Institution: University of Birmingham

Unit of Assessment: 14 – Geography and Environmental Studies

Title of case study: Protecting fish from high river temperatures under climate change

Period when the underpinning research was undertaken: 2004 - present

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor David M. Hannah	Professor	1997 – present
Dr Grace Garner	NERC-funded PhD and Postdoctoral Researcher	2010 – 2014
Dr Faye L. Jackson	NERC iCASE-funded PhD	2013 – 2017
Professor Jonathan P. Sadler	Professor	1993 – present
Dr Stephen J. Dugdale	Postdoctoral Researcher	2016 – 2018

Period when the claimed impact occurred: 2017 – December 2020

Is this case study continued from a case study submitted in 2014? No

1. **Summary of the impact** (indicative maximum 100 words)

We have **stimulated and informed policy** and **adaptation strategies** to protect Atlantic salmon populations, worth £80M annually to the Scottish economy, from the impacts of climate change. We have **transformed the management of environmental risk** from rising temperature on freshwater fish and their habitats by implementing the first-ever strategic, national-scale, quality-controlled river temperature monitoring network that has led to the targetted bankside **planting of >200,000 native trees** to provide river shade. Our approach was advocated by the **inter-governmental conservation efforts** of the North Atlantic Salmon Conservation Organisation (NASCO) review group and is now being **replicated in other nations**.

2. Underpinning research (indicative maximum 500 words)

Scotland's economy benefits greatly from its high quality natural resources with freshwater fisheries contributing £80M each year (PACEC, 2017). Scottish rivers account for 75% of UK and 30% of European wild salmon production, and these fisheries support >12,000 jobs in rural locations. However, climate change is increasing the temperature of rivers, with risks for native fish that are unable to adapt or compete with invasive species. In 2018 (the equal warmest summer on record), 69% of Scotland's rivers experienced temperatures exceeding thermal stress for juvenile Atlantic salmon — conditions expected every other year by 2050.

University of Birmingham (Prof. David M. Hannah; UoB) and Marine Scotland Science (Dr Iain Malcolm; MSS) have collaborated for more than 15 years. They have provided the evidence to identify the processes and circumstance under which riparian (riverside) tree cover can reduce water temperature extremes [R2–R3]. In particular, the cooling **effects of riparian woodland on river water temperature** [R1–R3] together with approaches to **predict the river temperature** [R4–R6].

Following a call by the Coordinated Agenda for Marine, Environment & Rural Affairs Scotland (CAMERAS) for a bespoke monitoring network to improve understanding of river temperature at a national scale, UoB and MSS co-designed and implemented the **Scotland River Temperature Monitoring Network** (SRTMN). The network comprised of an initial 223

dataloggers across 13 catchments delivered in collaboration with nine local fisheries organisations [R4]. It represents the world's first strategically designed, quality-controlled, national-scale river temperature network — yielding unprecedented data and demonstrating the financial and logistical feasibility of such large-scale monitoring (Fig.1).

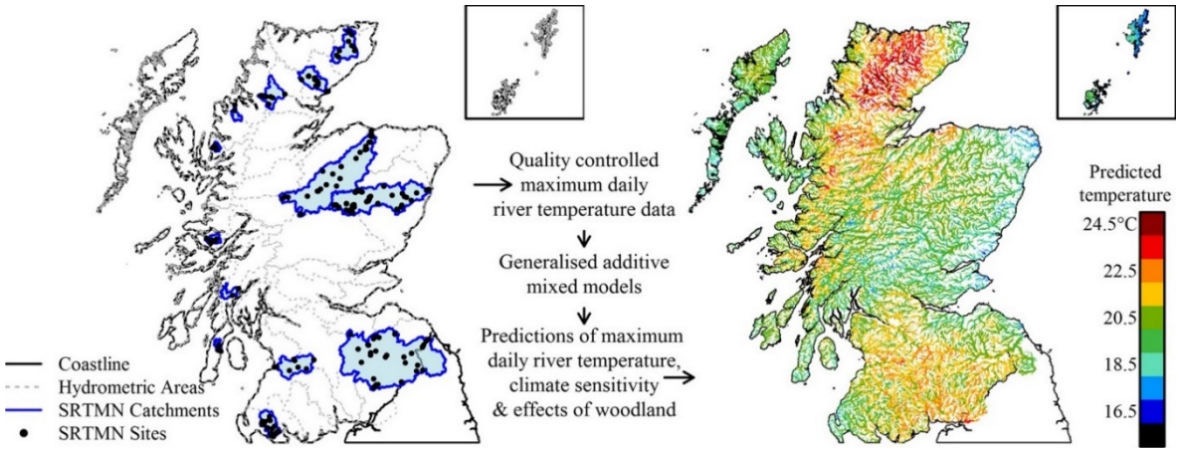

Fig. 1. SRTMN and predicted maximum daily river temperature (Jackson *et al*., 2018 [R6]).

By combining data from SRTMN with **new statistical approaches for river temperature modelling** [R5], it was possible to assess variability in river temperature at an unprecedented scale (Fig. 1), providing the means to better understand the transferability of models between catchments. Fundamentally, the research revealed the locations **where rivers are hottest and most susceptible to changing climate at a national scale** and the **conditions under which riparian shading has a maximum effect on water temperature** at the river reach to sub-catchment scale [R6]. The key findings [KF] from the body of work are as follows:

[KF1] There are numerous controls on river temperature that need to be quantified to provide the evidence base to prioritise management interventions (i.e. riparian tree planting) to mitigate the impact of climate change on freshwater fish and their habitat [R1–R3].

[KF2] The feasibility of large-scale thermal monitoring of rivers has been proven as a means to better understand the consequences of climate change on river temperature pattern. The extensive datasets now available can provide the underpinning basis for adaption efforts by the natural resources and freshwater fisheries sectors [R4–R6].

[KF3] Models of the water-air temperature relationships, which vary by season and landscape, can now be reliably implemented now as a series of user-friendly tools [R5–R6]**.**

3. References to the research (indicative maximum of six references)

Research Outputs:

[R1] Hannah, D.M., Malcolm, I.A., Soulsby, C., and Youngson, A.F. (2008) A comparison of forest and moorland stream microclimate, heat exchanges and thermal dynamics, *Hydrological Processes*, 22, 919–940. DOI: 10.1002/hyp.7003

[R2] Garner, G., Malcolm, I.A., Sadler, J.P., and Hannah, D.M. (2014) What causes cooling water temperature gradients in forested stream reaches?, *Hydrology and Earth Systems Science*, 18, 5361–5376. DOI: 10.5194/hess-18-5361-2014

[R3] Garner, G., Malcolm, I.A., Sadler, J.P., and Hannah, D.M. (2017) The role of riparian vegetation density, channel orientation and water velocity in determining river temperature dynamics, *Journal of Hydrology*, 553, 471–485. DOI: 10.1016/j.jhydrol.2017.03.024

[R4] Jackson, F.L., Malcolm, I.A., and Hannah, D.M. (2016) A novel approach for the design of large-scale river temperature monitoring networks, *Hydrology Research*, 47, 569–590. DOI: 10.2166/nh.2015.106

[R5] Jackson, F.L., Hannah, D.M., Fryer, R.J., Millar, C.P., and Malcolm, I.A. (2017) Development of spatial regression models for predicting summer river temperatures from landscape characteristics: implications for land and fisheries management, *Hydrological Processes*, 31, 1225–1238. DOI: 10.1002/hyp.11087

[R6] Jackson, F.L., Fryer, R.J., Hannah, D.M., Millar, C.P., and Malcolm, I.A. (2018) A spatio-temporal statistical model of maximum daily river temperatures to inform the management of Scotland's Atlantic salmon rivers under climate change, *Science of the Total Environment*, 612, 1543–1558. DOI: 10.1016/j.scitotenv.2017.09.010

Research Grants between UoB and MSS:

NERC Open CASE Studentship (Grant reference: NE/G523963/1) Predicting stream temperature response to changes in riparian land management.

NERC Open CASE Studentship (Grant reference: NE/1528226/1) River and stream temperature in a changing climate.

NERC Open CASE Studentship (Grant reference: NE/K007238/1) River temperature sensitivity and response to drivers of change.

EU-H2020 Marie Curie International Incoming Fellowship (Cordis Project ID: 702468), HoTRiverS: Heterogeneity of Temperature in Rivers and Streams.

4. Details of the impact (indicative maximum 750 words)

KF1–KF3 have underpinned policy and management interventions to mitigate high river temperature under climate change and protect freshwater fish. The high-profile nature of these activities has led to greater public understanding of rivers and freshwater fish under climate change.

Impacts on public policy by changing conservation practice of Scottish rivers

The SRTMN [KF2] has **stimulated debate and influenced policy** in Scotland where **research evidence has underpinned guidance** to use riparian tree planting to protect the river thermal habitat of salmon [KF1; E1]. Following a response to Scottish Parliament consultation and questions, SRTMN featured both in *The Environment Strategy for Scotland* and the *Scottish Budget 2020–2021* [E2]. Both policy documents reference directly SRTMN, for example:

> [the means] to mitigate high temperature extremes […using] a suite of tools to plan and prioritise bankside tree planting […to] protect young salmon and trout from high temperatures associated with climate change. [E2].

The SRTMN approach [KF2] was also advocated in **inter-governmental conservation efforts** of the North Atlantic Salmon Conservation Organisation (NASCO) review group [E3]. This has led since to other nations replicating our network design principles [E4].

Impacts on the environment by changing river management and preserving fish stocks

Fisheries and other natural resource managers access the SRTMN online **decision-making tools** [KF3] using Marine Scotland's National Marine Planning Interactive portal [E5]. We have

also produced a series of **best practice Scottish Government leaflets** for use by practitioners and the public [E6; 77 active enquiries to date].

The availability of these resources has **transformed the management of the environmental risk** of rising temperature [E7] by enabling managers to identify sections of river networks that are most likely to be impacted negatively by climate change [KF3] and in need of additional tree planting [KF1]. Uptake of SRTMN tools has been extensive with organisations including: The Tweed Foundation, River Dee Trust, Spey District Salmon Fisheries Board, Ayrshire Rivers Trust, Cromarty Firth Fishery Board and Kyle of Sutherland District Salmon Fisheries Board.

SRTMN outputs [KF2–KF3] are used to provide the evidence base to underpin **fisheries management plans** [E8] and **funding applications to support new riparian tree planning** (e.g. Cairngorms National Park Green Recovery Fund). In a high-profile example, it has resulted in the **planting of >200,000 native trees** along the river banks of the upper Dee where "SRTMN outputs [were] instrumental in helping target […] efforts" [E7]. The tools have also guided **decision-making on woodland restructuring** by Scottish Natural Heritage (the lead public body responsible for advising Scottish Ministers on all matters relating to the natural heritage) and resource allocation from the Biodiversity Challenge Fund [E8]. Fisheries Management Scotland (the representative body for Scotland's fishery and rivers boards/trusts) recognised the use of SRTMN in supporting fishery boards and riparian tree planting projects by river trusts to "be a valuable tool in targeting these efforts so that we can maximise the beneficial impact on our rivers" [E9]. As also stated by the Scottish Environment Secretary:

> [SRTMN] help[s] fisheries managers target work to protect stocks and increase the resilience of freshwaters. [E9]

Impacts on understanding, learning and participation

Practitioner and public awareness of the sensitivity of rivers and freshwater fish to climate change has been heightened through broad **media exposure**. STRMN [KF2] has featured on both national (Dr Faye Jackson on BBC2's 'The Adventure Show' in December 2017) and international television (Fuji TV News, Japan, in December 2018) as well as in national newspaper articles and specialist magazines [E9]. The tools [KF3] are discussed widely on social media and generate many practitioner and public enquiries to Marine Scotland Science for further information/ advice [E10]. At the time of writing, the STRMN webpage was accessed >8449 times. Increased understanding and learning about issues (including attending our SRTMN user workshops and information events), has motivated multiple stakeholders to take actions [E9] towards protecting fish and their habitats from high river temperature under climate change [E10].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[E1] Testimonial from Simon Dryden, The Marine Scotland Policy Team Leader, Salmon and Recreational Fisheries, including reference to Scottish Government *Conservation of wild salmon* [Accessed 12 February 2021]

[E2] Scottish Parliamentary response to Questions

Question S5W-19701: Gillian Martin, Aberdeenshire East, Scottish National Party, Date Lodged: 01/11/2018

Question S5W-31832: Oliver Mundell, Dumfriesshire, Scottish Conservative and Unionist Party, Date lodged: 15 September 2020

Scottish Budget 2020-2021: Chapter 11: Environment, Climate Change and Land Reform

The Environment Strategy for Scotland: Vision and Outcomes

[E3] Reports and implementation plans from North Atlantic Salmon Conservation Organisation (NASCO)

NASCO - Protection, Restoration and Enhancement of Salmon Habitat Focus Area Report, EU-UK (Scotland)

NASCO Implementation Plan for the period 2013–18 EU-UK(Scotland)

NASCO Implementation Plan for the period 2019–2024 EU – UK (Scotland)

NASCO Council - Annual Progress Report on Actions Taken Under the Implementation Plan for the Calendar Year 2019 EU-UK (Scotland)

[E4] Testimonial from Inland Fisheries Ireland [Dated October 2019]

[E5] Marine Scotland – National Marine Plan Interactive [Accessed 12 February 2021]

[E6] Marine Scotland Advice leaflets:

The Scotland River Temperature Monitoring Network (SRTMN)

Where should we plant trees to protect rivers from high water temperatures?

Summer 2018 river temperatures

[E7] Testimonials from Dee District Salmon Fishery Board and River Dee Trust [Dated 3 November 2020]

[E8] Testimonial from Scottish Natural Heritage [Dated 28 February 2020]

[E9] Press and Media coverage (The Daily Telegraph (Scotland), The Environment, The Scotsman, The Press & Journal and The National in March 2018: including statements by Alan Wells, Chief Executive of Fisheries Management Scotland; Mark Bilsby from the River Dee Trust; Simon McKelvey from the Cromarty Firth Fishery Board and Environment Secretary, Roseanna Cunningham MSP) and interview with Faye Jackson in BBC2's 'The Adventure Show' in December 2017 on importance of our research for salmon conservation and to support stakeholders management actions.

[E10] MSS Support: email correspondence and analytics to evidence views of STRMN website and downloads of leaflets.