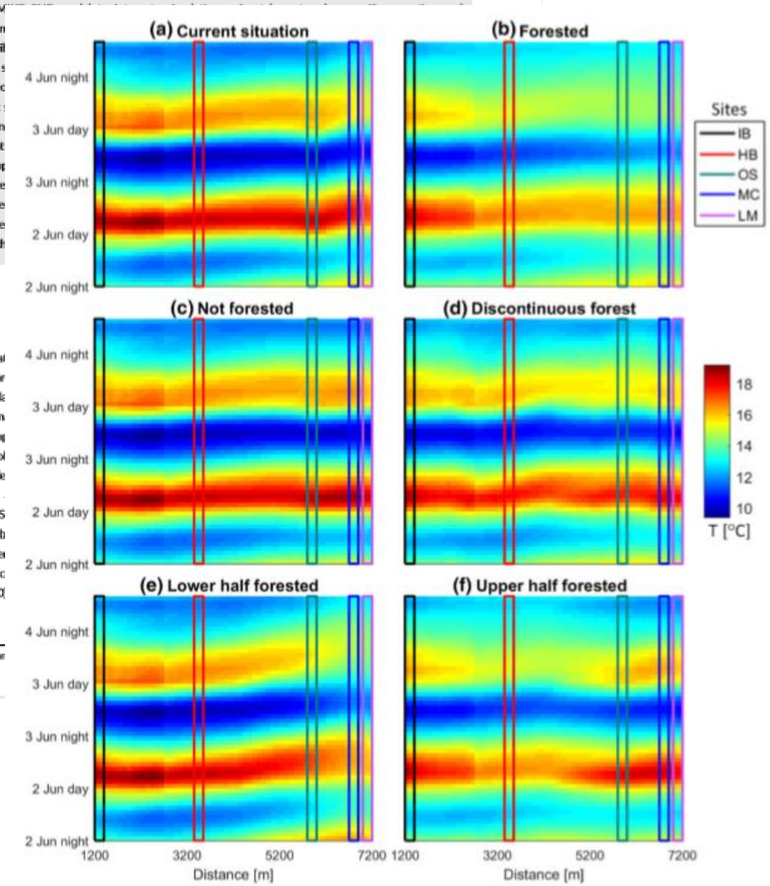
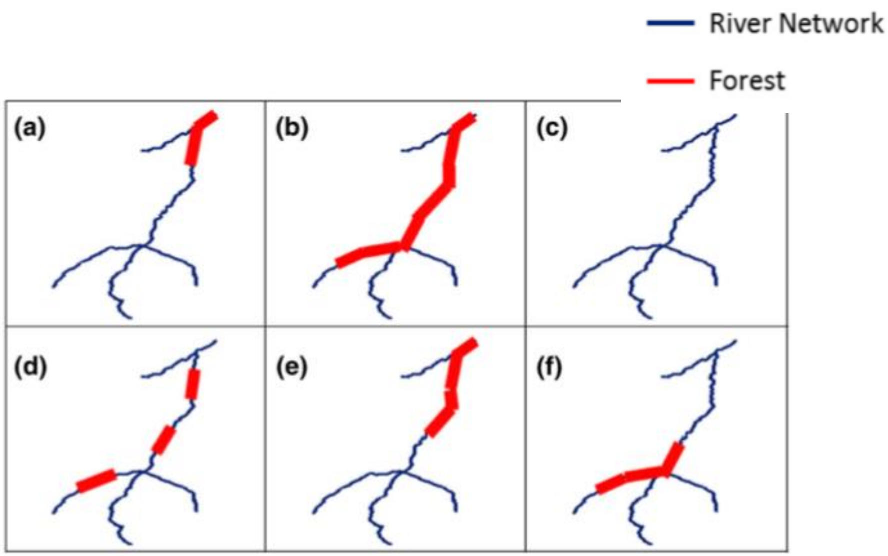
Funding information
University of Aberdeen; Marine Scotland Science

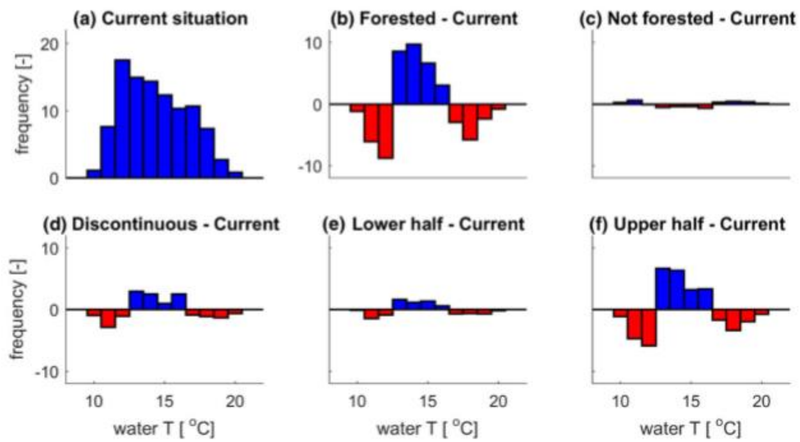
Abstract
The importance of riparian tree cover in reducing energy inputs to streams is increasingly recognized in schemes to mitigate climate change effects and protect freshwater ecosystems. Assessing different riparian management strategies requires catchment-scale understanding of how different planting scenarios would affect the stream energy balance, coupled with a quantitative assessment of spatial patterns of streamflow generation. Here, we use the physically based M... in-strean... ral distri... salmon s... effects c... Atlantic ... hood un... (daylight... the temp... effective... facilitate... strategie... for catch...

1 | INTRODUCTION

Increasing river temperatures is a major concern associa... warming especially in high-latitude and high-altitude ar... structure and function of freshwater ecosystems are ada... temperatures and many species are intolerant of therm... temperature observations are the result of comp... responses to short-term climate patterns and hydrol... (Garner, Malcolm, Sadler, Millar, & Hannah, 2015) mode... properties (Jackson, Hannah, & Millar, 2018) and ... impacts (Hester & Doyle, 2011; Jackson, Gibbins, & S... coupled with longer term trends (Hari, Livingstone, Sib... Holm, & Guttinger, 2006). In recent decades, rising wate... have been reported in many areas in response to c... (Caissie, 2006; Hari et al., 2006; Kaushal et al., 2010...







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What factors influence the effects of riparian woodland on stream temperature?

- Discharge (water volume)
- Mean column velocity (how much time does water spend in shaded reach)
- Channel width (how much radiation is received, and how much of the channel is shaded)
- Channel Orientation (how does orientation of vegetation and channel interact with solar position to affect receipt of radiation)
- Tree height and density

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Developing a simplified process based model to inform tree planting at large spatial scales

Simplifying processes

• Discharge & Hydraulics / Residence Time	→	• Gauging data related to River Order
• Energy gains (Incoming shortwave)	→	• Solar Arc / shading model (SAM)
• Energy Losses	→	• Simplified representation not readily possible

Translation to DRN

• Channel Orientation for SAM	→	• Mean Orientation DRN reach
• Channel Width for SAM	→	• OSMM river polygon width
• Tree Height	→	• Literature derived

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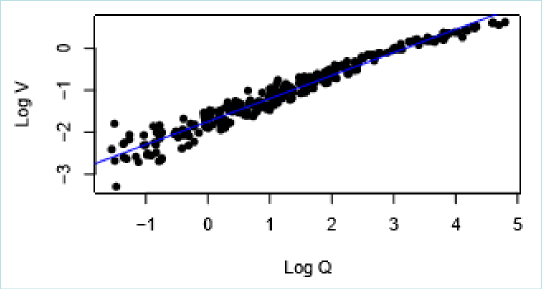
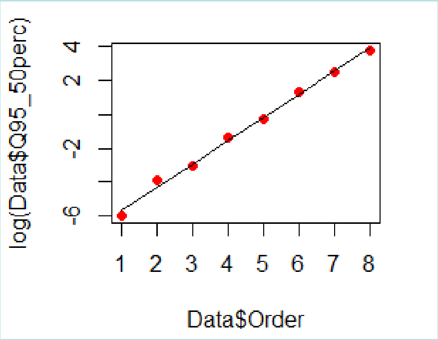
Hydrology and hydraulics (river order)

NRFA Flow Statistics Q95



SEPA gauging Data (Q) → Obtain River Order → Model Velocity ~ Q → Mean column velocity at Q95

Summarise median Q and V by river Order.
Model response

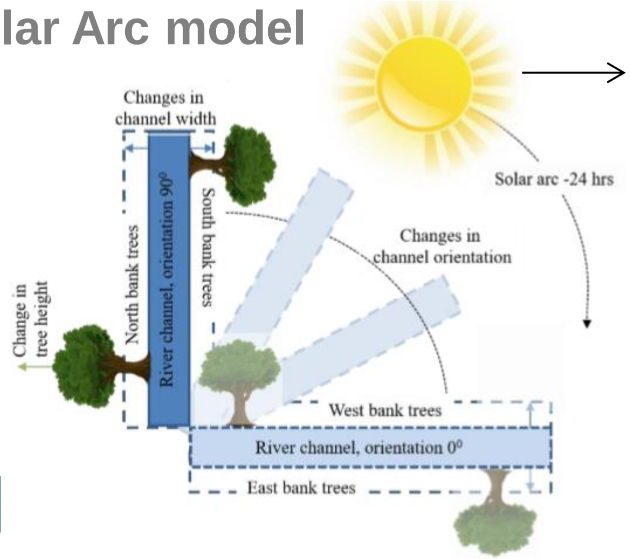


Hydrological & Hydraulic data By river order

Width scenarios by river order

Orientation scenarios

Solar Arc model



Cumulative shortwave → Tw gain over reach (assuming no losses) → TwDiff: difference from no tree baseline → Map of planting potential

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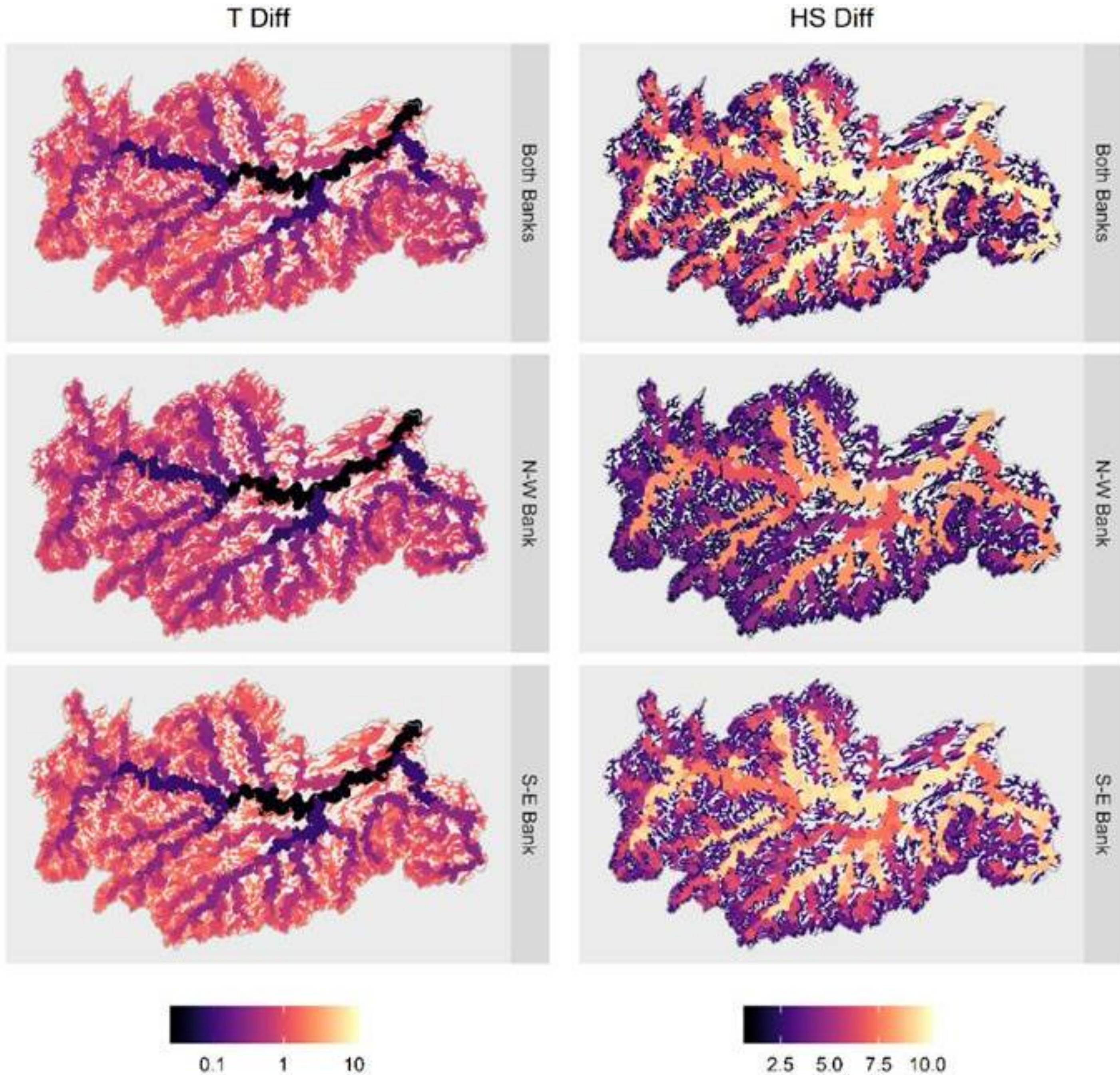
Planting Potential (to come 2020)



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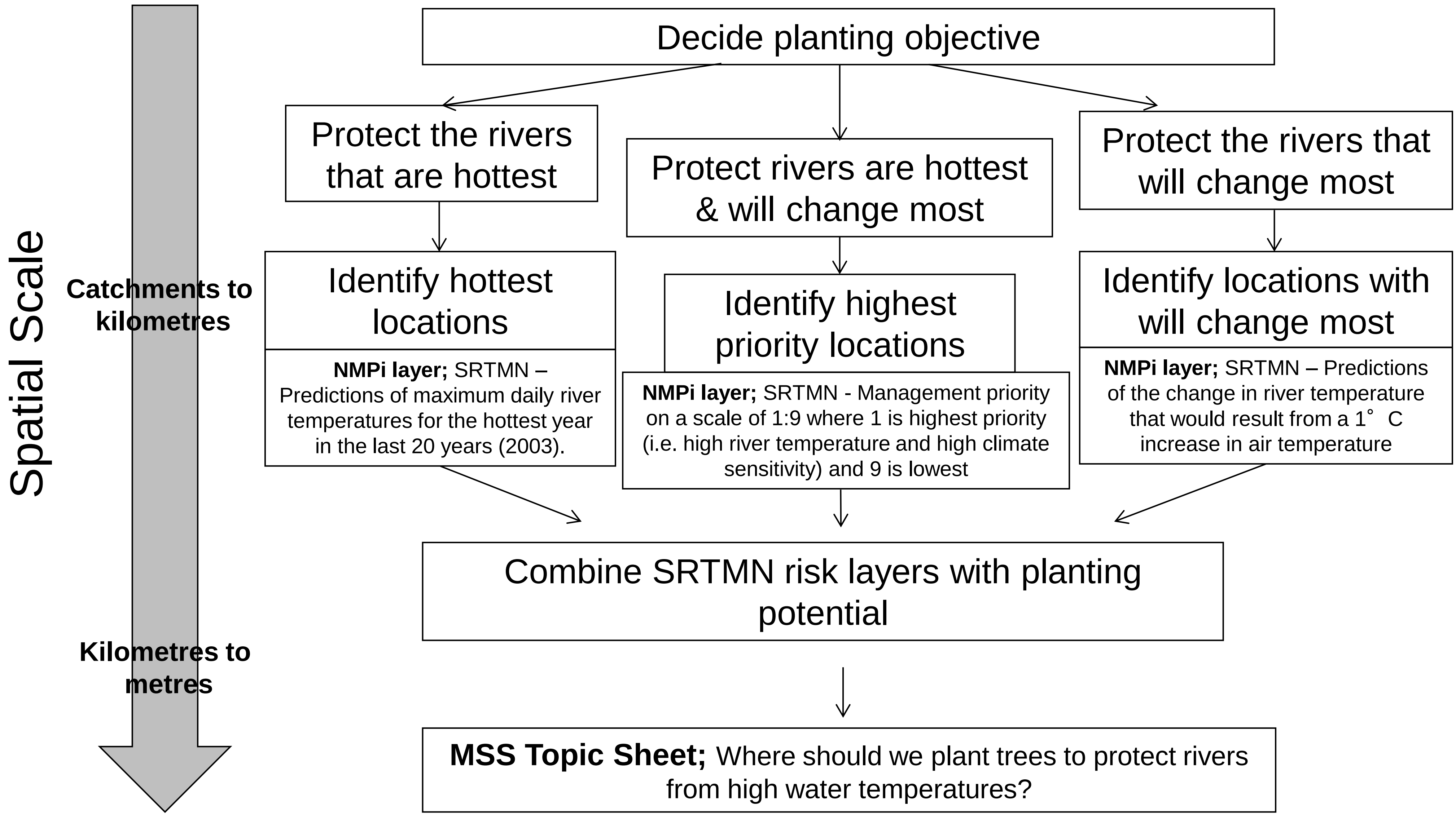
Deciding where to plant trees



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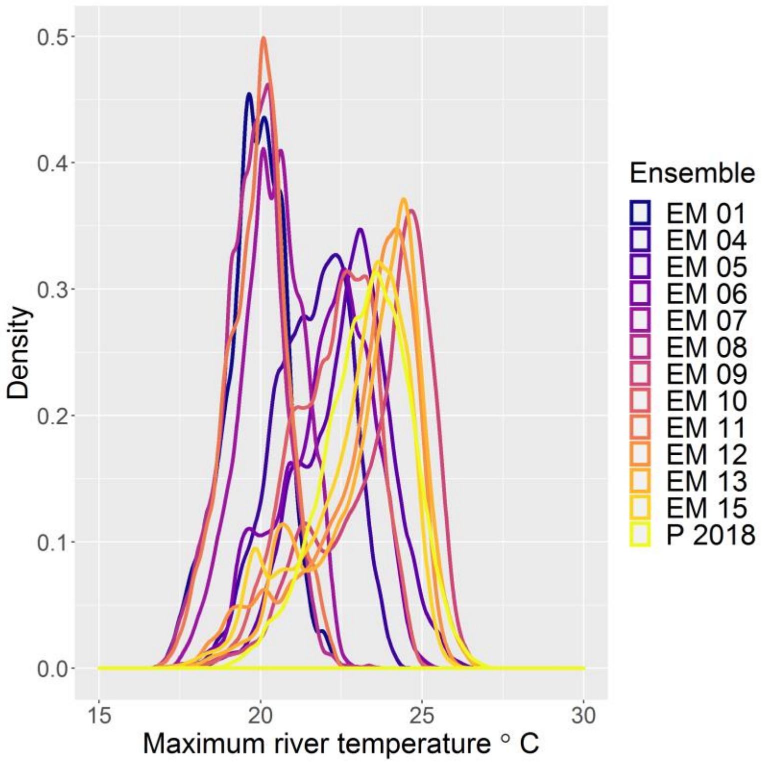
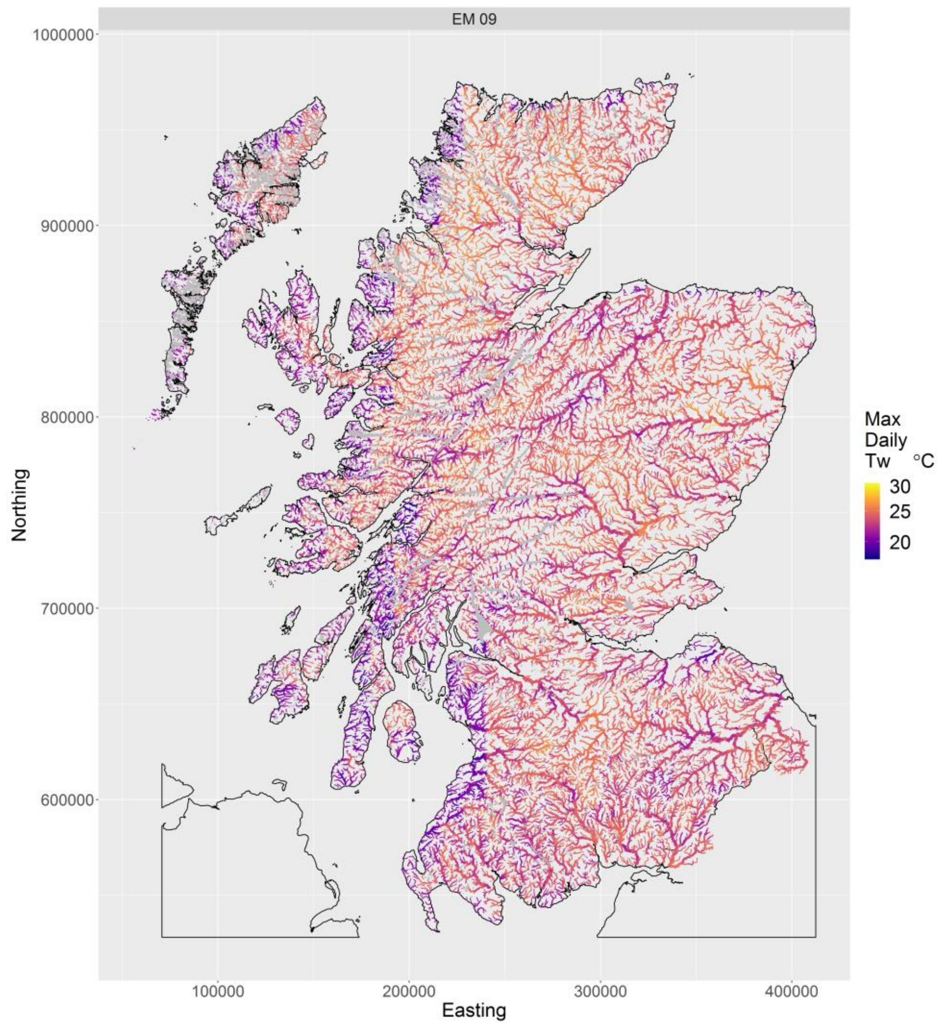
Please let us know your experiences of using these tools

Future work

- **Combine current prioritisation tool with Planting potential tool to provide single ranking of rivers**

- **Climate change predictions for Scotland's rivers using UKCP18 & update prioritisation tool**





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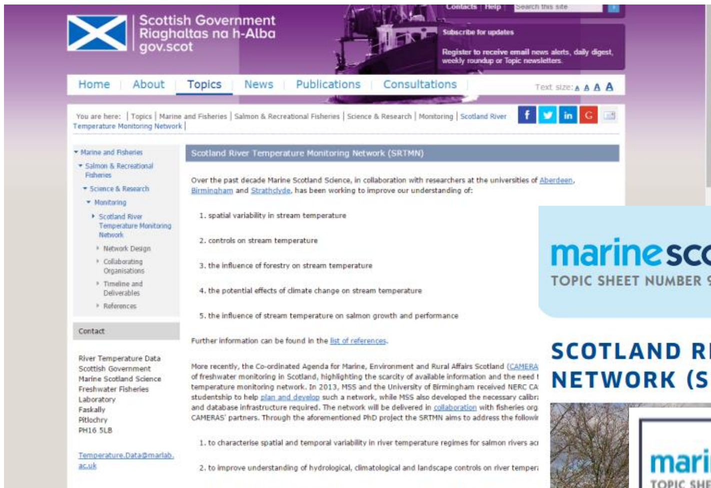
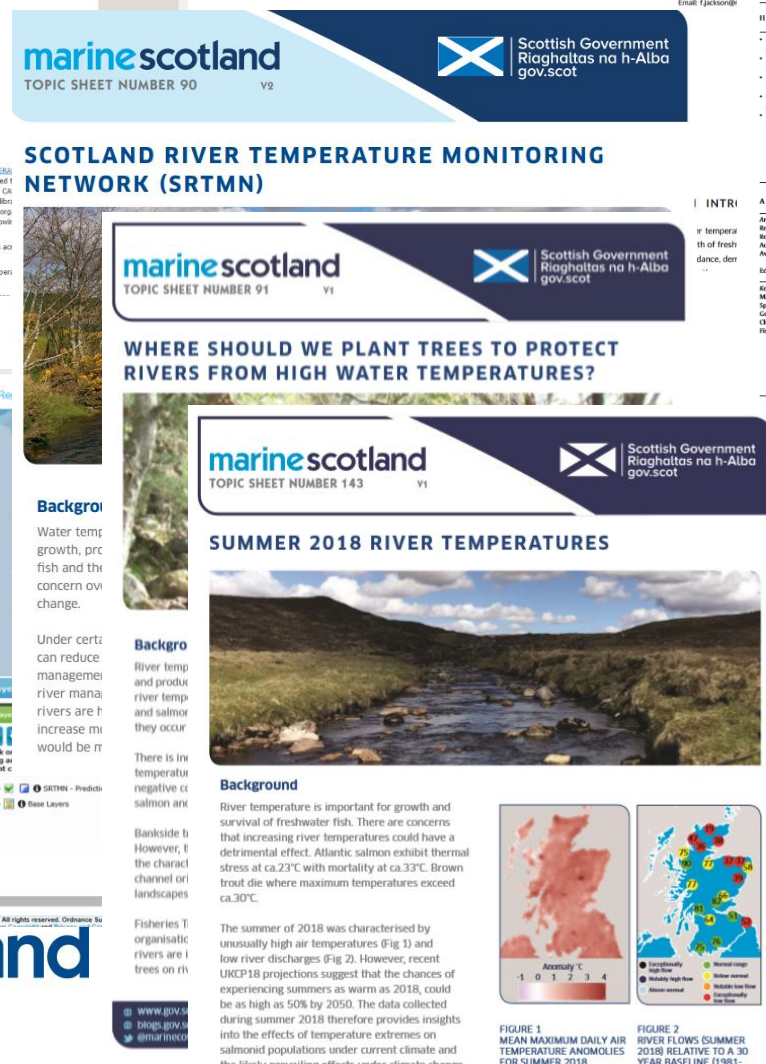
Where can I get more information?

http://www.gov.scot/Topics/marine/Salmon-Trout-Coarse/Freshwater/Monitoring/temperature

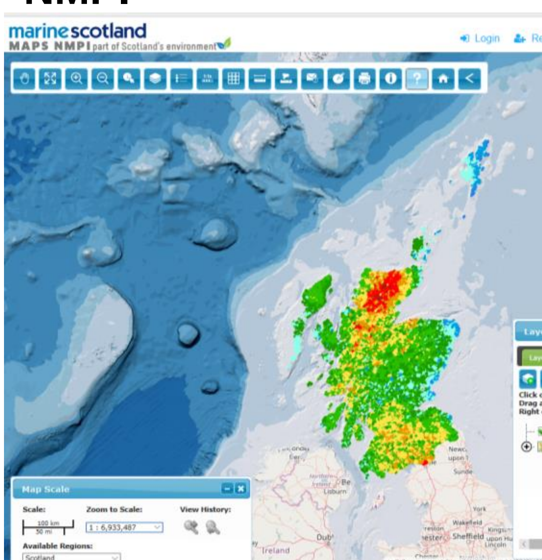


Topic sheets

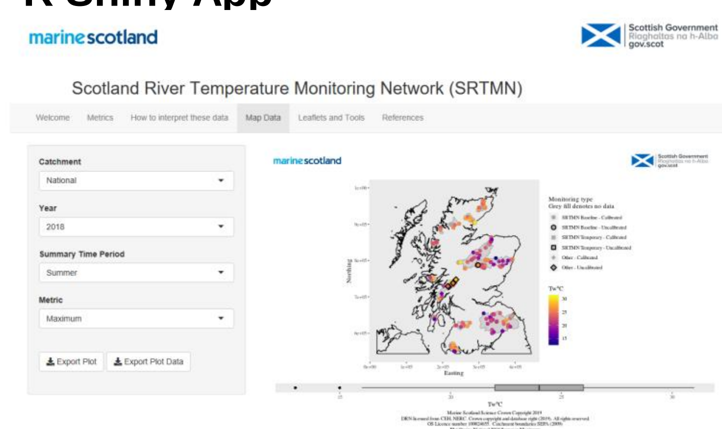


Peer reviewed Papers

NMPI



R Shiny App



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