

# Scotland River Temperature Monitoring Network:



**A national resource for understanding,  
assessing and managing the effects of  
climate change on Scotland's Atlantic  
Salmon rivers**

F.L. Jackson, R.J. Fryer, D.M. Hannah, C.P. Millar, I.A. Malcolm

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

marine scotland  
science

# Background and management context

River temperature is important to the health of cold water adapted fish like trout and salmon

Under climate change we expect rising river temperatures, potentially affecting fish populations

Bankside woodland a potential mitigation option

Requires information on:

- Where are temperatures going to be hottest?
- Which rivers and regions will change the most under climate change?



# SRTMN Objectives

AIM: Understand and predict river temperatures ( $T_w$ ) across Scotland and assess climate change effects on  $T_w$

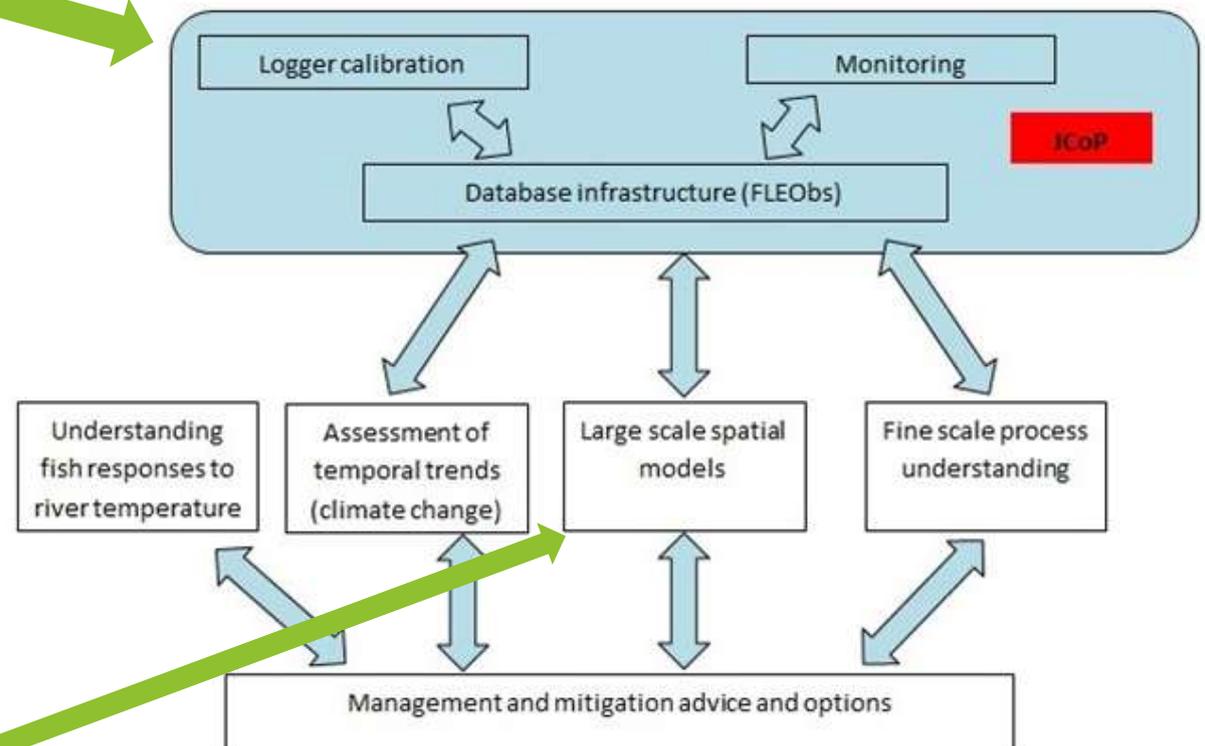
- Ob1: Design a large scale long-term quality controlled temperature monitoring network
- Ob2: Develop large-scale statistical models
- Ob3: Develop management tools to inform mitigation
- Ob4: Assess long-term monitoring to assess trends in  $T_w$

# What do you need to generate this information?

1. **High quality river temperature data at big spatial scale**  
Scotland River Temperature Monitoring Network

2. **Information on the rivers where river temperature is collected**  
e.g. how big the river is, what altitude is it, does it have woodland on the banks

3. **Scotland scale statistical models to let us predict river temperature in unmonitored locations**

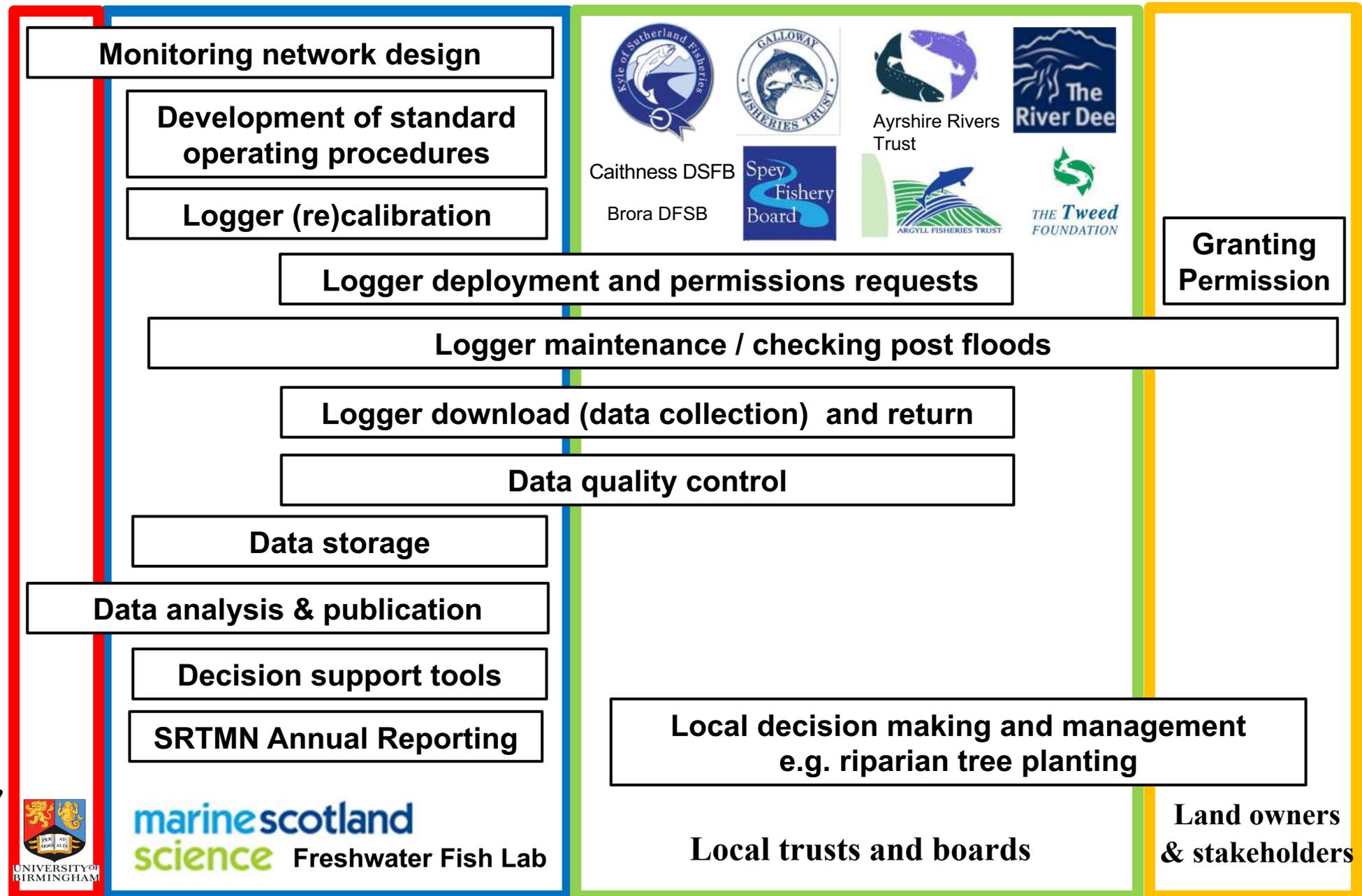


MSS River Temperature Research Programme

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# Delivery via a national ~ local collaboration

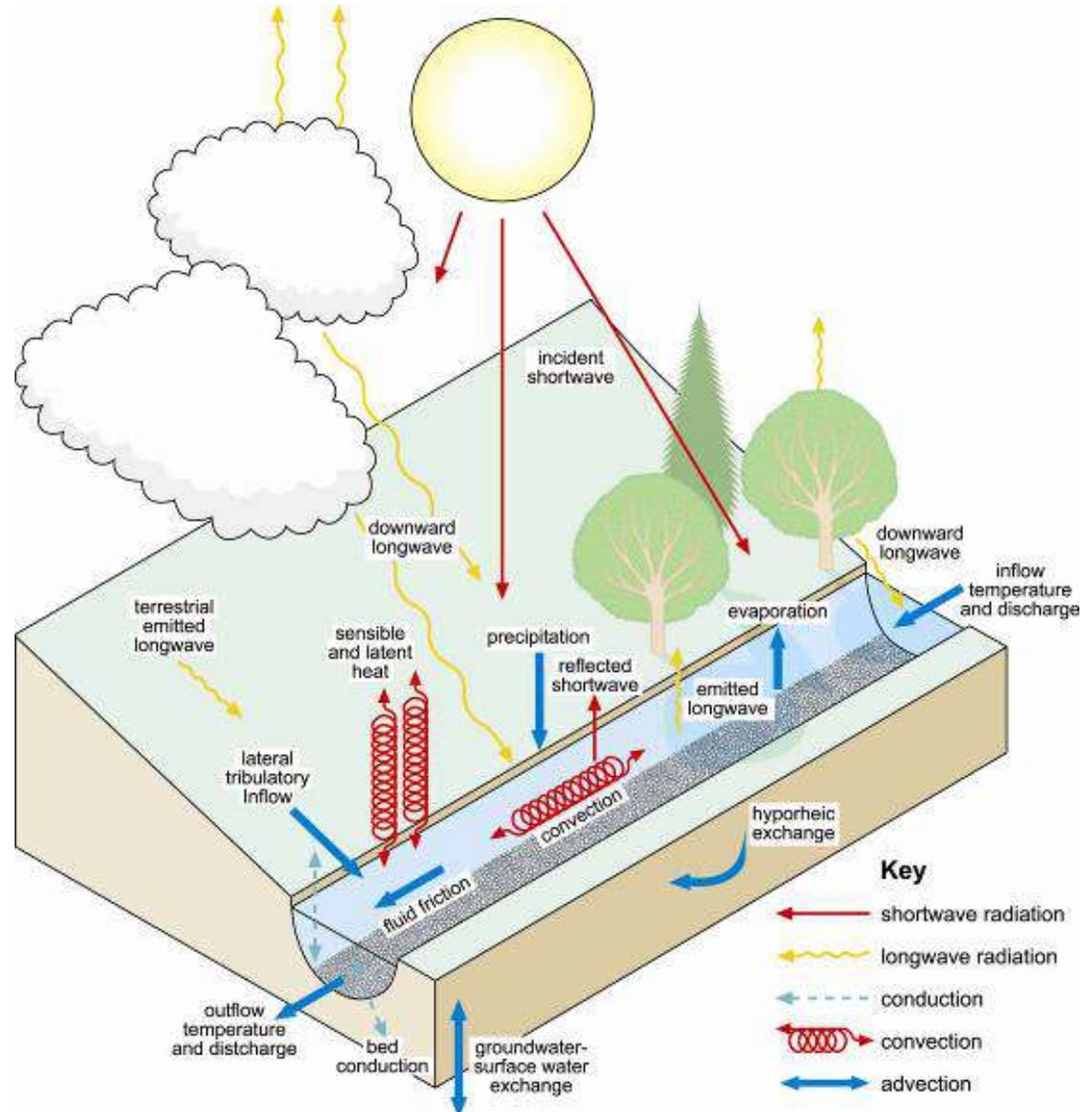
Following Joint Code of Practice for Research



# Network design: Controls on river temperature

Complex energy and heat exchange processes

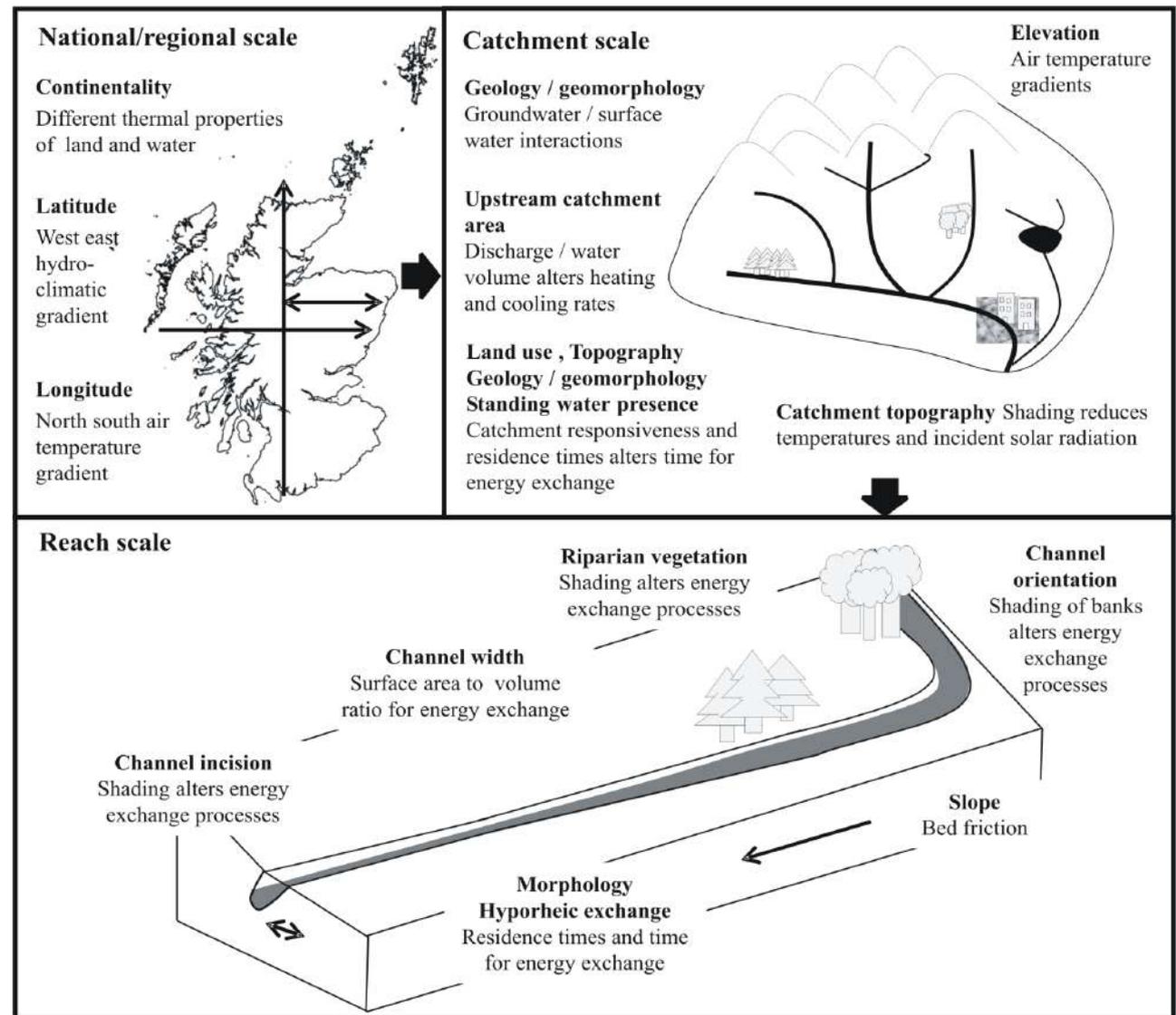
Not possible to monitor and model at national scales



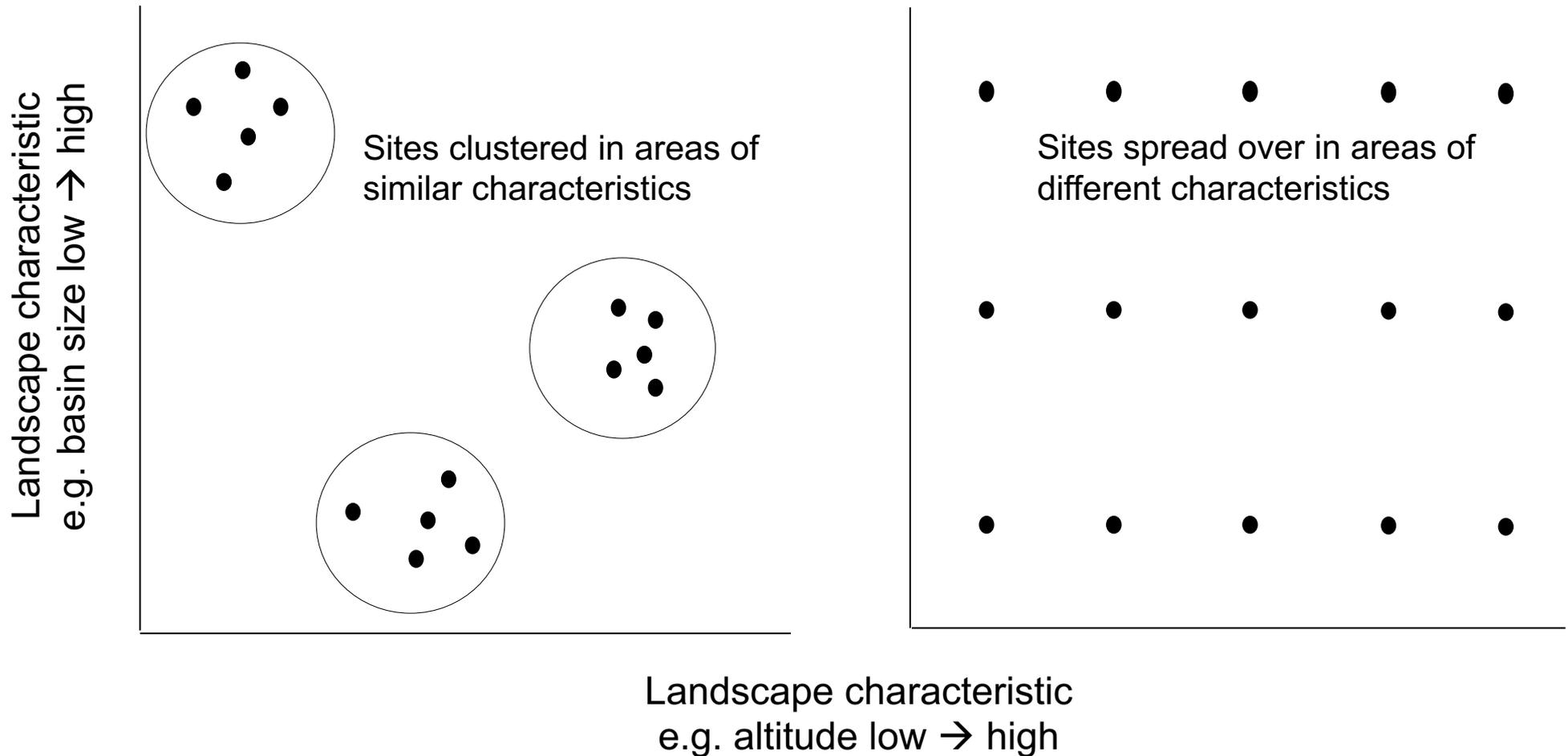
# Data collection: How can we use the landscape to explain controls ?

Strategically designed the Scotland River Temperature Monitoring Network to cover the environmental range of characteristics that influence river temperature

Proxies for processes



# Network design: selecting sites to cover different river characteristics



## Feedback from local collaborators on:

Site suitability in terms of practicality

Requests for permission to deploy

# What do we use to monitor?

A calibrated Tinytag datalogger

Measures the water temperature every 15 minutes

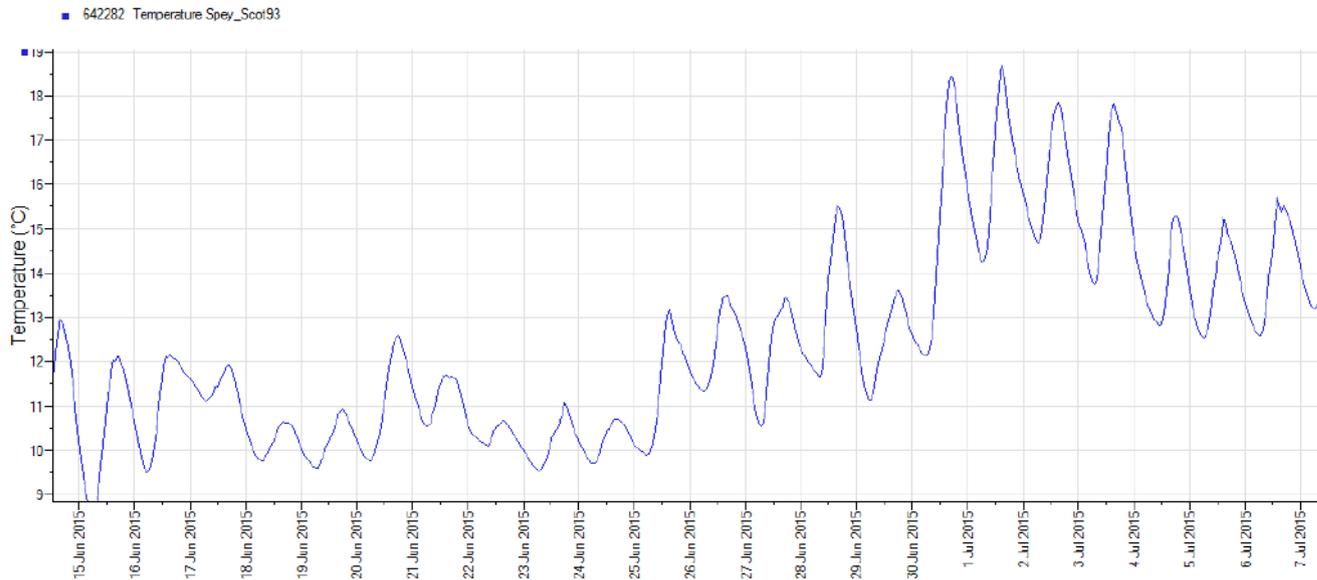
Downloaded twice a year

It can log for **339 days and 17 hours** before it becomes full!



# How can you ensure good data?

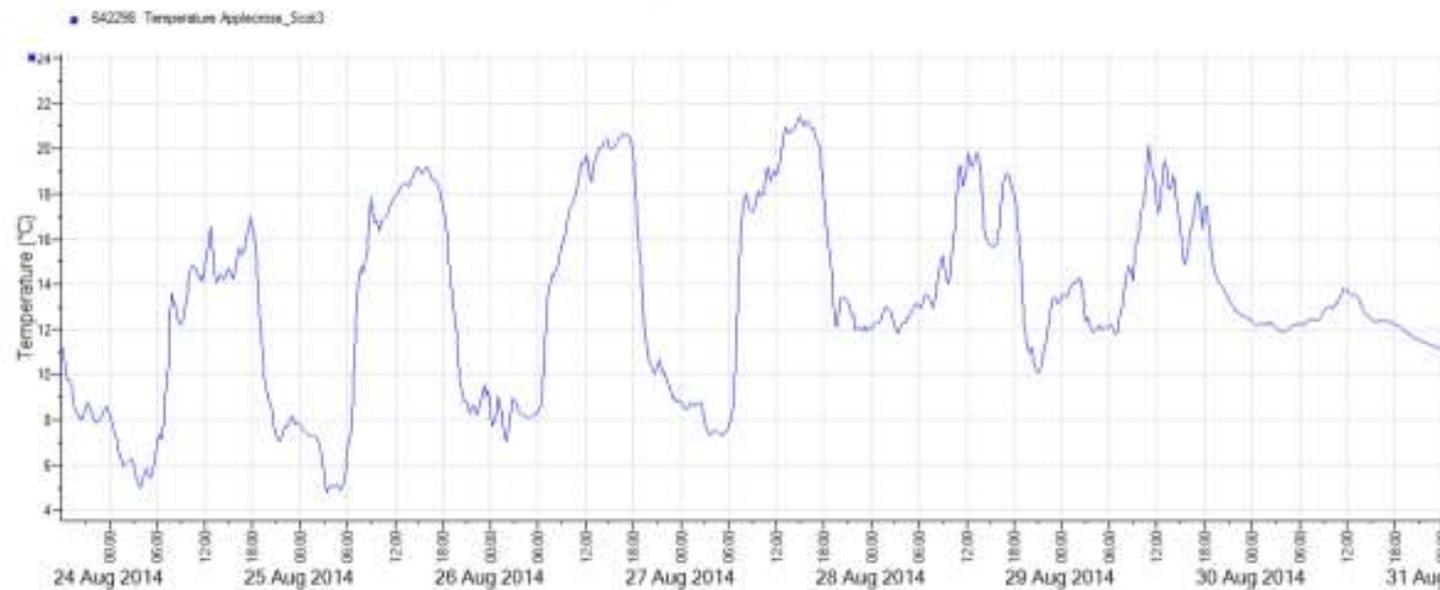
Spey\_Scot93



Data sheets  
Visual checks  
Correct data using  
our calibrations

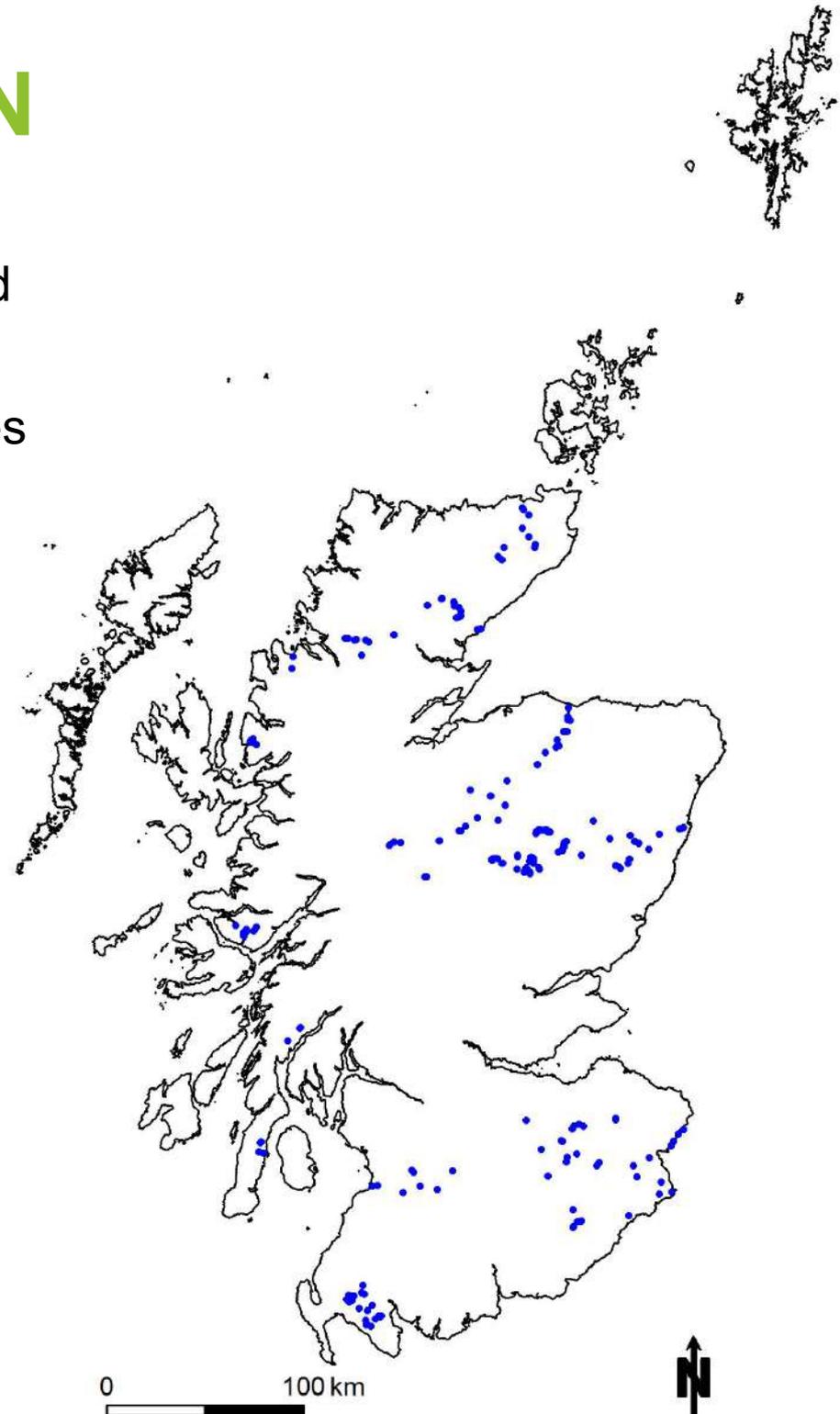
<https://www2.gov.scot/Topics/marine/Salmon-Trout-Coarse/Freshwater/Monitoring/temperature/QualityControl>

Applecross\_Scot3



# SRTMN

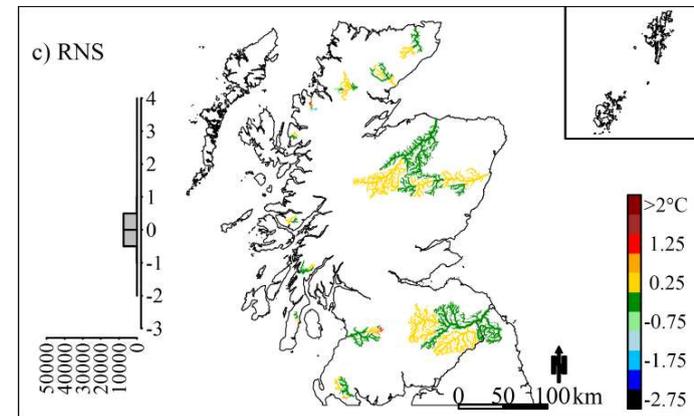
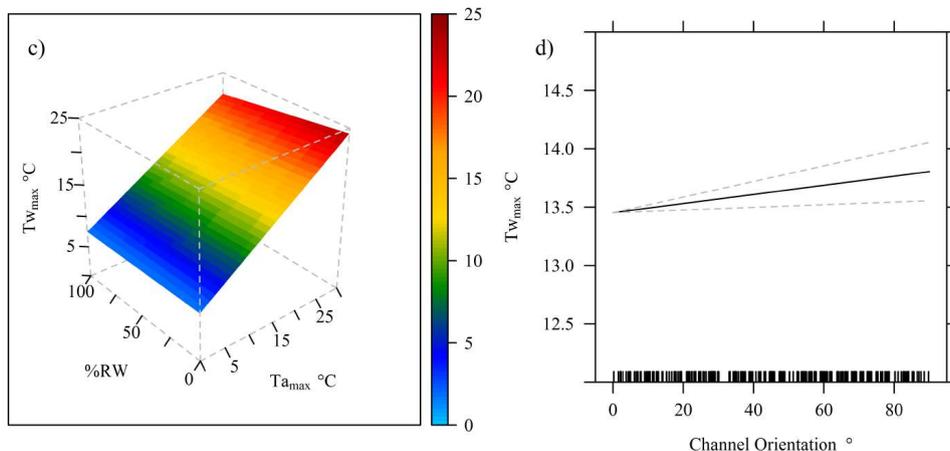
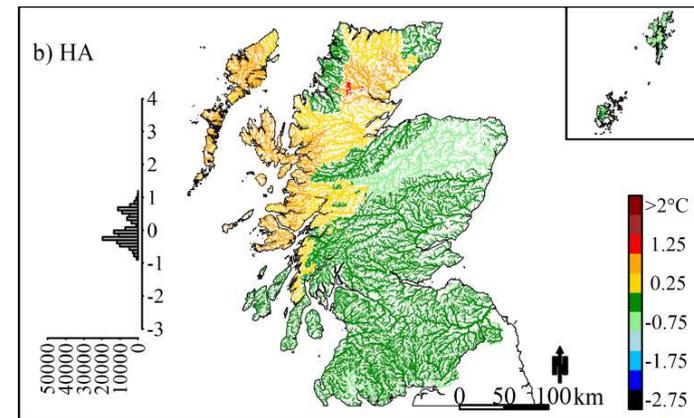
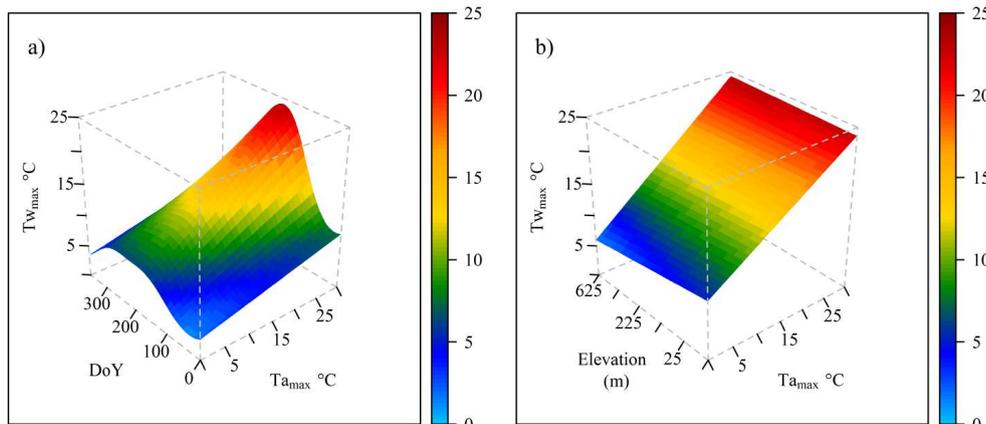
- First strategically designed national river temperature monitoring network in the world
- Deployed alongside local rivers and fisheries trusts and boards beginning in 2014
- Supported by local landowners granting permission for logger deployment
- Highly successful collaboration between government and local stakeholders
- 223 sites across 13 catchments
- >23,000,000 Tw observations in FleObs



# How do we predict river temperature in unmonitored locations?

## Large-scale spatio-temporal statistical models

$$T_{w_{max}} \sim T_{a_{max}} + s(\text{DoY}) + s(\text{DoY}) \times T_{a_{max}} + \text{Elevation} + \text{Elevation} \times T_{a_{max}} + \%RW + \%RW \times T_{a_{max}} + \text{Orientation} + \text{HAS} + \text{HAS} : T_{a_{max}} + \text{RNS:Catchment} + \text{RE}(\text{Site}) + \text{RE}(\text{Site}) : T_{a_{max}}$$



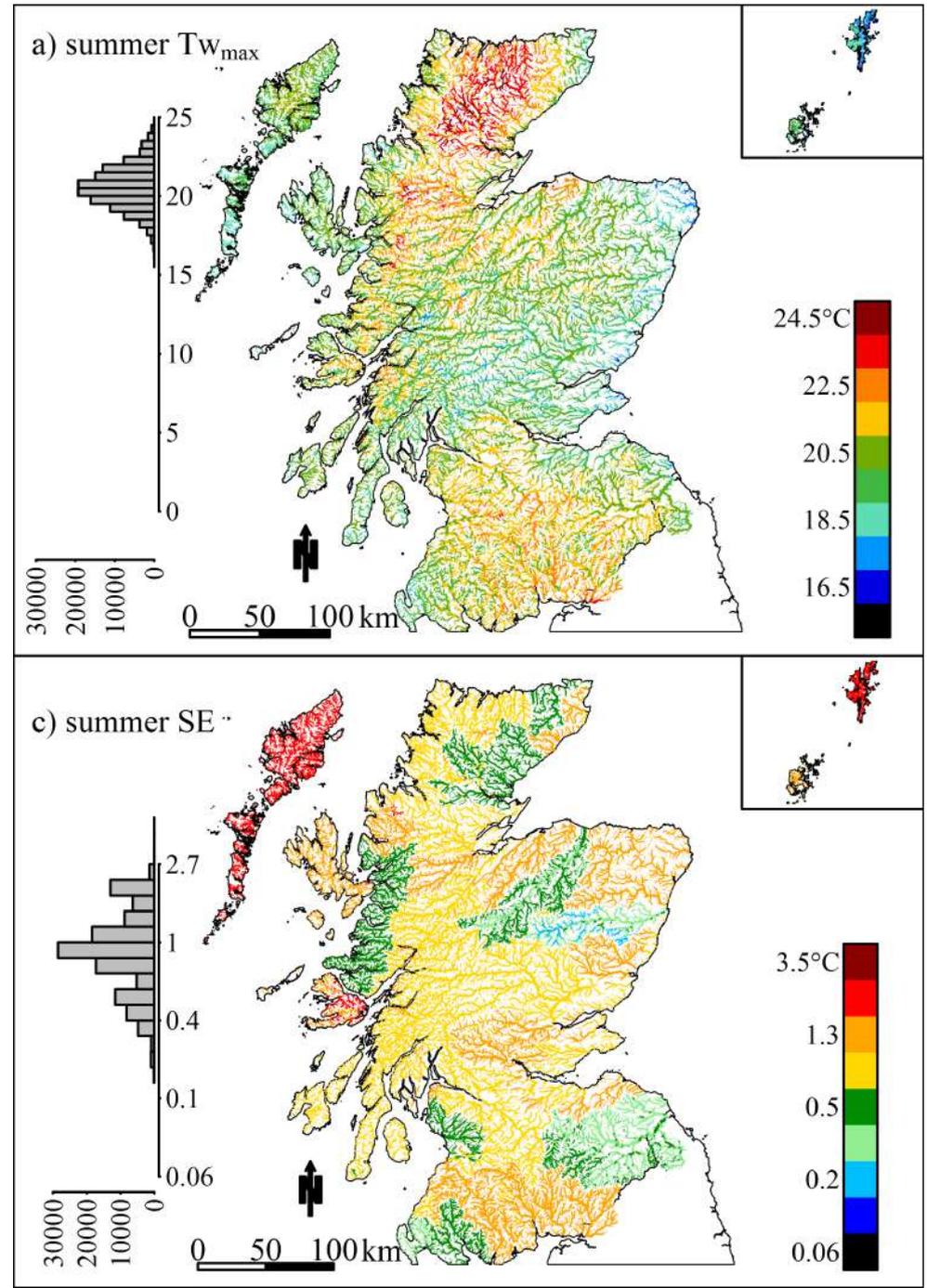
- Uses the relationship between river temperature and the air temperature, day of the year, location and characteristics of the landscape / river to explain temperature variability
  - A river with trees on the banks may be cooler than one without
  - A small river will heat up faster and also cool down faster than a big river
- Predict to new locations using the air temperature, day of the year, location and landscape characteristics

# Predictions and associated uncertainty for single day 2015/16

## Results:

Warmest temperatures in low altitude (high  $T_a$ ), unshaded rivers

Prediction error is lowest in catchments with data and highest in the islands

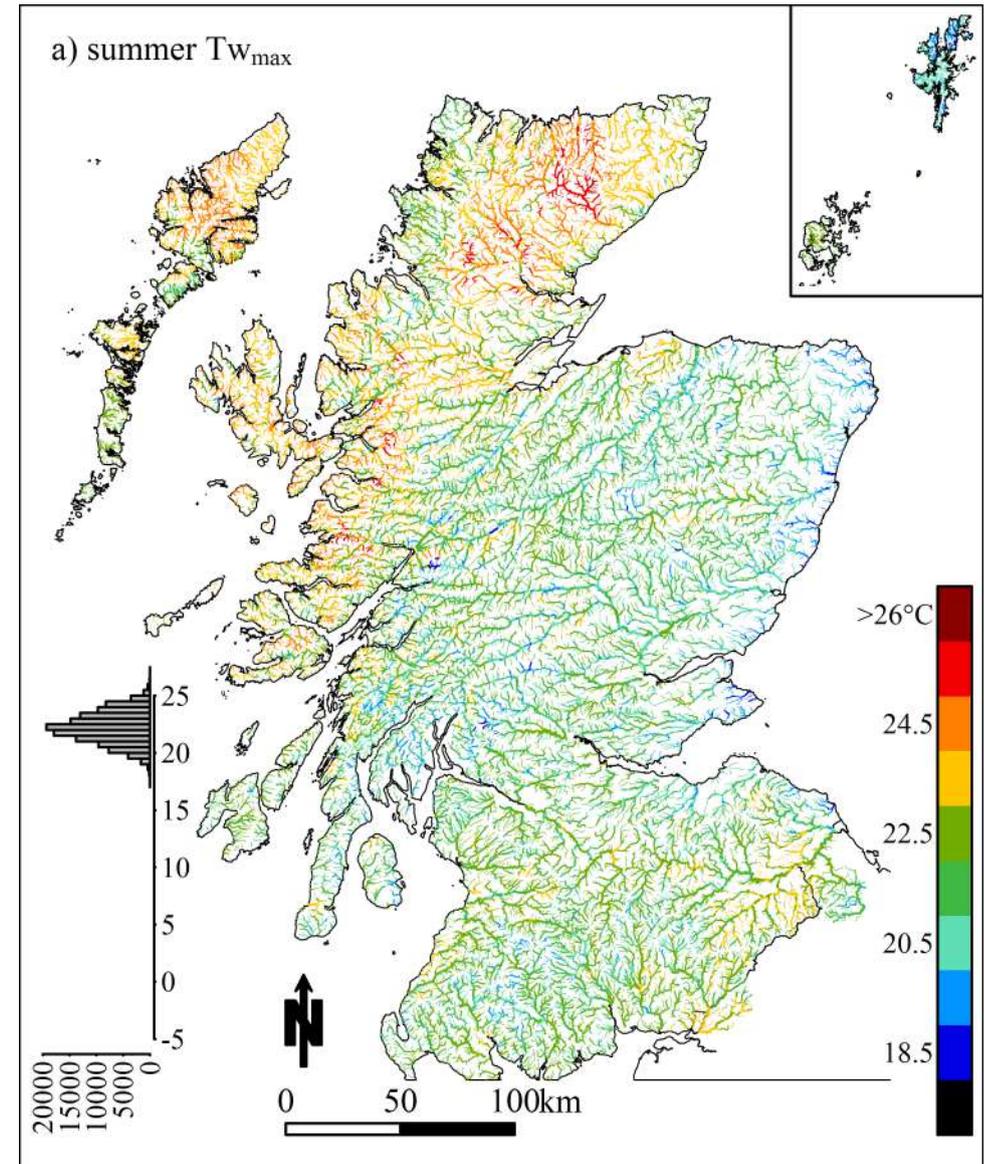


# Predictions of where is hottest

## Results:

Spatial patterns reflect air temperature, landscape covariates and location

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

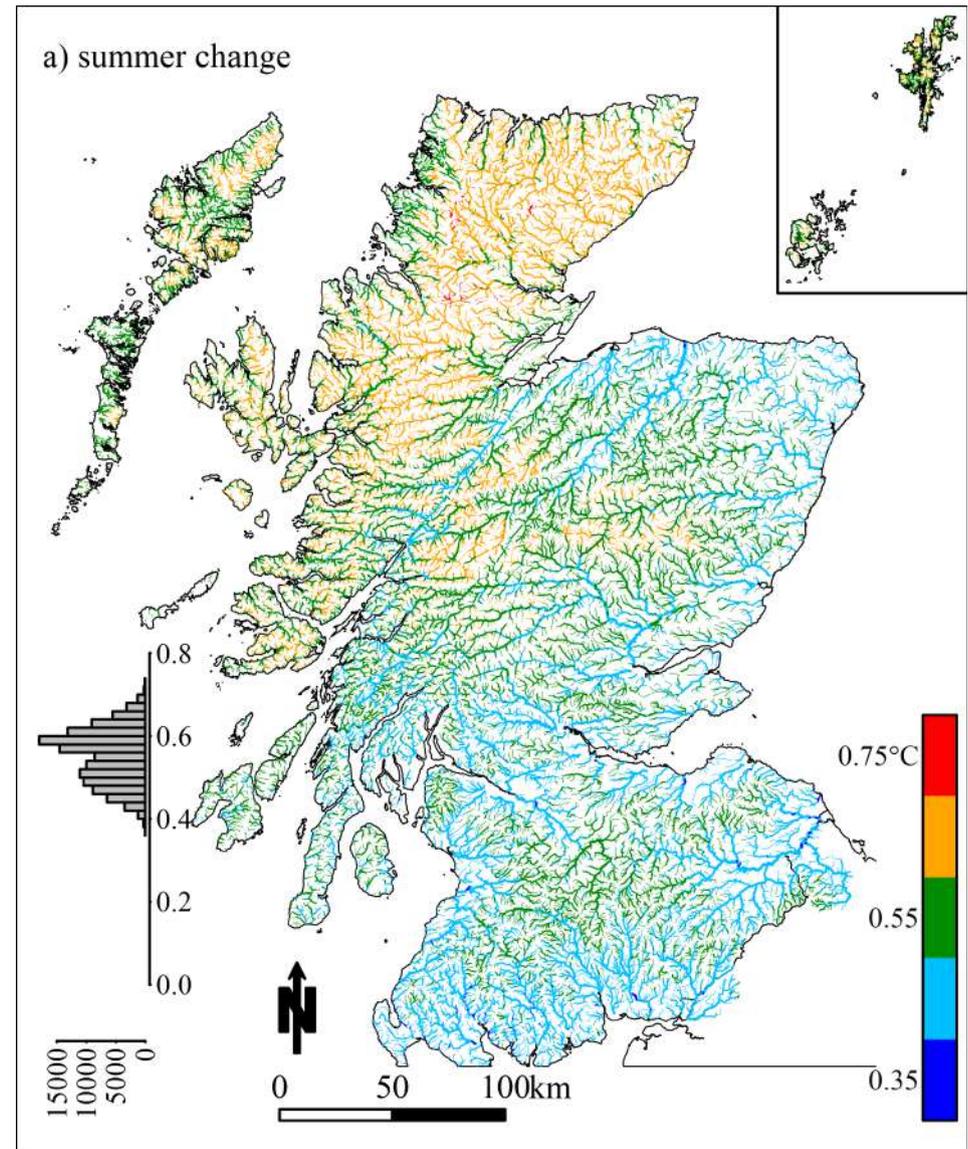


# Predictions of climate sensitivity

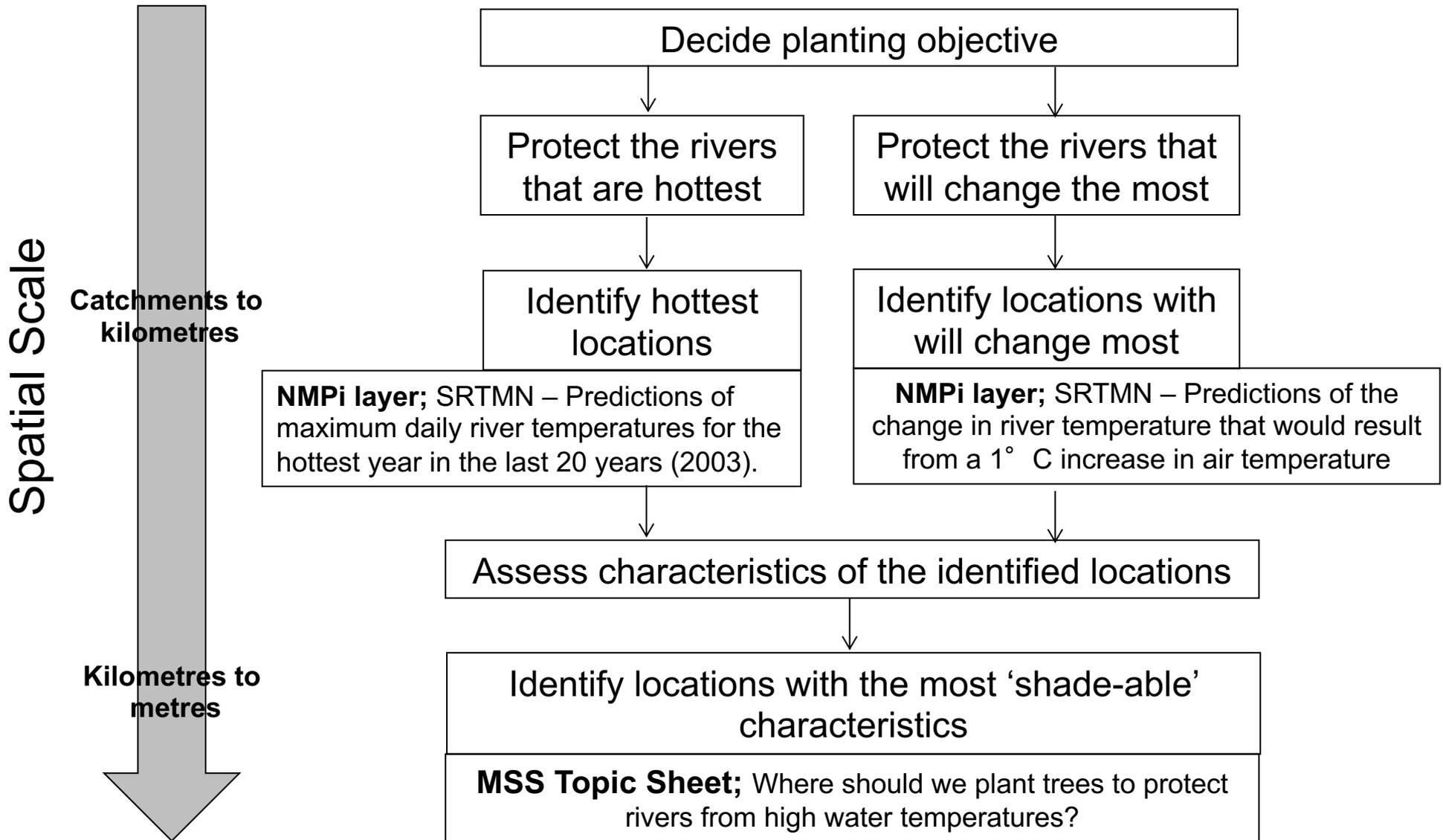
How much  $T_{w_{max}}$  will change for a 1 degree C change in  $T_{a_{max}}$

## Results:

Biggest changes are seen in northern rivers and in the Cairngorms



# How do I decide where to plant trees?



# NMPI

<https://marinescotland.atkinsgeospatial.com/nmpi/default.aspx?layers=1576>

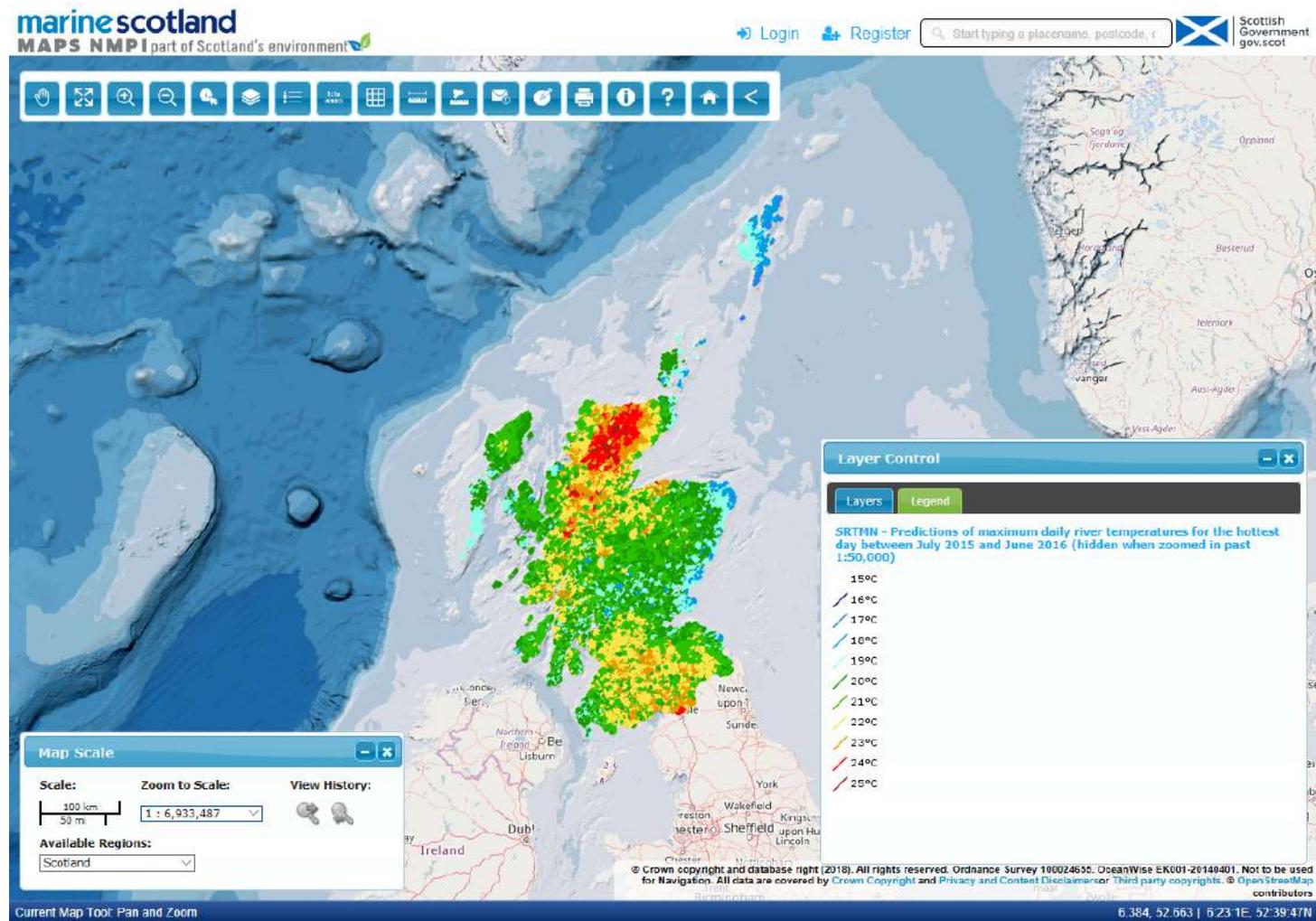
<http://marine.gov.scot/information/scotland-river-temperature-monitoring-network-srtmn-predictions-river-temperature-and>

Zoom

Print maps

Save images to add to reports or funding applications

Add/overlay other NMPI layers



## Planting advice from our deterministic modelling

- Decisions on planting at larger spatial scales should be informed by maps of predicted water temperature and climate sensitivity from statistical models
- Where a southerly bank is available for planting then less tree cover is needed to reduce river temperatures
- Where a southerly bank is not available (e.g. channels with a South–North orientation) then higher density, overhanging trees are required
- Planting has a greater effect in slower flowing rivers
- The benefits of planting are greater in medium sized rivers (ca. 10m width Holzapfel *et al.*, 2013) that are shallow and wide

# Where can I get more information?

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

Scottish Government  
Riaghaidh na h-Alba  
gov.scot

Home About Topics News Publications Consultations

Scotland River Temperature Monitoring Network (SRTMN)

Over the past decade Marine Scotland Science, in collaboration with researchers at the universities of Aberdeen, Birmingham and Glasgow, has been working to improve our understanding of:

1. spatial variability in stream temperature
2. controls on stream temperature
3. the influence of forestry on stream temperature
4. the potential effects of climate change on stream temperature
5. the influence of stream temperature on salmon growth and performance

Further information can be found in the list of references.

More recently, the Co-ordinated Agency for Marine, Environment and Rural Affairs Scotland (COMERAS) of freshwater monitoring in Scotland, highlighting the scarcity of available information, and the need for a temperature monitoring network. In 2012, MSc and the University of Birmingham received BBSRC CA funding to help plan and develop such a network, while MSc also developed the necessary policy and database infrastructure required. The network will be delivered in collaboration with freshwater or COMERAS partners. Through the aforementioned PhD project the SRTMN aims to address the following PhDs:

1. to characterise spatial and temporal variability in river temperature regimes for salmon rivers in Scotland
2. to improve understanding of hydrological, climatological and landscape controls on river temperatures

## Topic sheets

marine scotland  
TOPIC SHEET NUMBER 90

Scottish Government  
Riaghaidh na h-Alba  
gov.scot

### SCOTLAND RIVER TEMPERATURE MONITORING NETWORK (SRTMN)

INTRODUCTION

Abstract: Freshwater studies have long been limited by the scarcity of available information, and the need for a temperature monitoring network. In 2012, MSc and the University of Birmingham received BBSRC CA funding to help plan and develop such a network, while MSc also developed the necessary policy and database infrastructure required. The network will be delivered in collaboration with freshwater or COMERAS partners. Through the aforementioned PhD project the SRTMN aims to address the following PhDs:

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MAPS NMPI part of Scotland's environment

Background: River temperature influences feeding, growth and productivity of freshwater fish. Extreme high river temperatures (e.g. >29°C and >32°C for trout and salmon juveniles) can kill fish, even where they occur only for a short time (10 minutes).

There is increasing concern that river temperatures will rise under climate change with negative consequences for Scotland's valuable salmon and trout populations.

Bankside trees can reduce river temperatures. However, their effect varies depending on the characteristics of the rivers (e.g. width, channel orientation, speed) and the surrounding landscapes (e.g. tree density, landscape shading).

Fisheries Trusts, Fishery Boards and other organisations tasked with managing Scotland's rivers are increasingly interested in planting trees on rivers banks 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?

Recently, Marine Scotland Science and University of Birmingham have worked to develop tools and advice to help river managers decide where to plant trees to deliver the greatest benefits for reducing the impacts of climate change on river temperatures.

Two types of models have been used to develop these tools and advice: (1) statistical models that describe large scale (i.e. river catchments to national) variability in river temperatures, climate sensitivity (how much river temperatures will change) and planting potential (where greatest benefits can be expected); (2) deterministic

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science

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WILEY

### RESEARCH ARTICLE

Development of spatial regression models for predicting summer river temperatures from landscape characteristics: Implications for land and fisheries management

Peer reviewed  
Papers

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<sup>3</sup>Hydrology and Earth System Sciences, Indian Institute of Technology, Kanpur, India

#### Abstract

There is increasing demand for models that can accurately predict river temperature at the large spatial scales appropriate to river management. This paper combined summer water temperature data from a strategically designed, quality controlled network of 25 sites, with recently developed flexible spatial regression models, to understand and predict river temperature across a 3,000 km<sup>2</sup> river catchment. Minimum, mean and maximum temperatures were modelled as a function of river potential landscape covariates that represented proxies for heat and water exchange processes. Generalised additive models were used to allow for flexible responses. Spatial structure in the river network data (local spatial variation) was accounted for by including river network smoothness. Minimum and mean temperatures decreased with increasing elevation, riparian woodland and channel gradient. Maximum temperatures increased with channel width. There was greater between- and between-reach variability in all temperature metrics in lower-order rivers indicating that increased monitoring effort should be focused at these smaller scales. The combination of statistical methods chosen and recently developed spatial regression approaches enabled the resulting can planning and pre-

Hydrology and Earth System Sciences  
Hydro Earth Syst Sci, 18, 1393–1374, 2014  
www.hydrol-earth-syst-sci.net/18/1393/2014/  
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KEYWORDS  
landscape covariates

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

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Received: 21 May 2014 – Published: 12 November 2014 – Accepted: 10 July 2014

#### Abstract

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

Grace Caser<sup>1</sup>, Iain A. Malhotra<sup>1</sup>, Jonathan P. Sadler<sup>1</sup>, David M. Hannah<sup>1,2</sup>

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<sup>2</sup>Marine Scotland Science, Scottish Government, Freshwater Fisheries Laboratory, Pitlochry, PH26 5LJ, UK

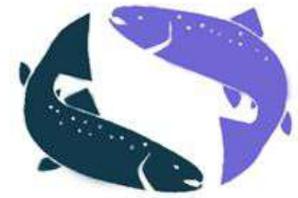
ABSTRACT  
A statistical experiment was used to understand the importance of riparian vegetation density, channel orientation and water velocity for stream temperature regimes and river temperature dynamics. Water temperature data and meteorological observations were obtained to describe the hydrological characteristics along a 1 km reach of the Great Ouse, a tributary of the River Great Ouse, in the UK. Riparian vegetation density was measured using a remote sensing approach and water velocity was measured using a velocity log. The effect of riparian vegetation density on stream temperature was investigated by changing the position of reach at 40° intervals in each hydrological reach. Stream temperature data were obtained from 2008 to 2010. High resolution water temperature data of the reach. Simulations were performed under low and high water velocity conditions. Both water velocity and stream temperature were found to be important in determining stream temperature. Riparian vegetation density and channel orientation were found to be important in determining stream temperature. Riparian vegetation density and channel orientation were found to be important in determining stream temperature. Riparian vegetation density and channel orientation were found to be important in determining stream temperature.

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# SRTMN Project Partners

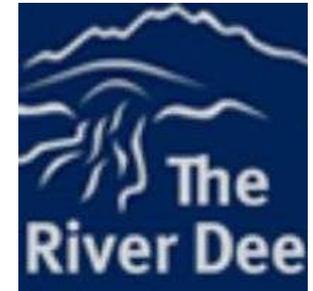
- Marine Scotland Science (MSS)  
Freshwater Fisheries Laboratory
- River Dee Trust
- Tweed Foundation
- Caithness District Salmon Fishery Board
- River Brora District Salmon Fishery Board
- Kyle of Sutherland Fisheries Trust
- Argyll Fisheries Trust
- Ayrshire Rivers Trust
- Galloway Fisheries Trust
- Spey Foundation
- University of Birmingham
- Landowners



Ayrshire Rivers Trust



THE *Tweed* FOUNDATION



River Brora District Salmon Fishery Board



The Scottish Government  
Riaghaltas na h-Alba

Caithness District Salmon Fishery Board

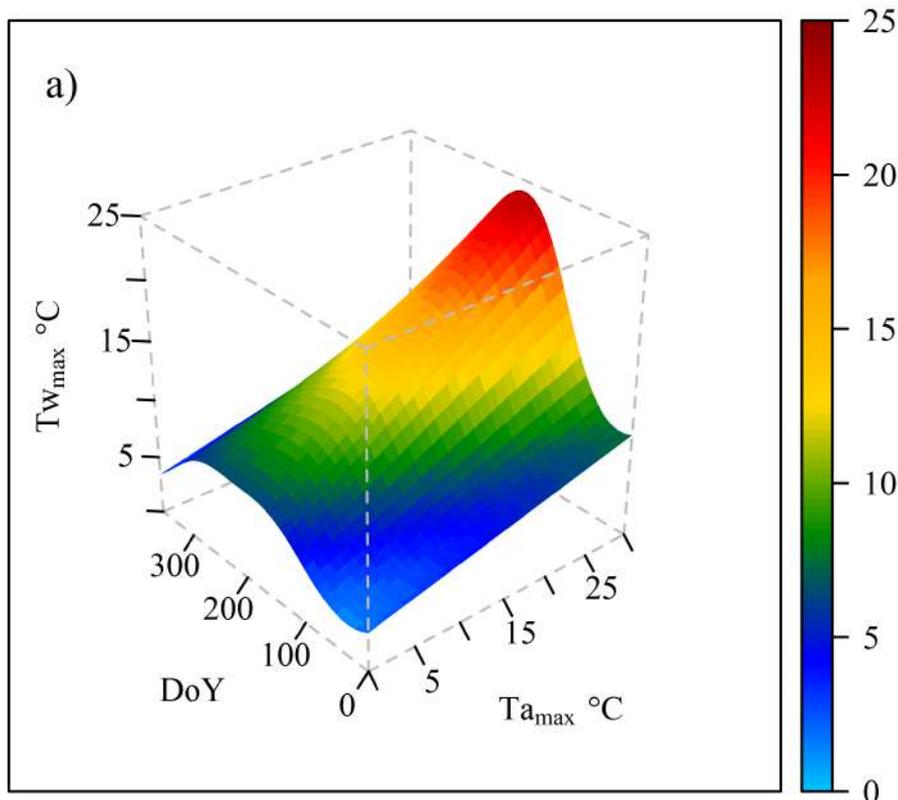


UNIVERSITY OF BIRMINGHAM



# National Tw Model : Fixed effects interactions

DoY:Ta



- Steeper relationship in summer compared to winter
  - Lower flows more responsive

X axis – Covariate

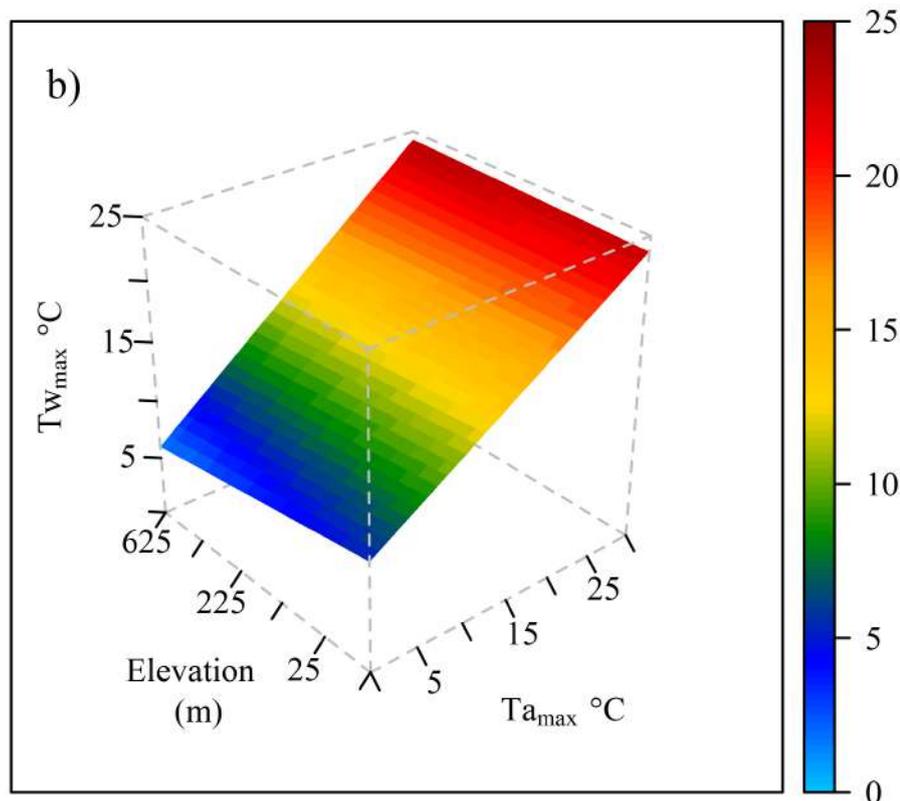
Y axis – River temperature

Z axis – Air temperature

Affecting both slope and intercept

# National Tw Model : Fixed effects interactions

## Elevation:Ta



- Reduces river temperature further at low air temperatures
  - Snow cover / melt
- Negligible effect in summer

X axis – Covariate

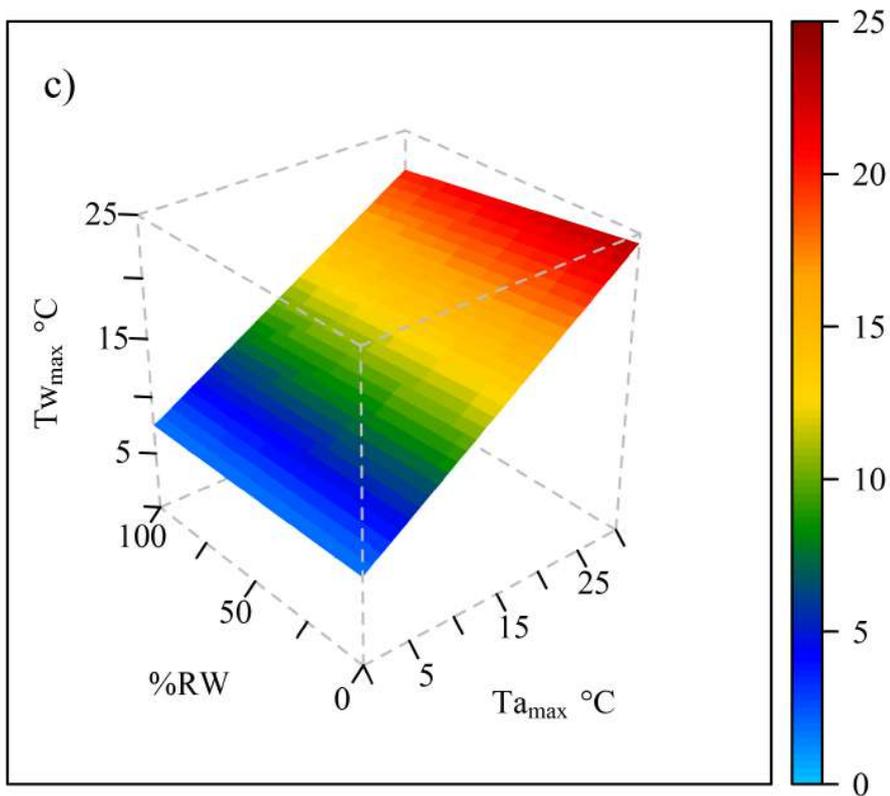
Y axis – River temperature

Z axis – Air temperature

Affecting both slope and intercept

# National Tw Model : Fixed effects interactions

## Woodland:Ta



- At high air temperatures, greater %RW reduces river temperatures
  - Shading
- At low air temperatures, high %RW increases river temperatures
  - Reducing net radiative losses

X axis – Covariate

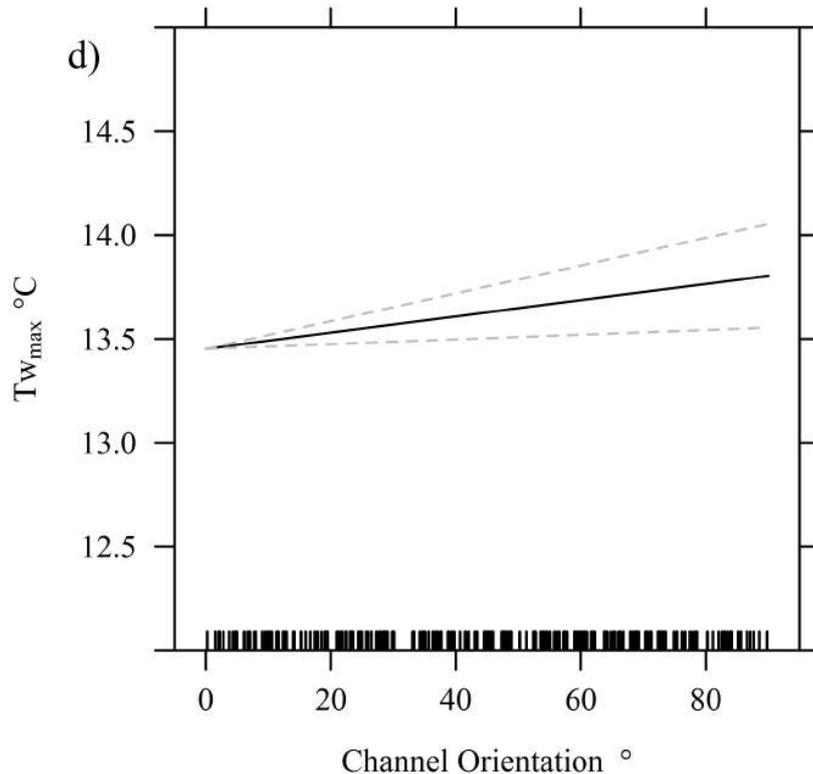
Y axis – River temperature

Z axis – Air temperature

Affecting both slope and intercept

# National Tw Model : Fixed effects

## Orientation



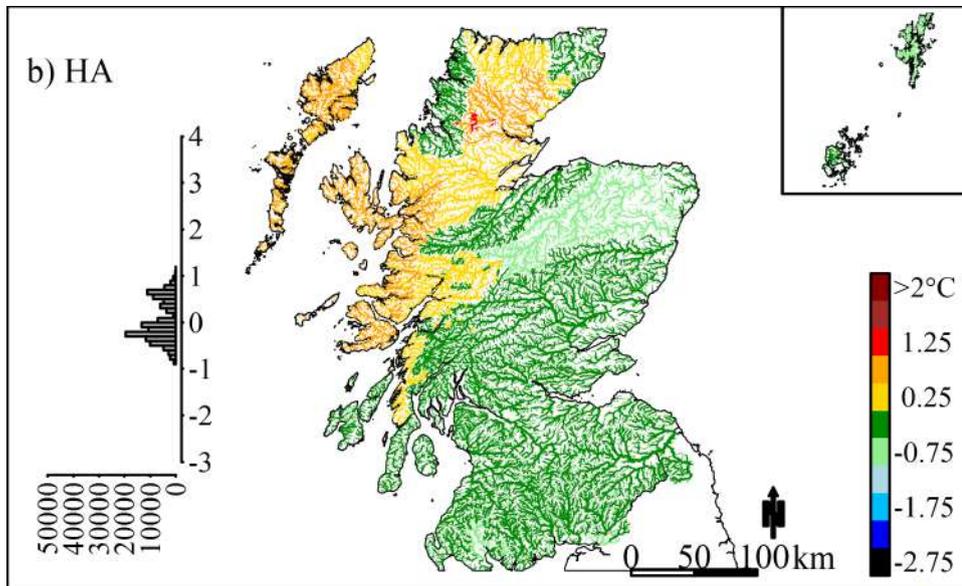
- Increases river temperature in N/S reaches
  - Most exposed when solar radiation is greatest

X axis – Covariate

Y axis – River temperature

Affecting only intercept

# National Daily Maximum Tw Model : Fixed effects

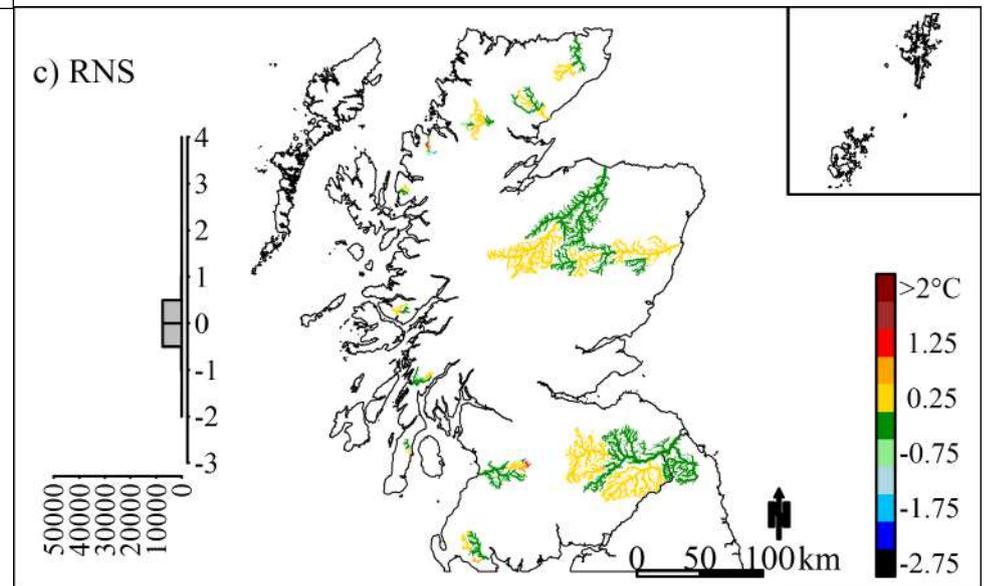


+ HAS + HAS:Ta<sub>max</sub>

Large-scale (regional)  
spatially correlated variability,  
not explained by covariates

+ RNS:Catchment

Within river spatially  
correlated variability, not  
explained by covariates,



# Metrics

## Methods for the metrics

Metrics are generated for each site from daily maximum, mean or minimum river temperatures depending on the metrics selected. Metrics are only generated where data is available for  $\geq 95\%$  of the time period.

Metric	Abbreviated Metric	Method
<b>Temperature metrics</b>		
Maximum	Maximum	Maximum observed river temperature over the time period selected
Mean	Mean	Mean observed river temperature over the time period selected
Minimum	Minimum	Minimum observed river temperature over the time period selected
Mean Maximum	Mean Maximum	Mean of the observed daily maximum river temperatures over the time period selected
Mean Minimum	Mean Minimum	Mean of the observed daily minimum river temperatures over the time period selected
<b>Salmon growth metrics</b>		
Days above optimal Tw for salmon growth	Optimal salmon growth	Number of days where mean daily river temperature is above 16 degrees (upper threshold for optimal growth of salmon given unlimited food resources) (Elliot and Hurley 1997) over the time period selected
Days above max for Tw salmon growth	Max salmon growth	Number of days where observed mean daily temperatures exceed 22.5 degrees (maximum temperature for growth of salmon given unlimited food resources) (Elliot and Hurley 1997) over the time period selected
Days below min for Tw salmon growth	Min salmon growth	Number of days where observed mean daily temperature is below 6 degrees (minimum temperature for growth of salmon given unlimited food resources) (Elliot and Hurley 1997) over the time period selected
<b>Trout growth metrics</b>		
Days above optimal Tw for trout growth	Optimal trout growth	Number of days where mean daily temperature is above 13.5 degrees (upper threshold for optimal growth of trout given unlimited food resources) (Forseth et al 2009) over the time period selected
Days above max Tw for trout growth	Max trout growth	Number of days where mean daily temperature is above 19.5 degrees (maximum temperature for growth of trout given unlimited food resources) (Forseth et al 2009) over the time period selected
Days below min Tw for trout growth	Min trout growth	Number of days where observed mean daily temperature is below 4 degrees (minimum temperature for growth of trout given unlimited food resources) (Forseth et al 2009) over the time period selected
<b>Salmon stress metrics</b>		
Days exceeding Tw threshold thermal stress for salmon	Salmon stress	Number of days where observed maximum daily temperature is above 23 degrees (where salmon begin to show behavioural changes, such as seeking thermal refugia) (Breau et al 2007) over the time period selected
Days where there is an increased mortality risk of catch and release	Salmon catch and release risk	Days where minimum temperature exceeds 20 degrees (Breau 2012) over the time period selected
<b>Salmon lethal limits</b>		
Days above instantaneous lethal temperature for salmon	Salmon lethal	Number of days where observed daily maximum temperature is above ca.31 degrees (Elliot and Elliot 1995) over the time period selected
<b>Trout lethal limits</b>		
Days above instantaneous lethal temperature for trout	Trout lethal	Number of days where observed daily maximum temperature is above ca.30 degrees (Elliot and Elliot 1995) over the time period selected