The influence of riparian woodland on stream temperatures: implications for juvenile salmon

FWS Freshwater Laboratory, Faskally, Pitlochry, Perthshire, PH16 5LB
School of Geosciences, University of Aberdeen, Elphinstone Road, Aberdeen, AB24 3UF
School of Geography, Earth & Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT

Introduction
In recent years there has been increasing awareness of summer temperature extremes across Europe, that in some cases resulted in fish mortality. There are now concerns for species which are internationally important for the production of Atlantic salmon. Current climate change predictions indicate that high summer temperatures and low flow conditions are likely to increase. Extreme high temperatures can cause outright mortality of Atlantic salmon, with near-natural effects on performance and population demographics observed at lower levels.

Riparian tree cover offers a potential mitigation against extreme high temperatures and has been suggested as a management tool under climate change. Riparian planting is also widely advocated as a general habitat improvement method, especially by fisheries groups who have obtained substantial European funding to carry out such measures. Despite these factors, the effects of riparian woodland on stream temperatures and ecological processes remain poorly understood.

This paper reports the results of a 3 year study into the effects of riparian woodland on stream temperatures and has been suggested as a management tool under climate change. Riparian planting is also widely advocated as a general habitat improvement method, especially by fisheries groups who have obtained substantial European funding to carry out such measures. Despite these factors, the effects of riparian woodland on stream temperatures and ecological processes remain poorly understood.

This paper reports the results of a 3 year study into the effects of riparian woodland on stream temperatures and ecological processes remain poorly understood.

Methods
Stream temperatures were monitored at two open moorland sites (HB, OW, Fig. 1) and three riparian woodland sites moving progressive downstream (FB 0.75km, LM 1.5km, FAWS 2km, Fig. 1). A further datalogger was located in the only significant tributary stream in the lower catchment (BB). Stream temperatures were recorded at 15 minute intervals using Cemini Telemetry Plus 2 high-resolution temperature dataloggers, with integrated thermistors. Data logging units were cross-calibrated and found to be in agreement to within ± 0.1°C. Stream temperatures were recorded at 15 minute intervals. Summarry statistics were produced for time periods where data was complete.

Results
Hydrological and climatological context
Monitoring was carried out over 36 months, each monitoring year ran from April to March. The three years were characterised by markedly different hydrological and climatological conditions. 2003/04 was characterised by a hot summer and cold winter (Fig 2a), with low flow conditions throughout (Fig 2b). 2004/05 was considerably wetter year characterised by relatively high flows, low summer and high winter air temperatures. 2005/06 was characterised by intermediate conditions. Winter high flows were comparable with 2003/04, but summer flow conditions were intermediate to the low flows of 2003 and the relatively high flows of 2004. Summer air temperatures in 2005/06 exceeded those in the other years and winter temperatures were comparatively low with those of 2003/04.

Figure 2 Monthly air temperatures (A) and flow duration curves (B) for the 3 monitoring years.

Temporal and spatial variability of stream temperatures
Figure 3 shows the temporal variability of mean, maximum and minimum monthly temperatures at each of the six temperature monitoring locations. Only small inter-site differences in mean monthly temperatures were observed between October and May in each of the 3 years (Fig 3a). Notable differences became apparent in June and were most marked in August. During the summer of 2003, mean temperatures declined from the OW/BB moorland sites with progressive decrease downstream through the forest. Similar patterns were observed in Summer 2004 and 2005 although inter-site differences were much less marked during 2004 and the OW site exhibited higher mean temperatures than HB during 2005. In all years where data was available, the BB site exhibited markedly lower mean summer and higher mean winter temperatures than the other sites.

Inter-site differences in maximum monthly temperatures were substantial (Fig 3b). These again exhibited a clear gradient with distance downstream, from HB to the FAWS. Winter maxima were similar between sites, with notable differences being apparent from April to October. Inter-site differences in maximum temperatures at the summers of 2003 and 2005 were greater than those in the summer of 2004. Where data was available, the BB tributary site again exhibited the lowest temperatures.

Figure 3 shows the temporal variability of mean, maximum and minimum monthly temperatures at each of the six temperature monitoring locations. Only small inter-site differences in mean monthly temperatures were observed between October and May in each of the 3 years (Fig 3a). Notable differences became apparent in June and were most marked in August. During the summer of 2003, mean temperatures declined from the OW/BB moorland sites with progressive decrease downstream through the forest. Similar patterns were observed in Summer 2004 and 2005 although inter-site differences were much less marked during 2004 and the OW site exhibited higher mean temperatures than HB during 2005. In all years where data was available, the BB site exhibited markedly lower mean summer and higher mean winter temperatures than the other sites.

Figure 3 shows the temporal variability of mean, maximum and minimum monthly temperatures at each of the six temperature monitoring locations. Only small inter-site differences in mean monthly temperatures were observed between October and May in each of the 3 years (Fig 3a). Notable differences became apparent in June and were most marked in August. During the summer of 2003, mean temperatures declined from the OW/BB moorland sites with progressive decrease downstream through the forest. Similar patterns were observed in Summer 2004 and 2005 although inter-site differences were much less marked during 2004 and the OW site exhibited higher mean temperatures than HB during 2005. In all years where data was available, the BB site exhibited markedly lower mean summer and higher mean winter temperatures than the other sites.

Inter-site differences in maximum monthly temperatures were substantial (Fig 3b). These again exhibited a clear gradient with distance downstream, from HB to the FAWS. Winter maxima were similar between sites, with notable differences being apparent from April to October. Inter-site differences in maximum temperatures at the summers of 2003 and 2005 were greater than those in the summer of 2004. Where data was available, the BB site again exhibited the lowest temperatures.

Figure 3 shows the temporal variability of mean, maximum and minimum monthly temperatures at each of the six temperature monitoring locations. Only small inter-site differences in mean monthly temperatures were observed between October and May in each of the 3 years (Fig 3a). Notable differences became apparent in June and were most marked in August. During the summer of 2003, mean temperatures declined from the OW/BB moorland sites with progressive decrease downstream through the forest. Similar patterns were observed in Summer 2004 and 2005 although inter-site differences were much less marked during 2004 and the OW site exhibited higher mean temperatures than HB during 2005. In all years where data was available, the BB site exhibited markedly lower mean summer and higher mean winter temperatures than the other sites.

Summary
Stream temperatures were monitored at 2 open and 3 woodland sites at distances ca. 0.75, 1.5 and 2km downstream of the first riparian trees over 3-12 month periods.

Inter-site differences in thermal regime were most marked in drier hotter years. Riparian woodland reduced summer mean and maximum temperatures and increased summer minimum temperatures, effectively moderating temperature extremes compared with open sites.

Inter-site variability in fish performance was not consistent with stream temperature differences, with most moderation observed within the first 1.5km. Inter-site variability in fish performance was small compared to the effects of density in this study. Further research is required to separate these effects.

Figure 5 shows mean and 95% normal confidence limits for 5 cohorts of salmon (juveniles hatching during 2001-2005). The 2001, 2002 and 2005 cohorts did not exhibit significant inter-site differences in terms of performance. 2003 and 2004 cohorts diverged from a common origin and were significantly different between open and forested sites. Where divergence occurred, fish were on average smaller at the forested site. It was observed that the majority of size divergence occurred at the fry (0+) stage and was then maintained in subsequent years.

Summary
Stream temperatures were monitored at 2 open and 3 woodland sites at distances ca. 0.75, 1.5 and 2km downstream of the first riparian trees over 3-12 month periods.

Inter-site differences in thermal regime were most marked in drier hotter years. Riparian woodland reduced summer mean and maximum temperatures and increased summer minimum temperatures, effectively moderating temperature extremes compared with open sites.

Inter-site differences in thermal regime were most marked in drier hotter years. Riparian woodland reduced summer mean and maximum temperatures and increased summer minimum temperatures, effectively moderating temperature extremes compared with open sites.

Inter-site variability in fish performance was not consistent with stream temperature differences, with most moderation observed within the first 1.5km. Inter-site variability in fish performance was small compared to the effects of density in this study. Further research is required to separate these effects.

Figure 5 shows mean and 95% normal confidence limits for 5 cohorts of salmon (juveniles hatching during 2001-2005). The 2001, 2002 and 2005 cohorts did not exhibit significant inter-site differences in terms of performance. 2003 and 2004 cohorts diverged from a common origin and were significantly different between open and forested sites. Where divergence occurred, fish were on average smaller at the forested site. It was observed that the majority of size divergence occurred at the fry (0+) stage and was then maintained in subsequent years.

Summary
Stream temperatures were monitored at 2 open and 3 woodland sites at distances ca. 0.75, 1.5 and 2km downstream of the first riparian trees over 3-12 month periods.

Inter-site differences in thermal regime were most marked in drier hotter years. Riparian woodland reduced summer mean and maximum temperatures and increased summer minimum temperatures, effectively moderating temperature extremes compared with open sites.

Inter-site variability in fish performance was not consistent with stream temperature differences, with most moderation observed within the first 1.5km. Inter-site variability in fish performance was small compared to the effects of density in this study. Further research is required to separate these effects.