**Adapting to life in an increasingly acid world: understanding tolerance to acidic waters in populations of trout (Salmo trutta)**

**Lead Supervisor Name**

Jamie Stevens

**Lead Supervisor Contact Details**

j.r.stevens@exeter.ac.uk

**Lead Supervisor Location/Student Home Institution**

Institution: Exeter

**Full Project Description**

Adapting to life in an increasingly acid world: understanding the basis of tolerance to acidic waters in populations of brown trout (*Salmo trutta*).

During the freshwater phases of their lifecycles, brown trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*) inhabit a broad range of environments, ranging from acidic upland streams to neutral-alkaline chalk streams. Due primarily to the impacts of human-driven ecological perturbations, e.g. forestry clearance and acid run-off, the pH of many of these systems is now fluctuating far beyond previously recorded levels.

Dartmoor National Park is a unique upland habitat in southwest England. Flowing over granite and peat, many rivers of the region are markedly acidic; nonetheless, compared to similar upland streams elsewhere in Britain and Ireland, local management activities, e.g. forestry clearance, have led to large fluctuations in pH, with readings of less than pH 4 being recorded. Despite this, most Dartmoor streams host healthy populations of trout and salmon, and molecular analysis shows trout from acid rivers to be genetically distinct (Griffiths et al. 2009).

This project aims to identify the basis of tolerance to acid waters in brown trout through analysis of single nucleotide polymorphisms (SNPs) and changes in gene expression. We propose to use the complementary approaches of restriction site associated DNA sequencing (RADseq) and transcriptomics (RNA sequencing [RNAseq]) to study trout populations inhabiting acid, neutral and alkaline rivers in southern Britain. This will allow us to explore common/convergent evolutionary 'solutions' to acid tolerance. Additionally, the student will gain field experience and work with a modern conservation organisation.

Our primary objective is to understand the genetic basis of acid tolerance in brown trout. We propose to use RADseq analysis of fish from rivers with low pH (Dartmoor streams), neutral rivers (other rivers in Cornwall and Devon) and more alkaline waters (chalk streams, Dorset/Hampshire). We already hold tissue samples from resident trout collected from across these regions, and the student will have the opportunity to partake in fieldwork to collect additional trout tissue samples. The sampling design includes fish from tributaries running off acid high-moor sites and neutral lowland locations (allowing us to eliminate the effects of differential genetic drift and catchment-specific selective pressures). This will allow us to identify SNPs that segregate definitively between the ecotypes and to identify regions of the trout genome associated with adaptations to living in a low pH environment. The study will provide a better understanding of the basis of acid tolerance in salmonids and addresses long-standing questions regarding persistence of this species in an otherwise species-poor (highly acid) ecosystem. It also offers the potential to reveal the mechanisms of local adaptation and the genetic architecture underlying this process. Such information will also be of value in fish conservation and aquaculture in the face of global pressures on aquatic systems, e.g. the acidifying effects of increased atmospheric CO2 (Hasler *et al*. 2016).

Collaboration with the CASE partner, Westcountry Rivers Trust, and The Game & Wildlife Conservation Trust also provides a rare opportunity to look for changes in gene expression in relation to exposure to highly acidic conditions. For the first time, permission was recently granted to add lime to an extremely acid stretch of river on Dartmoor, thereby artificially increasing the pH. Samples of gill and kidney will be collected from trout at the treatment site, alongside those in more acidic water immediately upstream. Analysis by RNAseq will then characterise changes in gene expression related to acidity, identifying genes important to physiological responses in wild trout populations. By combining population genomic and gene expression approaches, this exciting studentship offers the potential to address broader questions of acid tolerance and adaptation in this fish. The team at Exeter and Bristol have extensive experience in this field and we anticipate that our research findings will be used by fisheries managers, conservationists and other stakeholders to help in monitoring at-risk environments and detecting changes in water quality that may threaten fish health and population numbers.

Griffiths, Koizumi, Bright & Stevens (2009) A case of isolation by distance and short-term temporal stability of population structure in brown trout (*Salmo trutta*) within the River Dart, southwest England. *Evolutionary Applications*, 2: 537-554.

Hasler *et al.* (2016) Freshwater biota and rising pCO2? *Ecology Letters*, 19: 98-108.

**Real Life challenges this project will address**

The brown and sea trout fishery is extremely valuable socio-economically, bringing more than £12 million into the economy of southwest England. Accordingly, local environmental authorities are required to ensure sustainable management of their local fisheries and to ensure that: a) the local environment is conducive to a productive fish population, and b) that the genetic integrity of local (and locally-adapted) populations is maintained. The question of how fish colonise, survive and adapt to environmental perturbations, including human-induced changes to freshwater systems, is therefore of great relevance to the local economy and biodiversity of these rivers. By combining population genomic and gene expression analyses to investigate acid tolerance, this exciting studentship offers the potential to address broader questions of evolution and adaptation in brown trout in the rivers of southwest England.

**What you should know about this project**

During the freshwater phase of its lifecycle, brown trout (*Salmo trutta*) inhabit a broad range of environments, ranging from acidic upland streams to neutral-alkaline chalk streams. Due to the impacts of human-driven ecological perturbations, e.g. forestry clearance and acid run-off, the pH of many of these systems is now fluctuating far beyond previously recorded levels. This project will use cutting-edge genomic approaches to identify the basis of tolerance to acid waters in brown trout by comparing populations inhabiting rivers of widely varying pH in southern Britain, focusing on the local, low pH environment of Dartmoor National Park. This will allow exploration of the convergent evolutionary 'solutions' to acid tolerance and the mechanisms of local adaptation. Such insights are invaluable in salmonid conservation and aquaculture in the face of changing patterns of pH in aquatic systems globally. The supervisory team have diverse expertise in population genetics and applied fisheries management, with an exceptional track record in postgraduate student supervision: of the six PhD studentships held with the Westcountry Rivers Trust to date, all students have graduated with first author publications and have gone on to outstanding careers, as university lecturers, postdoctoral researchers or fisheries scientists with the Environment Agency.

**What expertise you will develop**

This project offers the potential to develop wide ranging expertise from fish handling and field sampling (electro-fishing), working in a molecular laboratory (Exeter), to the bioinformatic analysis of genomic data (Bristol). Placements with the CASE partner will also allow the student to see how stakeholder data can be applied to fisheries management. The student will use genome-wide sequencing (RADseq) to examine genetic diversity in trout from acid, neutral and alkaline rivers. Additionally, they will use transcriptomics to characterise changes in gene expression related to acidity and to identify genes important to physiological responses in wild trout populations. By combining population genomic data and gene expression analysis to investigate acid tolerance, this exciting studentship offers the potential to address broader questions of evolution and to investigate the genetic architecture of local adaptation.

**Why this project is novel**

To date, most research on the impacts of changing pH on fish has focused on marine species. This project broadens this focus to address the impacts of acidification on populations of a wild freshwater fish. The methodology is also novel – whole genome sequencing has not yet been applied to questions of conservation and adaptation in brown trout. This PhD is now possible because a brown trout reference genome has recently been produced as part of the Sanger Institute’s 25 Genomes Project (https://www.sanger.ac.uk/science/collaboration/25-genomes-25-years) and is currently in final annotation. Evidence for local adaptation to acidic water conditions has been reported previously in trout in Dartmoor streams (Griffiths et al. 2009). The proposed project will expand on this to explore whether trout in rivers of varying pH adapt to their environment by the same underlying genetic processes (or not). For the first time, we can study the basis of adaption to environmental acidity in trout with a powerful combination of genomic and geospatial tools.

**Rest of Supervisory Team:**

**Stakeholder Organisation** Westcountry Rivers Trust

**Stakeholder Supervisor** Bruce Stockley

**Co-Supervisor 1** Martin Genner

**Affiliation:** Bristol

**Email:** m.genner@bristol.ac.uk

**Co-Supervisor 2** Andrew Griffiths

**Affiliation**: Exeter

**Email:** A.M.Griffiths2@exeter.ac.uk