



**Systematic Review CEE 08-008**  
*(previously SR45)*

**WHAT ARE THE EFFECTS OF WOODED RIPARIAN ZONES ON  
STREAM TEMPERATURE?**

**DRAFT REVIEW**

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## COVER SHEET

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## 1 Summary

2  
3 Current evidence suggests that temperate stream water temperature is likely to increase with  
4 estimated climate warming. Increased stream temperature will have a number of direct and  
5 indirect impacts on stream biota, among which changes in fish mortality are of major  
6 ecological and socio-economic concern. A potential intervention for mitigating stream  
7 temperature rise is the use of wooded riparian zones to increase shade and reduce direct  
8 warming through solar radiation. In order to assess the effectiveness of this intervention we  
9 conducted a systematic review of the available evidence for the effects of wooded riparian  
10 zones on stream temperature.

11  
12 **Methods:** We systematically searched literature databases, carried out web searches and  
13 interrogated relevant websites using the following search terms (where \* denotes a wild card  
14 term): ((stream\* or river\*) and (forest\* or wood\*) and (afforest\* or harvest\* or logg\*) and  
15 (temperature\*)); (riparian) AND temperature\* AND (logg\* OR harvest\* OR tree\* OR shad\*  
16 OR wood\* or forest\*). Inclusion criteria were: subject - any stream in a temperate climate;  
17 intervention - presence of trees in the riparian zone; comparator - absence of trees in the  
18 riparian zone; outcome measure - stream temperature. Included studies were sorted into 3  
19 groups based on the scale of the intervention and design of the study. Two groups were taken  
20 forward for synthesis; Group 1 studies comparing water temperature in streams with and  
21 without buffer strips/riparian cover and Group 2 comparisons of stream temperatures in open  
22 and forested landscapes. Temperature data were extracted from each study and quantitative  
23 synthesis performed using a random effects meta-analysis with weighting by inverse variance  
24 to calculate the average effect size and its 95% confidence interval. Analysis was conducted  
25 on the differences in average and maximum temperature.

26  
27 **Results:** The search identified 42 articles of relevance to the review question. Ten studies  
28 were included in each of Groups 1 and 2. Results for both groups suggest that riparian  
29 wooded zones lower spring and summer stream temperatures. Lowering of maximum is  
30 greater than lowering of mean temperature. The magnitude of effect is likely to be  
31 ecologically/physiologically relevant for indigenous fish species. Further analysis of key  
32 environmental variables that might modify the effects of the intervention was not possible  
33 using the current set of studies.

34  
35 **Review conclusions:** wooded riparian zones can reduce stream temperatures, particularly in  
36 terms of maximum temperatures. In addition, since temperature is known to affect fish and  
37 invertebrate life history, the reported effect sizes are likely to have a biological significance  
38 for the stream biotic community. Consequently investment in creation of wooded riparian  
39 zones might provide benefits in terms of mitigating some of the ecological effects of climate  
40 change on water temperature. Considerable uncertainty lies in the environmental variables  
41 that may modify the cooling effect of wooded riparian zones, and therefore it is not possible  
42 to identify when the use of trees for cooling would be most valuable. The challenge for  
43 research is to enable better prediction of the effect of such an intervention across the full  
44 range of rivers and streams, as well as to provide information on the most effective design of  
45 riparian buffer. Future research would be facilitated by standardisation of study design and  
46 reporting standards, particularly regarding the selection of temperature sampling sites, the  
47 presentation of means and variances over time and space and the reporting of other key  
48 environmental site variables that can be expected to modify the effect size of the presence of  
49 trees in the riparian zone.

50

## 51 Introduction

52

53 There is a growing body of evidence to suggest that stream water temperature may be  
54 increasing (Kaushal et al. 2010). Increased stream temperature can have direct effects on  
55 poikilothermic organisms, such as fish, through changes in metabolism and ultimately  
56 mortality rates. There has been a particular concern that extreme summer temperatures, which  
57 may increase further with climate change, can increase fish mortality (Malcolm et al. 2008).  
58 Additionally, changes in riparian temperature can have a diverse range of impacts on primary  
59 productivity and decomposition, and may lead to changes in the structure and functioning of  
60 the whole biotic community (Pusey and Arthington 2003; Durance and Ormerod, 2007).  
61 Although, the relative importance of water temperature, compared to other environmental  
62 factors that may also be changing, can be difficult to isolate (e.g. Malcolm et al. 2008).  
63 Notably, riparian habitat can affect the amount of solar (shortwave) radiation received by the  
64 stream (i.e. the dominant heat flux) and so removal of tree cover may lead to an increase in  
65 water temperature (Moore et al., 2005). In addition to energy receipt, other factors including  
66 hydraulic retention time and hydrological fluxes, especially ground water inflow or outflow,  
67 may also affect stream temperature (Ward, 1985; Caissie, 2006; Hannah *et al.*, 2004; Webb *et*  
68 *al.*, 2008), and affect the importance of riparian habitat for water temperature.

69 The riparian zone is the transition zone between a freshwater and terrestrial ecosystem  
70 (Naiman and Décamps, 1997). The unique, dynamic and complex nature of riparian habitat  
71 means that it can support relatively high biodiversity and hence can be important for  
72 conservation management (Pusey and Arthington, 2003). Changes in land use and river  
73 regulation may have led to a reduction in wooded riparian habitats next to rivers and streams;  
74 evidence is largely anecdotal but in many heavily grazed areas there is clearly little natural  
75 regeneration of trees to replace any lost through windthrow or bank erosion. Different  
76 activities have contributed to the declining riparian woodland, such as logging for timber  
77 (Young, 2001) and livestock grazing and trampling (Belsky et al. 1999). Increasingly, there is  
78 concern that degradation of this habitat, and loss of riparian trees, may lead to a reduction in  
79 the abundance and diversity of species in the aquatic environment (Pusey and Arthington,  
80 2003).

81 The riparian zone can play a key role in the functioning of the aquatic ecosystem,  
82 affecting chemical, physical and biological processes (Naiman and Décamps 1997; Pusey and  
83 Arthington, 2003). Therefore, degradation of this environment has implications for many  
84 different aspects of river function and services, such as a loss of bank stability leading to  
85 increased erosion and chemical leaching from the surrounding land. One potentially major  
86 impact of riparian habitat on stream functioning is on water temperature (Moore et al. 2005;  
87 Hannah et al. 2008).

88 Management interventions have been proposed to limit the consequences of riparian  
89 degradation, such as the use of riparian buffer strips (Osborne and Kovacic, 1993; Haycock  
90 and Muscutt, 1995) or livestock exclusion fencing (Belsky et al. 1999). Empirical research  
91 has been carried out to explore the importance of the riparian habitat and several reviews  
92 have been published addressing issues on this topic such as the effects of logging (Young  
93 2001) and livestock (Belsky et al. 1999) on stream and riparian ecosystems, and the  
94 relationship between stream temperature and forest harvesting (Moore et al. 2005).

95

96 Restoration of riparian trees has been proposed as a means of increasing shade and countering  
97 rising stream temperature in the context of unavoidable climate change (Wilby *et al.*, 2010).  
98 However, the scientific basis for these management decisions is limited with respect to  
99 stream temperature due to a lack of both primary data and understanding of key physical  
100 process to inform predictive modelling of land use change (Hannah *et al.*, 2008)

101  
 102 This review examines the empirical evidence for the relationship between wooded riparian  
 103 cover and stream temperature. CEE systematic review guidelines were used to  
 104 comprehensively search for data, critically appraise the quality of study and quantitatively  
 105 synthesise and compare the outcomes of different studies.  
 106  
 107

## 108 **2. Objectives**

109  
 110 What are the effects of wooded riparian zones on stream temperature?  
 111

112 For the purpose of conducting the systematic review the primary question was broken down  
 113 into the following defined elements.  
 114

<b>Subject</b>	<b>Intervention</b>	<b>Comparator</b>	<b>Outcome</b>
Streams in a temperate climate	Trees in the riparian zone	Presence versus absence of trees in the riparian zone	Stream temperature

## 115 116 117 **3. Methods**

### 118 119 **3.1 Search strategy**

#### 120 121 **3.1.1 Databases**

122 Searching for relevant research data was conducted using a range of databases and document  
 123 types (peer-reviewed, theses, grey literature) to ensure a comprehensive and, as much as  
 124 possible, unbiased sample of the relevant literature was obtained. In each case, no time or  
 125 document type restrictions were applied. The following databases were used:  
 126

127 Agricola, CAB abstracts, Conservation evidence, Copac, Index to Thesis on-line, Science  
 128 Direct, Web of Science  
 129

#### 130 **3.1.2 Web sites**

131 An internet search was undertaken using the following web sites:  
 132

133 United States Forest Service, Unites States Fish and Wildlife Service, Environment Agency,  
 134 Scottish Natural Heritage, European Environment Agency. World Wildlife Fund, Norwegian  
 135 Water Resources and Energy Directorate, Centre for Ecology and Hydrology, Forest  
 136 Research, River Restoration Centre, Freshwater Biological Association, Marine Scotland,  
 137 Centre for Environment, Fisheries and Aquaculture Science, Forest Commission, Scottish  
 138 Environment Protection Agency, Countryside Council for Wales and the Tweed Foundation.  
 139 We also used Google to perform a general internet search.  
 140

141 Experts in the field, identified by review team members, were also contacted directly for  
 142 suggestions of relevant studies.  
 143

144 **3.1.3 Search terms**

145 The following search terms (where \* denotes a wild card term) were used to search the  
146 databases.

147 ((stream\* or river\*) and (forest\* or wood\*) and (afforest\* or harvest\* or logg\*) and  
148 (temperature\*))

149

150 (riparian) AND temperature\* AND (logg\* OR harvest\* OR tree\* OR shad\* OR wood\* or  
151 forest\*)

152

153 For the web sites, either all publication titles were scanned or search words, such as  
154 'riparian' and/or 'water temperature' used to search the site, depending on the search  
155 capability of the website and the number of publications.

156

157 **3.2 Study inclusion criteria**

158 References captured from computerised databases were imported into an *Endnote* library and  
159 duplicates were removed. The following inclusion criteria were applied to each article:

160

161 Relevant subject(s): Any stream in a temperate climate

162

163 Types of intervention: Presence of trees in the riparian zone

164

165 Types of comparator: Absence of trees in the riparian zone

166

167 Types of outcome measured: Stream temperature

168

169 In the first instance, the inclusion criteria were applied to title only to efficiently remove  
170 clearly irrelevant citations. Articles remaining were filtered further by viewing abstracts and  
171 then full text, to reach the final list of relevant articles. Two reviewers repeated the  
172 application of inclusion criteria on a subset (205 papers) at title and abstract reading level to  
173 ensure repeatability, calculated a kappa statistic of 0.54 and any discrepancies were resolved.  
174 After Kappa, the rules for title and abstract inclusion were clarified between the reviewers  
175 (exclusion of studies that only mention lakes, tropical climates,  
176 channelization/restoration/grazing/fires/hurricanes, unless it clearly created differences in  
177 riparian tree cover, or no indication of water temperature measurement in the abstract)

178

179 Studies that met the inclusion criteria of the review were pooled into three groups:

180

181 1) Studies comparing water temperature in reaches/streams with buffer strips versus  
182 reaches/streams without buffer strips. Usually this comparison was created following logging  
183 (i.e. the comparison was streams that were fully logged versus streams which were logged but  
184 a buffer strip was left) but there a study (Parkyn et al. 2003) that involved the deliberate  
185 planting of buffer strips in comparison to a site without planting and a study that focused only  
186 on the effect of open/shaded riparian cover (Broadmeadow et al. 2010).

187 2) Studies comparing water temperature in reaches/streams through meadows/moorland  
188 versus forests/plantations.

189 3) Studies aiming to investigate the effects of forest harvesting and therefore comparing  
190 water temperature in logged versus unlogged (i.e. undisturbed) reaches or catchments.

191

192

### 193 **3.4 Study characterisation and quality assessment**

194 Basic information was extracted from articles (from groups 1 and 2), when available, which  
195 included details of location of study (country and catchment/ river name), type of forest (as  
196 described by the author), type of study (before and after, inter-site comparison), intervention  
197 type (logging, buffer following logging, planted, experimental [i.e. the change in tree density  
198 was a manipulation performed by the researcher] etc.), number of catchments/streams,  
199 pairing of sites, presence of confounders/other managements, times of data collection and the  
200 presentation of data that would be suitable for meta-analysis. For group 3, information has  
201 also been recorded, when available, on buffer width and length, aspect of sites, stream width,  
202 elevation, stream discharge, habitat (e.g. pool-riffle) and stream order.  
203

### 204 **3.4 Data extraction and analysis**

205  
206 Temperature data were extracted from articles or obtained from the author. In most cases, the  
207 observed temperature measurements could be extracted; exceptions were two studies  
208 presenting temperature change between upstream and downstream (Wilkerson and Hagan  
209 2006; Shrimpton et al. 2000) or one study presenting temperatures change from a forest  
210 control (Lynch et al. 1984). Effect sizes from studies were calculated as the difference  
211 between average temperature in the streams with trees and average temperature in streams  
212 without trees in the riparian zone (or difference in the temperature change in the case of the  
213 three studies cited above). We used a non-standardised metric as all studies measured  
214 temperature in the same units (degrees Celsius = °C). The variance of the effect size was  
215 calculated as the standard error of the difference between the means. Standard error for each  
216 mean was extracted when possible from the article (if multiple variances were presented,  
217 their average, and then the standard error was calculated) or calculated using temperature data  
218 presented; sample size was the number of reaches in each group. In the case of buffer  
219 studies, if there was more than one buffer width in a study, effect sizes were calculated  
220 separately for each width. Effect sizes of the average difference in maximum temperature  
221 are based on either average daily maximum or maximum observed over the study period  
222 depending on how the data were presented (in some studies this was not clearly reported). To  
223 separate effect sizes by seasons, we followed the classification of spring and summer of the  
224 author; in cases when this was not stated, we labelled spring as March -May, and summer as  
225 June-August (all included studies collected data in the Northern Hemisphere). Spring and  
226 summer were considered as the focus of the review was on higher temperatures due to their  
227 potentially lethal effects on biota. For the same reason, minimum temperature was not  
228 considered as a measure of thermal response to riparian land cover.  
229

230 For groups 1 and 2 Six analyses have been run for each group of studies: (1) averages based  
231 on any/all data available (2) maximums based on any/all data available; (3) as 1 except for  
232 spring data only; (4) as 2 except for spring data only; (5) as 1 except for summer data only;  
233 (6) as 2 except for summer data only. Data from Group 3 were not extracted/analysed (see  
234 section 4.4)  
235

236 The basic analysis (1) was a random effects meta-analysis with weighting by inverse variance  
237 to calculate the average effect size and its 95% confidence interval (see Table 1). We ran a  
238 series of analyses to verify the robustness of these results. (2) An unweighted analysis with  
239 the same total error as the weighted analysis; this was to test whether the assumption of  
240 comparability of the variance calculation of different studies was important. (3) Analysis 1  
241 repeated on the aggregated data set (i.e. averaging over multiple data points from the same

242 article) to account for issues of non-independence. We also performed (4) a test for the  
243 presence of publication bias, as indicated by a relationship between the effect size and  
244 precision (inverse variance of effect size), using the (Egger's test; Egger et al. 1997) on the  
245 aggregated data set when there was at least four articles in the analysis. Using Stata's  
246 "Metainf" function (5), we tested the effect of removing each effect size, one-by-one in turn,  
247 on the average effect obtained by the meta-analysis of analysis 1 to verify that the results  
248 from single studies were not driving the overall average results. Finally (6), for studies in  
249 Group 1, we tested the relationship between buffer width and effect size with metaregression,  
250 which can be regarded as the same as standard regression (investigating whether the slope of  
251 the relationship significantly differs from zero) but individuals points (i.e. effect sizes) are  
252 weighted by their inverse variance, following the standard procedure of meta-analysis.  
253  
254  
255

## 256 **4. Results**

### 257 **4.1 Review statistics**

258  
259 An initial search was conducted on 22<sup>nd</sup> December 2008. The search was updated on the 5<sup>th</sup>  
260 August 2010 using the main databases from the first search. The initial search found a total of  
261 1042 articles and the updated search found an additional 137 articles (including 4 articles  
262 suggested by experts, 3 which had only been published online and so had not yet been added  
263 to databases and one which was not picked up by the search terms) (see Appendix A for  
264 details of search results). Of those articles captured in the initial search, 293 articles passed  
265 title and abstract inclusion, of which 204 were successfully retrieved and read at full text. Of  
266 the articles captured in the updated search 24 passed the title and abstract inclusion.  
267 Following full text assessment, and assessment of articles from which data could be  
268 extracted, 39 articles were initially included in the review. The updated search found three  
269 additional articles.  
270  
271

### 272 **4.2 Group 1: Studies comparing water temperature in streams with and without buffer 273 strips/riparian cover.**

274  
275 Ten articles were identified following full text assessment, and from which data could be  
276 retrieved. These studies were conducted in USA (4), Canada (3), New Zealand (2) and UK  
277 (1). Eight were site comparison studies while the remaining two also had before-after data  
278 (BACI design). The interventions were: buffers created following harvesting (5 studies; in 2  
279 cases the buffer was experimentally removed [i.e. the manipulation was performed by the  
280 researcher] for comparison); experimental buffer manipulations (3); planted buffer schemes  
281 (1) and a comparison of 'open' versus 'shaded' riparian zones (1). See Appendix B for  
282 further details on these studies.  
283

284 Analysis was conducted on the differences in average and maximum temperature. Firstly,  
285 data from all months were analysed together to maximise the number of studies in each  
286 analysis. Secondly, spring and summer months were analysed separately. See Appendix C  
287 for the forest plots of each parameter analysis.  
288

289 The overall mean difference in mean temperature of streams with and without a buffer strip  
290 was 0.39°C (95 % CI = -0.13, 0.91). The effect size is larger for maximum temperature than  
291 mean temperatures (Table 1). Maximum temperature was 3.16°C lower in the presence of

292 buffer strips (95 % CI = 2.06, 4.27). There was no evidence that the effect varied among  
293 different studies (no significant heterogeneity) in the weighted analysis. However, there was  
294 some evidence of variation in the summer mean and maximum differences among the results  
295 of different studies in the unweighted analysis. This was probably because the studies  
296 reporting the largest effect sizes were downweighted in the weighted analysis because of their  
297 greater variance.

298

299 The pattern in temperature difference is reflected in the spring and summer means and  
300 maxima. Small sample sizes restrict further analysis but average differences in maximum  
301 temperature in the order of 2–3°C are typical for both seasons. The outcomes appear  
302 reasonably robust to whether studies are weighted by inverse of variance, and the results were  
303 not driven by data from single studies.

304

305 Metaregression found no significant effect of buffer width but the statistical power was low  
306 because of the low number of studies. In all analyses, the coefficient was positive, which  
307 indicates that the difference in temperature tended to increase with greater buffer widths.

308

#### 309 **4.3 Group 2: Comparison of streams temperatures in open and forested landscapes.**

310

311 Ten studies were identified following full text assessment, and from which data could be  
312 retrieved (see Appendix D). These studies were in: New Zealand (3), UK (2), USA (2),  
313 Ireland (1), Spain (1) and Denmark (1). All were site comparisons. See Appendix C for  
314 further details on these studies. See Appendix E for the forest plots of each parameter  
315 analysis.

316

317 The overall mean difference in mean temperature of open-landscape and forested streams is  
318 1.48 °C (95 % CI = 0.60, 2.36). The effect size is larger for maximum temperature than mean  
319 temperatures (Table 2). Maximum temperature was 4.94°C, lower in the presence of forest  
320 (95 % CI = 2.70, 7.17). However, there is evidence that the effect varied among different  
321 studies (significant heterogeneity). Compared with Group 1 the effects sizes for mean and  
322 maximum temperature were markedly larger.

323

324 As with Group 1, the patterns in the seasonal means and maxima are similar to those of the  
325 annual values. Small samples sizes restrict further analysis. Unweighted figures suggests the  
326 weighting of effect sizes (by inverse variance) did not fundamentally alter the outcome of the  
327 synthesis, which suggests these results are robust to the assumption of comparability of  
328 variance calculation from different studies made by the meta-analysis. However, there was  
329 some evidence that single studies modified the magnitude of the effect size, increasing or  
330 decreasing it, but even so the general interpretation of the average was not affected.

331

**Table 1. Summary temperature data (°C) from synthesis of Group 1: Local scale studies**

Variable	No. of effect sizes (no. independent articles)	Range	(1)Weighted average (* = Heterogeneity P<0.05)	(2)Unweighted average (* = Heterogeneity P<0.05)	(3)Aggregated weighted average (* = Heterogeneity P<0.05)	(4) Pub Bias? p-value of Egger's test (on aggregated data)	(5) Metafns= no study has significant effect on omission	(6) Effect of buffer width? P-Value Coef and its SE
ALL mean	8 (6)	0 – 0.74	0.39 (-0.13, 0.91)	0.22 (-0.30,0.75)	0.39 (-0.140,0.92)	P=0.60	Ns	P=0.85 coef=0.01 0.06 (SE)
Summermean	5(4)	0.03– 1.36	0.57 (0.14, 1.00)	0.71* (0.25,1.18)	0.63 (0.06, 1.20)	P=0.49	Ns	P=0.62 coef=0.04 0.07(SE)
Springmean	4(3)	0.1– 0.72	0.26 (-0.80, 1.3)	0.29 (-0.77, 1.35)	0.23 (-0.92,1.37)	-	Ns	P=0.79 coef=0.25 0.92 (SE)
ALLmax	9(7)	0.86– 6.99	3.16 (2.06, 4.27)	3.08 (1.91,4.25)	3.37 (1.74, 5.01)	P=0.82	Ns	P=0.44 coef=0.06 0.08 (SE)
Summermax	7(5)	1.79– 8.08	3.26 (2.20, 4.32)	3.42* (1.85,4.98)	3.46 (1.96,4.95)	P=0.53	Ns	P=0.08 coef=0.13 0.07(SE)
Springmax	3(2)	1.48– 3.04	2.60 (0.58, 4.62)	2.30 (0.27,4.32)	2.71 (0.52,4.91)	-	Ns	-

Table 2. **Summary temperature data from synthesis of Group 2:** Large scale studies (meadows/moorland vs forests)

Parameter	No. of effect sizes (no. independent articles)	Range	(1)Weighted average (* = Heterogeneity P<0.05)	(2)Unweighted average (* = Heterogeneity P<0.05)	(3)Aggregated weighted average (* = Heterogeneity P<0.05)	(4) Pub Bias? p-value of Egger's test (on aggregated data)	(5) Metainf ns= no study has a significant effect
ALL mean	10(10)	0.25–5.23	1.48* (0.60, 2.36)	1.68* (0.73, 2.63)	-	P=0.27	yes <sup>1</sup>
Summermean	7(7)	0.75–5.23	1.39 (0.68, 2.10)	2.03* (0.85, 3.21)	-	P=0.43	ns
Springmean	6(6)	-0.05–2.67	1.48* (0.21, 2.76)	1.61* (0.79, 2.42)	-	P=0.97	yes <sup>2</sup>
ALLmax	5(5)	1.37–6.89	4.94* (2.70, 7.17)	4.51* (2.17, 6.84)	-	P=0.52	ns
Summermax	3(3)	1.37–6.27	2.58 (0.25, 4.90)	3.73* (0.95, 6.50)	-	-	ns
Springmax	2(2)	3–6.89	6.610 (4.66, 8.56)	4.95* (1.14, 8.75)	-	-	ns

1 Removal of Harding et al. 2006 decreases the effect size but it is still positive

2Removal of Harding et al. 2006 decreases the effect size while removal of Dineen et al. 2007 increases the effect size

**4.4 Group 3** - Studies aiming to investigate the effects of forest harvesting and therefore comparing water temperature in logged versus unlogged (i.e. undisturbed) reaches or catchments.

This group of studies has more complexity because in many cases, although trees were logged from the riparian zone, this did not necessary lead to a decrease in riparian shade because the logged trees were not always retrieved when they fell across the stream. Some studies reported that trees/woody logging debris was removed while others did not report this issue at all. Because of this problem, investigation of group 3 data would be better conducted as a separate review on the effects of logging rather than included in our review, which is considering the effects of riparian shade. Group 3 is primarily composed of North American/Canadian studies of the effects of logging old growth forests. A list of included articles is provided in Appendix F.

## 5. Discussion

Data from the included studies were broadly in agreement that streams with trees in the riparian zone have a lower average water temperature, and reach lower maximum temperatures, than streams without trees in the riparian zone.

Despite the consistency in the pattern, the strength of evidence this provides depends on the methodological quality of the studies in the analysis. Most of these studies were site comparisons (i.e. they compared the water temperature among streams, or different sections of the same stream, under different wooded riparian zone treatments). Significantly, many did not have baseline data to verify that the stream temperatures were similar in the absence of differences in tree presence. Further experimental manipulation (e.g. Kiffney et al. 2003) of tree presence could provide more reliable estimates of the effect size by accounting for the effects of confounding variables.

Our study was able to estimate the average effect size of the temperature difference across different studies. However, ideally, within a meta-analysis, variation in effect size among studies would be explored. In particular, there was evidence of heterogeneity within the comparison of open and forested landscapes. Information on variables, such as river discharge, stream order, habitat type, aspects and other variables that may affect temperature were reported to varying extents by the articles. Because of this variation in reporting, in combination with the low number of studies, we could not explore the role of these variables on the effect size. Similarly, variation in how water temperature data were reported in the articles, which meant that the same data calculation procedure could not be applied consistently to all studies, could have affected our meta-analysis. However, the general similarity between the patterns of the weighted meta-analysis and unweighted averages indicate this did not introduce serious bias. Standardization of water temperature data presentation, and environmental contextual variables, as listed above, would aid future meta-analysis. We suggest that climate will be a first order driver but basin properties affecting microclimate and hydrology (relative contribution from surface vs. groundwater) and scaling (to thermal capacity) will also be important.

Most of the included studies measured water temperature from a small number of separate reaches. This is perhaps not surprising given the extensive field work that can be involved. However, this feature does mean that it is not possible to make general conclusions based on the findings of a single study. Therefore, the approach of meta-analysis, combining data from

multiple studies, is particularly powerful in this area of research to make more general conclusions on the effects of interventions. Meta-analysis can also be a simpler approach to ask questions such as on the effect of climate types that would be difficult to address within a single study, which are usually focused on one geographic region. However, meta-analysis is still limited by the number of studies reporting data that can be extracted.

## 6. Review Conclusions

### 6.1 Implication for policy

This systematic review provides evidence that wooded riparian zones can reduce stream temperatures, particularly in terms of maximum temperatures. Additionally, since temperature is known to affect fish and invertebrate life history, the reported effect sizes are likely to have a biological significance for the stream biotic community. Consequently investment in creation of wooded riparian zones might provide benefits in terms of mitigating some of the ecological effects of climate change on water temperature. Considerable uncertainty lies in the environmental variables that may modify the cooling effect of wooded riparian zones, and therefore it is not possible to identify when the use of trees for cooling would be most valuable. Variables such as stream width and river discharge (thermal capacity), river basin location (headwater or lowlands) and the degree to which the wider catchment is forested are likely to be critical controls on the efficacy of riparian trees as a temperature moderator. Our analysis also does not inform on how trees should be planted, in terms of buffer width, length of reach requiring a buffer and the types of trees that should be planted, nor on the roles of stand density/age and nature of understory vegetation. The results were broadly similar between group 1 (local scale tree variation e.g. buffers) and group 2 (larger scale tree variation e.g. forest/plantation), at least based on the limited data set we obtained (confidence intervals for the weighted average overlap except for spring maximum); however, our analysis did not specially test for a difference between these two groups, and this clearly requires further investigation. More strategic allocation of resources to riparian intervention requires development of the evidence base on the influence of these variables.

### 6.2 Implication for research

Using basic comparisons of stream temperature between treatment and control sites, it has been possible to demonstrate an effect of wooded riparian zones on both mean and maximum temperatures. The challenge for research is to enable better prediction of the effect of such an intervention across the full range of rivers and streams, as well as to provide information on the most effective design of riparian buffer.

Fundamental process understanding about the energy and hydrological fluxes that determine river temperature in different riparian zone contexts is required. This mechanistic understanding is needed to underpin transferrable, process-based modelling studies and to factor out/ in confounding factors other than riparian tree cover.

Future research would be facilitated by standardisation of study design and reporting standards, particularly regarding the selection of temperature sampling sites, the presentation of means and variances over time and space and the reporting of other key environmental variables that can be expected to modify the effect size of the presence of trees in the riparian zone.

## 7. Potential conflicts of interest and sources of support

No conflicts of interest reported. This review was part supported by a UK Natural Environment Research Council Grant (REF No.?) to ASP.

## 8. Acknowledgements

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## 9. References

- Belsky, A. J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. *Journal of Soil and Water Conservation* 54: 419-431.
- Boegh, E, et al 2009. Modelling the spatial variations of stream temperature and its impacts on habitat suitability in small lowland streams. *Ecohydrology of Surface and Groundwater Dependent Systems: Concepts, Methods and Recent Developments (Proc. of JS.1 at the Joint IAHS & IAH Convention, Hyderabad, India, September 2009)*. IAHS Publ. 328.
- Bott, T. L., J. D. Newbold, et al. 2006. Ecosystem metabolism in Piedmont streams: reach geomorphology modulates the influence of riparian vegetation. *Ecosystems* 9: 398-421.
- Broadmeadow, S.B., et al 2010. The influence of riparian shade on lowland stream water temperatures in southern England and their viability for brown trout. *River Research and Applications* (published online wiley)
- Brown et al. 1971. Water temperature in the Steamboat Drainage. USDA Forest Service Research Paper.
- Brown L. E., Holden, C. L. and Ramchunder, S. J. 2010. A comparison of stream water temperature regimes from open and afforested moorland, Yorkshire Dales, northern England." *Hydrological Processes* 24: 3206–3218.
- Caissie, D. 2006. The thermal regime of rivers: a review. *Freshwater Biology* 51.:1389-1406.
- Curry, R. A., D. A. Scruton, et al. (2002). The thermal regimes of brook trout incubation habitats and evidence of changes during forestry operations." *Canadian journal of forest research* 32: 1200-1207.
- Dineen, G., S. S. C. Harrison, et al. 2007. Growth, production and bioenergetics of brown trout in upland streams with contrasting riparian vegetation. *Freshwater biology* 52: 771-783.
- Durance, I., Ormerod, S.J. 2007. Climate change effects on upland stream macroinvertebrates over a 25-year period. *Global Change Biology* 13, 942-957.
- Graynorth 1979. Effects of logging on stream environments and faunas in Nelson. *New Zealand Journal of Marine and Freshwater Research* 13: 79-109.

Hannah, D.M., Malcolm, I.A., Soulsby, C. and Youngson, A.F. 2004. Heat exchanges and temperature within a salmon spawning stream in the Cairngorms, Scotland: seasonal and sub-seasonal dynamics. *River Research and Applications* 20:635-652

Hannah, D.M., Webb, B.W., Nobilis, F. 2008. River and stream temperature: dynamics, processes, models and implications. *Hydrological processes* 22: 899-901.

Harding, J. S., K. Claassen, et al. 2006. Can forest fragments reset physical and water quality conditions in agricultural catchments and act as refugia for forest stream invertebrates? *Hydrobiologia* 568: 391-402.

Haycock, N.E. and Muscutt, A.D. 2000. Landscape management strategies for the control of diffuse pollution. *Landscape and Urban Planning* 31: 313-321.

Kaushal, S.S., Likens, G.E., Jaworski, N.A., Pace, M.L., Sides, A.M., Seekell, D., Belt, K.T., Secor, D.H. and Wingate, R.L. 2010. Rising stream and river temperatures in the United States. *Frontiers in Ecology and Environment* 8: 461-466.

Keim, R. E. and S. H. Schoenholtz 1999. Functions and effectiveness of silvicultural streamside management zones in loessial bluff forests. *Forest Ecology and Management* 118: 197-209.

Kiffney, P. M., J. S. Richardson, et al. 2003. Responses of periphyton and insects to experimental manipulation of riparian buffer width along forest streams. *Journal of Applied Ecology* 40: 1060-1076.

Lynch, J. A., Rishel, G.B., and Corbett, E.S. 1984. Thermal Alteration of Streams Draining Clear-Cut Watersheds - Quantification and Biological Implications. *Hydrobiologia* 111: 161-169.

Malcolm, I.A., Soulsby, C., Hannah, D.M., Bacon, P.J., Youngson, A.F., Tetzlaff, D. 2008. The influence of riparian woodland on stream temperatures: implications for the performance of juvenile salmonids. *Hydrological processes* 22: 968 – 979.

Moore, R. D., D. L. Spittlehouse, and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting: a review. *Journal of the American Water Resources Association* 41: 813-834.

Naiman, R. J., and H. Decamps. 1997. The Ecology of Interfaces: Riparian Zones. *Annual review of ecology and systematics* 28: 621-658.

Osborne, L.L. and D.A. Kovacic, 1993. Riparian vegetated buffer strips in water quality restoration and stream management. *Freshwater Biology* 29: 243-258.

Parkyn, S. M., R. J. Davies-Colley, et al. 2003. Planted riparian buffer zones in New Zealand: do they live up to expectations? *Restoration ecology* 11: 436-447.

Pusey, B. J., and A. H. Arthington. 2003. Importance of the riparian zone to the

conservation and management of freshwater fish: a review. *Marine & Freshwater Research* 54: 1-16.

Rutherford, J. C., R. J. Davies-Colley, et al. 1999. Stream shade: towards a restoration strategy. Wellington, New Zealand, Department of Conservation: 159 pp.

Sabater, S., J. Armengol, et al. 2000. Algal biomass in a disturbed Atlantic river: water quality relationships and environmental implications. *The Science of The Total Environment* 263: 185-195.

Shrimpton, J.M., Bourgeois, J.F., Quigley, J.T. and Blouw, D.M. 2000. Removal of the Riparian Zone during Forest Harvesting: Are the Effects Cumulative Downstream? In, L. M. Darling, editor. *Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk*, Kamloops, B.C., 15 - 19 Feb., 1999. Volume Two. B.C. Ministry of Environment, Lands and Parks, Victoria, B.C. and University College of the Cariboo, Kamloops, B.C. 520pp.

Storey, R. G. and D. R. Cowley 1997. Recovery of three New Zealand rural streams as they pass through native forest remnants. *Hydrobiologia* 353: 63-76.

Tait, C. K., J. L. Li, et al. 1994. Relationships between Riparian Cover and the Community Structure of High Desert Streams. *Journal of the North American Benthological Society* 13: 45-56.

Ward, J.V. 1985. Thermal characteristics of running waters. *Hydrobiologia* 125: 31-46.

Webb, B. W. and D. T. Crisp 2006. Afforestation and stream temperature in a temperate maritime environment. *Hydrological Processes* 20: 51-66.

Webb, B.W., D.M. Hannah, R.D. Moore, L.E. Brown, and F. Nobilis 2008. Recent advances in stream and river temperature research. *Hydrological Processes* 22: 902-918.

Wilby, R.L., Orr, H., Watts, G., Battarbee, R.W., Berry, P.M., Chadd, R., Dugdale, S.J., Dunbar, M.J., Elliott, J.A., Extence, C., Hannah, D.M., Holmes, N., Johnson, A.C., Knights, B., Milner, N.J., Ormerod, S.J., Solomon, D., Timlett, R., Whitehead, P.J., Wood, P.J. 2010. Evidence needed to manage freshwater ecosystems in a changing climate: Turning adaptation principles into practice. *Science of the Total Environment* 408: 4150-4164.

Wilkerson, E., J. M. Hagan, et al. (2006). "The effectiveness of different buffer widths for protecting headwater stream temperature in Maine." *Forest science* 52: 221-231.

Young, K. 2001. A review and meta-analysis of the effects of riparian zone logging on stream ecosystems in the Pacific Northwest. Centre for Applied Conservation Research, Forest Sciences Department, University of British Columbia, Vancouver.

Appendix A  
Original search

Database	Date search	Search string used	Hits
Agricola	22 <sup>nd</sup> December 2008	Search 1 - Keyword Anywhere Riparian AND Temperature? AND logg? harvest? tree? shad? wood? forest? (“any of these”) Search 2 - Keyword Anywhere stream? river? (“any of these”) AND forest? wood? (“any of these”) AND afforest? harvest? logg? (“any of these”) AND Temperature?	92 hits  41 hits
CAB abstracts (and archive)	22 <sup>nd</sup> December 2008	Search 1 “Free text search” (stream* OR river*) AND (forest* OR wood*) AND (afforest* OR harvest* OR logg*) AND (temperature*) Search 2 “Free text search” (riparian) AND temperature* AND (logg* OR harvest* OR tree* OR shad* OR wood* or forest*)	221 hits  346 hits
Conservat ion Evidence	22 <sup>nd</sup> December	Riparian’ as keyword ‘Temperature’ as keyword ‘Temperatures’ as keyword	11 hits 3 Hits None
Copac	22 <sup>nd</sup> December	Search 1a “stream temperature*” Search 1b: River* temperature* Search 2 riparian temperature*	6 Hits 15 Hits 9 Hits
Index to Theses	22 <sup>nd</sup> December	QUICK SEARCH <i>Riparian and Temperature*</i> QUICK SEARCH ( <i>stream* OR river*</i> ) and ( <i>forest* OR wood*</i> ) AND ( <i>temperature*</i> ) QUICK SEARCH " <i>stream temperature*</i> " OR " <i>river temperature*</i> "	10 hits 0 Hits 10 Hits
Science direct	22 <sup>nd</sup> Dec 08	Search 1 TITLE-ABSTR-KEY ( <i>stream* OR river*</i> ) AND TITLE-ABSTR- KEY ( <i>forest* or wood*</i> ) AND TITLE-ABSTR-KEY ( <i>afforest* OR harvest* or logg*</i> ) AND TITLE-ABSTR-KEY ( <i>temperature*</i> ) Search 2 TITLE-ABSTR-KEY (riparian) AND TITLE-ABSTR-KEY ( <i>temperature*</i> ) AND TITLE-ABSTR-KEY ( <i>logg* OR harvest* OR tree* OR shad* OR wood* or forest*</i> )	21 Hits  57 Hits
All Web of Science databases	22 <sup>nd</sup> December	Topic Search Search 1 (( <i>stream* or river*</i> ) and ( <i>forest* or wood*</i> ) and ( <i>afforest* or harvest* or logg*</i> ) and ( <i>temperature*</i> )) Search 2 (riparian) AND <i>temperature*</i> AND ( <i>logg* OR harvest* OR tree* OR shad* OR wood* or forest*</i> )	190 Hits  543 Hits

Updated search

Database	Date search	Search string used	Hits
Agricola 18	5/8/2010	Search included articles published after 2008 Search 1: Riparian AND Temperature? AND (logg? OR harvest? OR tree? OR shad? OR wood? OR forest?) Search 2: (stream? OR river?) AND (forest? OR wood?) AND (afforest? OR harvest? OR logg?) AND Temperature?	35hits  14 hits
CAB abstracts (and archive)	5/8/2010	Search 1: ((stream* OR river*) AND (forest* OR wood*) AND (afforest* OR harvest* OR logg*) AND (temperature*)) AND yr:[2009 TO 2010] Search 2: ((riparian) AND temperature* AND (logg* OR harvest* OR tree* OR shad* OR wood* or forest*)) AND yr:[2009 TO 2010]	25 hits  65 hits
Science direct	5/8/2010	Searches included articles 2009 to present Search 1 TITLE-ABSTR-KEY (stream* OR river*) AND TITLE-ABSTR- KEY (forest* or wood*) AND TITLE-ABSTR-KEY (afforest* OR harvest* or logg*) AND TITLE-ABSTR-KEY (temperature*) Search2: TITLE-ABSTR-KEY (riparian) AND TITLE-ABSTR-KEY (temperature*) AND TITLE-ABSTR-KEY (logg* OR harvest* OR tree* OR shad* OR wood* or forest*)	5 hits  14 hits
web of science	5/8/2010	Searched years 2009 and 2010 Search 1 TS=((stream* or river*) and (forest* or wood*) and (afforest* or harvest* or logg*) and (temperature*)) Search 2 TS=((riparian) AND temperature* AND (logg* OR harvest* OR tree* OR shad* OR wood* or forest*))	28 hits  80hits

## Appendix B

### Group 1-Local scale studies

For “no. of reaches”, in brackets are additional “treatments” not used in the analysis – either because they were not relevant or because data from another treatment closer to the comparison of interest was available.

BACI=Before-After-Control-Impact site; SC=site comparison

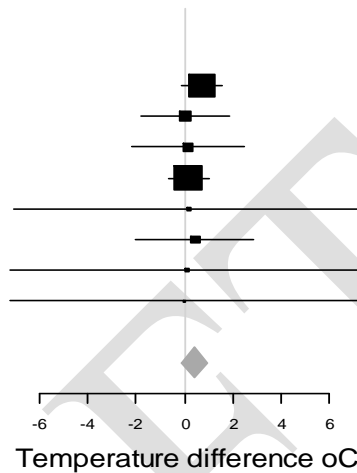
Citation	Locality/Country	Type of forest	Design	Intervention	Buffer width	No. of reaches with cover	No. of clearcut reaches	Site selection	Times/Length of collection
Curry et al. (2002)	Newfound-land, Canada (Copper Lake Watershed)	Northern Temperate forest	BACI	Buffer following harvesting	20m	1  (2 control streams)	1	Within same watershed	monitored before, during and the year following harvesting
Keim and Schoenholtz (1999)	Mississippi, USA (Deep Loess region)	Plantation	SC	Experiment buffer (2 types: Cable only SMZ and No-harvest SMZ) following harvesting	30m each side	6 - 3 of each buffer type  (3 forested controls)	3	Rivers from 12 similar watershed were selected (randomised treatment)	15 months
Kiffney et al. (2003)	British Columbia, Canada (Maple Ridge)	Coastal western hemlock biogeoclimatic zone	SC (BACI for other outcomes though)	Experiment buffer following harvesting	10m and 30m	6 - 3 of each buffer type  (forested controls)	4	Treatments partially randomised between different stream reaches in the research forest	1 year
Lynch et al. (1984)	Pennsylvania, USA (Leading Ridge Watershed Research Unit)	Uneven-aged Oak-hickory forest	SC	Commerical clear cut with buffer versus experimental clearcut	30m	1  (1 forests control)	1	Adjacent watersheds and all have south-easterly aspects and had similar vegetation before harvesting; Precutting data states similar temperature regimes	6 years post treatment
Parkyn et al. (2003).	North Island, Waikato Region, New Zealand	Various (Manuka, Mixed natives, Kanuka, Introduced poplars and willows etc..)	SC	Planted buffer zone schemes (fenced and planted)	3.5 m to 75 m	8	8	Paired along same stream (controls are upstream) (or neighbouring stream in the case of 2 sites) (3 cobble; 3 silt/lowland; 2 pumice)	1-3 weeks in late summer
Wilkerson, et al. (2006).	western Maine, USA	Acadian Forest Regiom	BACI	Experiment buffer following harvesting	11m and 23m	6 - 3 of each  (3 partial cut and 3	3	15 streams selected within the same 100km radius; with mature closed canopy cover and no logging	1 yr before and 2 yr after in the summer

						control)		activity within the past 20 years (treatments randomised within) *Control and partial cut treatments as well	
Shrimpton et al. (2000).	Prince George, British Columbia, Canada (Torpy River watershed)		SC	Buffer following harvesting vs buffer removal (also experimental heat manipulation experiment)	10m	1	1	2 forks of the same creek: reported as having similar slope, aspect, discharge and understory vegetation.	April to Nov
Brown et al. (1971).	Oregon, USA, (Steamboat Creek)	old growth Douglas fir	SC	Buffer following harvesting	Various: 1x 30 ft wide Deep Creek; 1 x 50 ft wide (Deep Cut Creek); 1 x average 47 feet at Little Hock Creek	3	3	Buffer and clearcut sections paired by the same stream	varies between the streams: between July and September
Graynorth (1979)	Nelson, New Zealand (Golden Downs State Forest)	various beech species (buffer catchment)	SC	Buffer following harvesting	wide buffer strip - few trees within 150m of the stream felled. After more felling in 1993 and 1994 a 30m buffer was left.	1 (partial cut and control)	1	Upper and lower sections of the same catchment.	1 year
Broadmeadow et al (2010)	southern England, UK (NewForest)	Broad-leaved woodland; Coniferous plantations	SC	Open versus shaded riparian cover		8 (3 partial shade)	5	Sites along three rivers	3 years

Appendix C. Forest plots - Group 1 Studies comparing water temperature in streams with and without buffer strips/riparian cover

**Study**

Broadmeadow et al. 2010  
 Parkyn et al. 2003 3.5 m to 75m  
 Kiffney et al. 2003 10m  
 Shrimpton et al. 2000 10m  
 Curry et al. 2002 20m  
 Kiffney et al. 2003 30m  
 Keim & Shoenholtz 1999 30m  
 Keim & Shoenholtz 1999 30m Cable-only

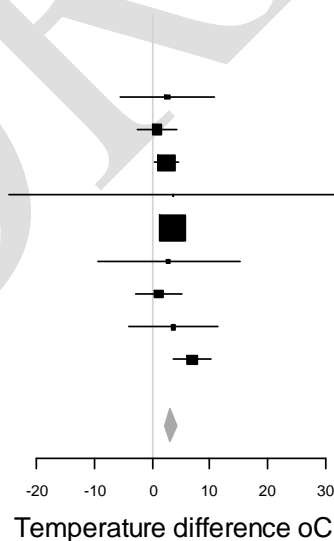


**Summary**

**Fig 1.** forest plot of “effect size” measured as difference between the mean temperatures in the unbuffered compared to buffered streams. Positive effect sizes indicate warmer temperatures without a buffer. By the side of each study citation is given the width of the buffer in that particular study.

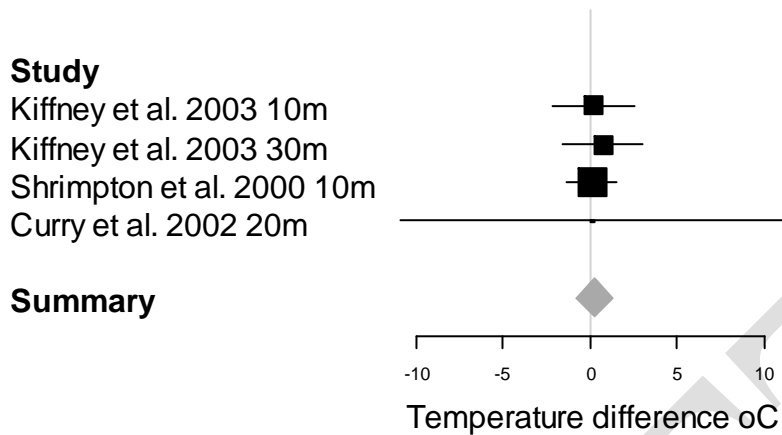
**Study**

Brown 1971 9 to 15m  
 Kiffney et al. 2003 10m  
 Wilkerson et al. 2006 11m  
 Curry et al. 2002 20m  
 Wilkerson et al. 2006 23m  
 Graynorth 1979 30m  
 Kiffney et al. 2003 30m  
 Lynch et al. 1984 30m  
 Broadmeadow et al. 2010

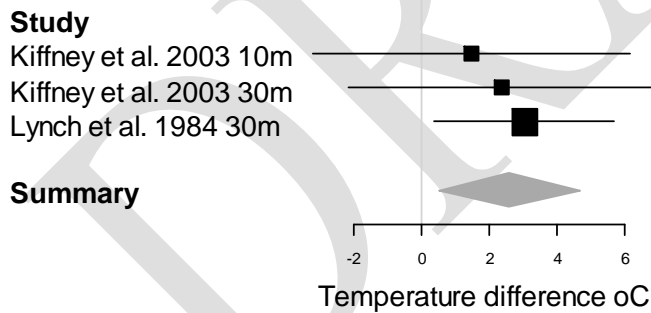


**Summary**

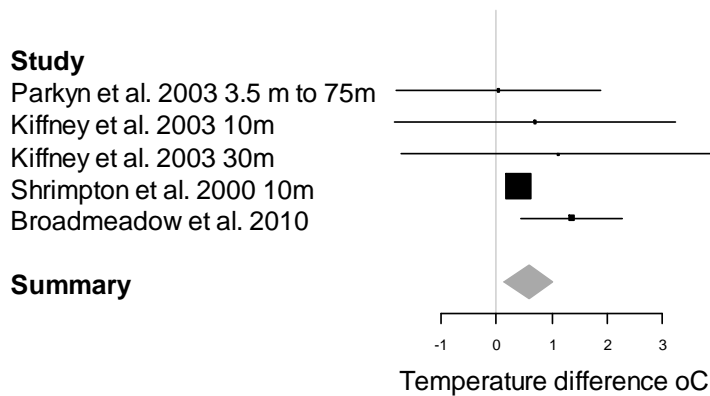
**Fig 2.** forest plot of “effect size” measured as difference between the maximum temperatures in unbuffered compared to buffered streams. Positive effect sizes indicate warmer temperatures without a buffer. By the side of each study citation is given the width of the buffer in that particular study.



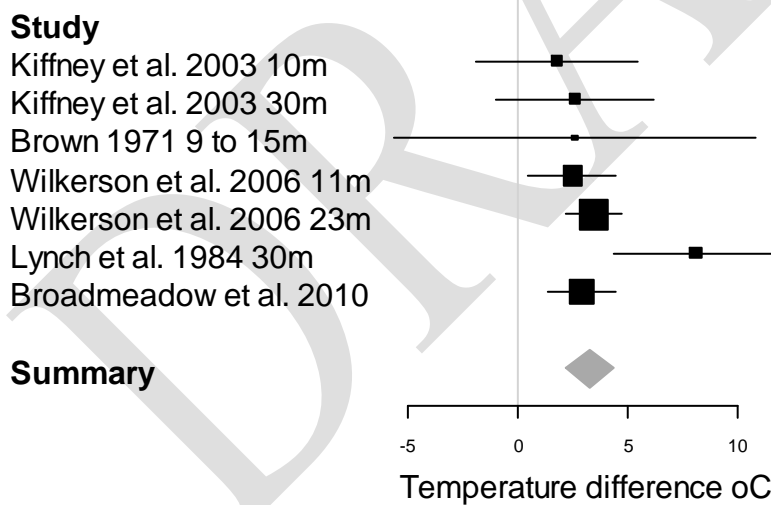
**Fig 3.** forest plot of “effect size” measured as difference between the spring mean temperatures in the unbuffered compared to buffered streams. Positive effect sizes indicate warmer temperatures without a buffer. By the side of each study citation is given the width of the buffer in that particular study.



**Fig 4.** forest plot of “effect size” measured as difference between the spring maximum temperatures in unbuffered compared to buffered streams. Positive effect sizes indicate warmer temperatures without a buffer. By the side of each study citation is given the width of the buffer in that particular study.



**Fig 5.** forest plot of “effect size” measured as difference between the summer mean temperatures in the unbuffered compared to buffered streams. Positive effect sizes indicate warmer temperatures without a buffer. By the side of each study citation is given the width of the buffer in that particular study.



**Fig 6.** forest plot of “effect size” measured as difference between the summer maximum temperatures in unbuffered compared to buffered streams. Positive effect sizes indicate warmer temperatures without a buffer. By the side of each study citation is given the width of the buffer in that particular study.

## Appendix D

### Group 2 –Large scale studies

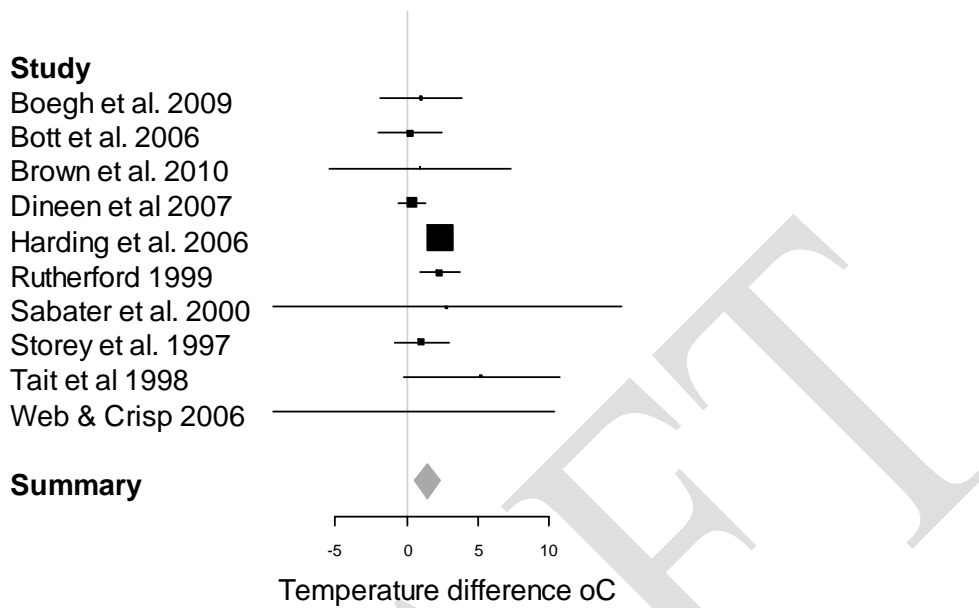
For “no. of reaches”, in brackets are additional “treatments” not used in the analysis

Citation	Locality	Type of forest	Design	Tree comparison	Comparison	No. of reaches with cover	No. of reaches without cover	Times/ Length of data collection
Bott et al. (2006).	Pennsylvania & Maryland, USA (Brandywine, White Clay and Big Elk)	-	SC	forested reach	meadow reaches	13	13	Warm season (May-Oct) and Cold season (Nov-April). Times vary among streams.
Dineen et al. (2007)	County Mayo, Ireland	Forest (willow and alder)	SC	open canopy/closed canopy	grassland	4	2 (2 with open canopy)	spring, summer and autumn
Harding et al. 2006.	Banks Peninsula, New Zealand	Forest (old growth/regenerating indigenous)	SC	continuous forest	agricultural land	2	2	September and October
Rutherford, et al. (1999).	Hakarimata Ranges, New Zealand	Planted pine ( <i>Pinus radiata</i> ) forest catchments & native forest	SC	native forest	Pasture	4 (4 pine forest)	4	1 to 5 weeks in the spring (November)
Sabater et al. (2000). 185-195	Basque Country, Spain (Oria)	-	SC	forested (& nutrient poor)	open (and nutrient rich)	1	1	1 year
Storey and Cowley (1997). "	Auckland City, New Zealand (Kaipara River catchment)	mature secondary forest consisting of mixed kauri; treefern and broadleaf species with a well-established understorey and ground cover	SC	pristine forest stream (but also downstream of forest remnants)	pastoral stream (with forest remnants; sites are upstream)	3	3	Dec- July
Tait et al. (1994)	Oregon, USA (John Day Basin)	streamside vegetation include grasses, sedges, willows, white alder, black cottonwood	SC	closed canopy	open canopy	3 (partial closed canopy)	3	July

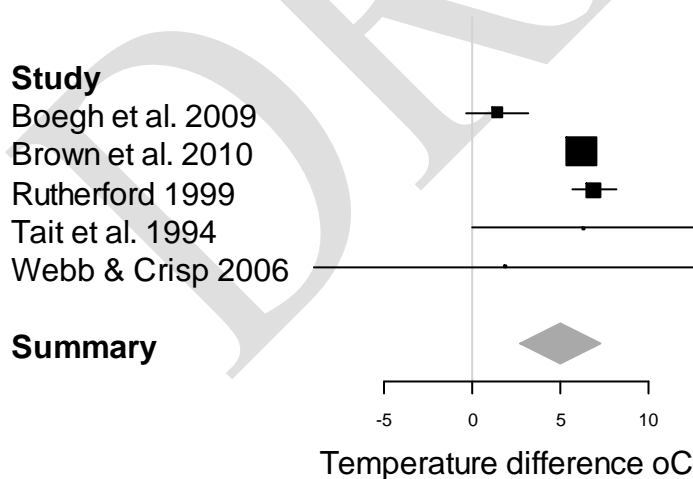
Webb and Crisp (2006).	Galloway, Scotland (Loch Grannoch)	sitka spruce	SC	coniferous forest	moorland stream	1	1	4 years
Brown et al.(2010).	Yorkshire Dales, (England)	Spruce forest	SC	Forest stream	Moorland stream	3	3	2 years
Boegh et al. (2009)	Sjælland, (Denmark)	-	SC	Forest	Grass meadows	1	1	10 days in August

DRAFT

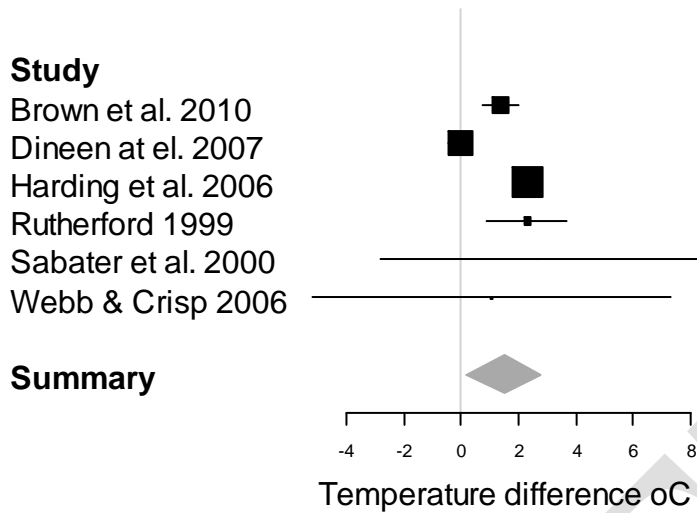
Appendix E. Forest plots - Group 2: Comparison of streams temperatures in open and forested landscapes.



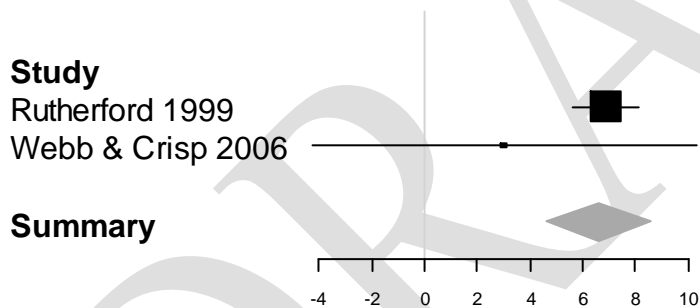
**Fig 1.** forest plot of “effect size” measured as difference between the mean temperatures in the unforested compared to forested streams. Positive effect sizes indicate warmer temperatures without forest. By the side of each study citation is given the width of the buffer in that particular study.



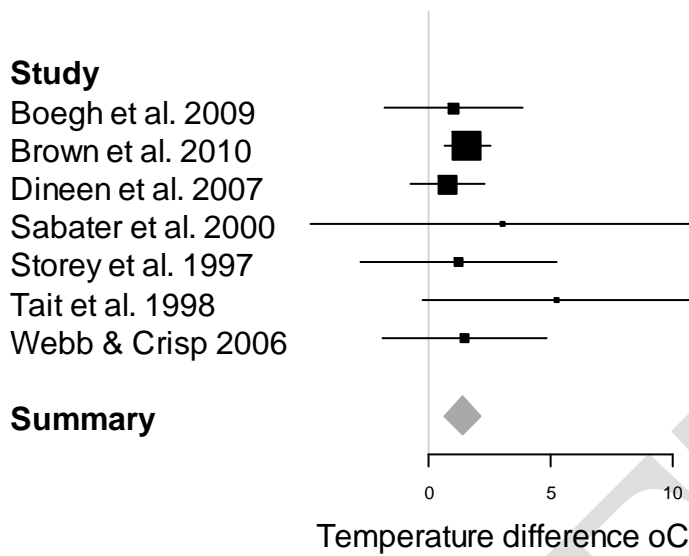
**Fig 2.** forest plot of “effect size” measured as difference between the maximum temperatures in unforested compared to forested streams. Positive effect sizes indicate warmer temperatures without forest. By the side of each study citation is given the width of the buffer in that particular study.



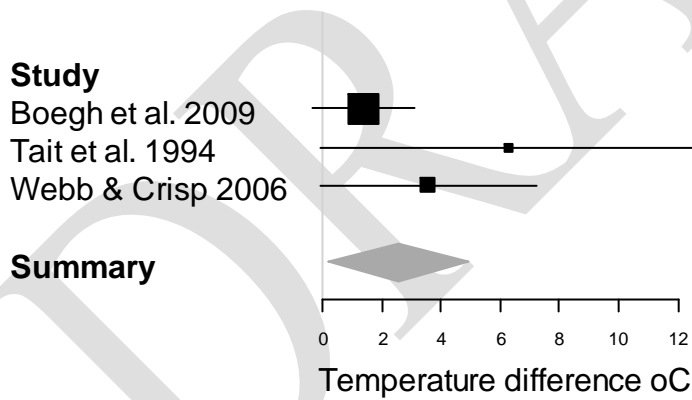
**Fig 3.** forest plot of “effect size” measured as difference between the spring mean temperatures in the unforested compared to forested streams. Positive effect sizes indicate warmer temperatures without forest. By the side of each study citation is given the width of the buffer in that particular study.



**Fig 4.** forest plot of “effect size” measured as difference between the spring maximum temperatures in unforested compared to forested streams. Positive effect sizes indicate warmer temperatures without forest. By the side of each study citation is given the width of the buffer in that particular study.



**Fig 5.** forest plot of “effect size” measured as difference between the summer mean temperatures in the unforested compared to forested streams. Positive effect sizes indicate warmer temperatures without forest. By the side of each study citation is given the width of the buffer in that particular study.



**Fig 6.** forest plot of “effect size” measured as difference between the summer maximum temperatures in unforested compared to forested streams. Positive effect sizes indicate warmer temperatures without forest. By the side of each study citation is given the width of the buffer in that particular study.

## Appendix F: Group 3 - logging studies

Reference	Country	Locality	Catchment	Type of forest	Intervention	BA/SC/BAC I
Baillie, B. R., K. J. Collier, et al. (i2005). "Effects of forest harvesting and woody-debris removal on two Northland streams, New Zealand." <i>New Zealand Journal of Marine and Freshwater Research</i> 39(1): 1-15.	New Zealand	Northland	Mahurangi Forest	Plantation ( <i>Pinus radiata</i> )	harvesting	BACI
Banks, J. L., J. Li, et al. (i2007). "Influence of clearcut logging, flow duration, and season on emergent aquatic insects in headwater streams of the Central Oregon Coast Range." <i>Journal of the North American Benthological Society</i> 26: 620-632.	USA	Central Oregon	Central Oregon Coastal Range (Most of the streams feed tributaries to the North Fork of the Alsea River. Only 1 stream, a headwater of Greasy Creek, ultimately drains into the Willamette River)	Catchments that had not been logged for at least 34 years	logging	SC
Brown, G. W. and J. T. Krygier (i1970). "Effects of clear-cutting on stream temperature." <i>Water Resources Research</i> 6(4): 1133-9.	USA	Oregon	Alea Basin (Needle Branch; Deer creek; Flynn Creek)	-	logging	BACI
Brownlee, M. J., B. G. Shepherd, et al. (i1988). "Some Effects of Forest Harvesting on Water Quality in the Slim Creek Watershed in the Central Interior of British Columbia Canada." <i>Canadian Technical Report of Fisheries and Aquatic Sciences</i> (1613): I-VI, 1-41.	Canada	British Columbia	Slim Creek Watershed	Forest (white spruce, subalpine fir, western red cedar)	harvesting	SC
Burton, T. M. and G. E. Likens (i1973). "The effect of strip-cutting on stream temperatures in the Hubbard Brook Experimental Forest, New Hampshire." <i>BioScience</i> 23(7): 433-435.	USA	New Hampshire	Hubbard Brook Experimental Forest (watershed no. 4)	Northern Hardwood forest	harvesting	SC
Curry, R. A., D. A. Scruton, et al. (i). "The thermal regimes of brook trout incubation habitats and evidence of changes during forestry operations." <i>Canadian journal of forest research</i> July 2002. v. 32 (7): 1200-1207.	Canada	Newfoundland	Copper Lake Watershed	Northern Temperate forest	harvesting	BACI (partial)
Fowler, W. B., J. D. Helvey, et al. (i1987). Hydrologic and climatic changes in three small watersheds after timber harvest. Portland, Oregon, USA, USDA Forest Service: ii + 13 pp.	USA	Oregon	The High Ridges Evaluation Area	Forest (various fir, spruce and larch)	harvesting	BACI
Garman, G. C. and J. R. Moring (i1991). "Initial Effects of Deforestation on Physical Characteristics of a Boreal River." <i>Hydrobiologia</i> 209(1): 29-37.	USA	Maine	(Piscataquis River)	Forest (white spruce and balsam fir)	harvesting	BA

Hartman, G., J. C. Scrivener, et al. (i). "Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain forest stream in British Columbia." Streamside management : forestry and fishery interactions / edited by Ernest O. Salo, Terrance, W: 330-372 ill , maps.	Canada	British Columbia	Carnation Creek	-	logging	BA?
Jackson, C. R., C. A. Sturm, et al. (i2001). "Timber harvest impacts on small headwater stream channels in the coast ranges of Washington." Journal of the American Water Resources Association 37(6): 1533-1549.	USA	Washington	Palix River Basin; Willapa River Basin; Newkah Creek Basin; Humptulips River Basin	Uniformly mature conifers	harvesting	BACI
Keim, R. E. and S. H. Schoenholtz (i1999). "Functions and effectiveness of silvicultural streamside management zones in loessial bluff forests." Forest Ecology and Management 118(1-3): 197-209.	USA	Mississippi	Deep Loess region	Plantation: the silvicultural system in place on the research watersheds, common in the deep loess, is uneven-aged management for the high quality hardwood sawtimber and hardwood pulpwood	Experiment harvesting	SC
Kiffney, P. M., J. S. Richardson, et al. (i2003). "Responses of periphyton and insects to experimental manipulation of riparian buffer width along forest streams." Journal of Applied Ecology 40(6): 1060-1076.	Canada	British Columbia	Maple Ridge (Malcolm Knapp Research Forest)	Forest (conifers are the dominant tree species)	Experiment harvesting	SC
Likens, G. E., F. H. Bormann, et al. (i1970). "Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem." Ecological Monographs 40(1): 23-47.	USA	New Hampshire	Hubbard Brook Experimental Forest (watershed no. 2)	Northern Hardwood forest	Experiment: Vegetation cut and subsequently treated with herbicides	BA
Lynch, J. A., G. B. Rishel, et al. (i1984). "Thermal Alteration of Streams Draining Clear-Cut Watersheds - Quantification and Biological Implications." Hydrobiologia 111(3): 161-169.	USA	Pennsylvania	Leading Ridge Watershed Research Unit	Uneven-aged Oak-hickory forest	Experiment: Clearcut and herbiced watershed	SC
Mellina, E. (i2006). "Stream temperature responses to clearcut logging in the central interior of British Columbia: test of the predictive model developed by Mellina et al. (2002)." Mountain Pine Beetle Initiative Working Paper - Pacific Forestry Centre, Canadian Forest Service(No.2006-8): 32 pp.	Canada	British Columbia	Fraser River and Nation River watersheds	Old Growth	logging	SC

Mellina, E., R. D. Moore, et al. (i2002). "Stream temperature responses to clearcut logging in British Columbia: the moderating influences of groundwater and headwater lakes." Canadian Journal of Fisheries and Aquatic Sciences 59(12): 1886-1900.	Canada	British Columbia	Fraser River and Nation River watersheds	Boreal and subboreal forests	clearcut logging	BACI
Moore, R. D., P. Sutherland, et al. (i2005). "Thermal regime of a headwater stream within a clear-cut, coastal British Columbia, Canada." Hydrological Processes 19(13): 2591-2608.	Canada	British Columbia	Malcolm Knapp Research Forest	Dominated by western hemlock with some western red cedar and Douglas fir		SC
Musslewhite, J. and M. S. Wipfli (i2004). "Effects of alternatives to clearcutting on invertebrate and organic detritus transport from headwaters in Southeastern Alaska." General Technical Report - Pacific Northwest Research Station, USDA Forest Service(No.PNW-GTR-602): i + 28 pp.	USA	Alaska	Hanus Bay	upland old-growth forest (western hemlock and sitka spruce)	Experiment: clearcut logging	BACI
Quinn, J. M., I. K. G. Boothroyd, et al. (i2004). "Riparian buffers mitigate effects of pine plantation logging on New Zealand streams 2. invertebrate communities." Forest ecology and management 191, issues 1-3: 129-146.	New Zealand	Coromandel Peninsula	Whangapoua Forest	-	clearcut logging	SC
Rayne, S., G. Henderson, et al. (i2008). "Riparian Forest Harvesting Effects on Maximum Water Temperatures in Wetland-sourced Headwater Streams from the Nicola River Watershed, British Columbia, Canada." Water resources management 22(5): 565-578.	Canada	British Columbia	North Tributary Creek & West Tributary Creek	Engelmann Spruce; Subalpine Fir, Montane Spruce and Interior Douglas Fir	harvesting	BACI
Rishel, G. B., J. A. Lynch, et al. (i). "Seasonal stream temperature changes following forest harvesting." Journal of environmental quality Jan/Mar 1982. v. 11 (1): 112-116.	USA	Pennsylvania	Leading Ridge Watershed Research Unit	-	Commerical clear cut and Experiment: clearcut herbicide experiment	
Swift, L. W., Jr. and J. B. Messer (i1971). "Forest cuttings raise temperatures of small streams in the southern Appalachians." Journal of Soil and Water Conservation in India 26(3): 111-6.	USA	North Carolina (southern Appalachian Mountains)	Coweeta Hydrologic Laboratory	Deciduous forests (oak an hickory specues dominate ridges and upper slopes; whole yellow poplar and red oak occupy the moist coves)	harvesting	SC
Wilkerson, E., J. M. Hagan, et al. (i2006). "The effectiveness of different buffer widths for protecting headwater stream temperature in Maine." Forest	USA	western Maine		northern hardwood; spruce-fir and mixed hardwood-softwood	Experiment harvesting	BACI

science 52(3): 221-231.				stands		
Young, K. A., S. G. Hinch, et al. (1999). "Status of resident coastal cutthroat trout and their habitat twenty-five years after riparian logging." North American Journal of Fisheries Management 19(4): 901-911.	USA	British Columbia	Malcolm Knapp Research Forest (East Creek)	Western hemlock, Douglas fir; western redcedar, red alder	harvesting	SC

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