Appendix B

B1: Studies included in quantitative analysis

<table>
<tr><th>Study name, Location and source</th><th>Focus of study – details of liming, sites</th><th>Focus of study – outcomes measured</th><th>Outcome of study</th><th>Bias/Confounding factors</th></tr>
<tr>
<td>Afon Tywi, UK
Scarr, A., et al. (2002). Acid waters remediation and long term monitoring in Wales, Environment Agency</td>
<td>BA study
Doser and lake liming, Continuous application from a doser downstream of limed catchment, Llyn Brianne (separate study).
Dose: Lake dosed with 5000t powdered limestone twice a year for 6 years(1991-1996); Stream dosed continuously since last year of lake liming (1996)
pH: Pre liming pH 5.55, post liming 6.56
Replication: one river (before and after liming)</td>
<td>Fish abundance:
quantitative electro-fishing method; river enclosed by stop nets and divided into two or three corridors, catch depletion methods were used to calculate fry and par densities
Replication: River measured at six sites along river each year. 1 year sampled pre liming (1990) and 10 years sampled since liming started (1991- 2000).</td>
<td>Fish abundance:
Number of fry and par per 100m^2 (SD, over all sites and years)
<table>
<tr><th></th><th>Salmon</th><th>Trout</th><th>Both</th></tr>
<tr><td>Pre</td><td>0.2 (SD 0.3)</td><td>3.4 (SD 3.1)</td><td>3.6 (SD 3.0)</td></tr>
<tr><td>Post</td><td>11 (SD 13)</td><td>8.9 (SD 6.3)</td><td>18 (SD 17)</td></tr>
<tr><td>Effect size (log ratio)</td><td>4.2 (SE 22.9)</td><td>1.4 (SE 1.0)</td><td>1.7 (SE 0.4)</td></tr>
</table>
(effect size is average logged ratio of, abundance before liming divided by average abundance after liming, across 6 sites)</td>
<td>More years surveyed after liming than before.

No control present

Stocking: not mentioned in paper, however may have occurred in the river (Franks Jones, Association of river trusts Wales, personal communication) Unclear if levels changed before and after liming</td>
</tr>
<tr>
<td>Audna, Norway
Norwegian Survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2
Also publications:
Acid sensitive invertebrates:
Fjellheim, A. and G. G. Raddum (1995). "Benthic animal response after liming of three South Norwegian rivers." Water, Air, and Soil Pollution 85(2): 931-936.
Invertebrates::
Fjellheim, A. and G. G. Raddum (1992). "Recovery of acid-sensitive species of ephemeroptera, plecoptera and trichoptera in river audna after liming." Environmental Pollution 78(1): 173-178.</td>
<td>BA study, Norwegian survey
Doser and Lake
Since 1985 river continuously limed with two dosers on the river and directly into lakes.
Dose: Dose from the dosers controlled by flow, dosers have stopped for periods of time (hours or days) due to technical problems - but dissolution of previously sediment limestone on river bed meant water chemistry changed only moderately
pH: prior to liming river 5 pH, after liming pH downstream of doser varied between 6 to 7 except for a few episodes (i.e. pH 5.6 in May 1986) . Upstream tributaries very episodic pH 5 to 6, unlimed tributaries 4.6-5.5pH
Replication: one river limed, for invertebrate surveys unlimed tributaries and upstream of liming used as control sites.</td>
<td>Fish:
Catch of salmon and sea trout, total angling catch reported for the river
Replication: Angling effort unclear. Trout: 10yrs pre liming (1969, 73, 1977-1984), 21 yrs during (1986-98, 2000-08). Salmon: 2yrs pre liming (1982,83), 21 yrs during (1986-98, 2000-08)

Invertebrates:
Sampling according to the method of Frost et al. (1971), using a 250µm collecting net
Replication: 4 reference sites and 7 limed sites, each site sampled twice a year for 5 years (1985-1990). Probably one sample per site but unclear

Acid sensitive Invertebrates:
Samples taken in spring and summer by kick sampling (Frost et al. 1971) and using a 30cm x 30cm opening landing net for approx. 2 mins per sample
Replication: 6 limed sites and 5 reference sites, samples taken over 10 years (1985-1994).</td>
<td>Acid sensitive invertebrate diversity:
<table>
<tr><td>Control</td><td>2.4 (2.2)</td></tr>
<tr><td>Limed</td><td>11.4 (10.2)</td></tr>
</table>
Effect size (log ratio): 0.93 (SE 0.23)
(limed divided by control for each year, logged and then averaged)

Invertebrate diversity (number of taxa of Ephemeroptera, Plecoptera and Trichoptera, average over 5 yrs) :
<table>
<tr><td>Control</td><td>17.5 (SD 1.5)</td></tr>
<tr><td>Limed</td><td>26.3 (SD 3.5)</td></tr>
</table>
Effect size (log ratio): 0.40 (SE 0.06)
(limed divided by control for each year, logged and then averaged

Fish abundance (Weight caught in kgs):
<table>
<tr><th></th><th>Trout</th><th>Salmon</th><th>Both</th></tr>
<tr><td>Pre liming</td><td>73 (SD 60)</td><td>0</td><td>114 (SD 62)</td></tr>
<tr><td>During liming</td><td>379 (SD 320)</td><td>1214 (SD 839)</td><td>1603 (SD 842)</td></tr>
</table>
Effect size (log ratio), trout: 1.64 (SE 1.17)
Salmon: can not calculate one as zero before treatment
Both: 2.64 (SE 1.95)
(effect size calculated as average after liming divided by average after liming and then logged)</td>
<td>Angling effort may not have been uniform through time, was not scientifically or systematically collected.

No control for fish data. Control data for the invertebrates – controls were upstream sections and tributaries in the catchment. Rivers can vary naturally along their course.

Only two years pre liming with salmon data recorded.

No before (baseline) data for the invertebrate surveys.

Stocking: River was stocked with salmon smolts and fry to establish a new salmon population. Some stocking prior to liming but extensive stocking since liming.</td>
</tr>
</table>

<table>
<tr>
<td>Bear Run, USA
LeFevre, S. R. and W. E. Sharpe (2002). "Acid stream water remediation using limestone sand on bear run in southwestern Pennsylvania." Restoration Ecology 10(2): 223-236.</td>
<td>CI study
Direct point application of limestone placed in a pile in the river.
Dose: Limestone sand applied for three years in a row (1997-1999).
Between 21-23tons per year
pH: Treatment pH above treatment mean 4.7, below mean 5.2-5.8; Control pH highest site 5.0, lower sites 5.1-5.2.

Replication: One treated stream and one neighbouring control stream.</td>
<td>Invertebrates
Samples taken using a 0.1m2 Surber sampler; samples identified to genus (Ephemeroptera, Plecoptera, Trichoptera, Megloptera), family (Diptera), or order (all other groups)
Replication: Unclear exactly when samples taken but methods suggest one sample in each season (spring, summer, autumn, winter) for one year (May1999-June 2000). Each time 5 replicates from each sampling site in comparable riffles for each stream, two sites downstream of treatment and one upstream on each river

Fish - electrofishing a 90m section at each sampling site using a Coffelt Mark 10 electrofisher, using 3 passes (if fish were found on the first pass)
Replication: two sites downstream of treatment and one upstream on each river</td>
<td>Invertebrate diversity (number of taxa):
<table>
<tr><td></td><td>Downstream</td><td>Upstream</td></tr>
<tr><td>Control</td><td>12.8 (4.1)</td><td>17.5 (2.5)</td></tr>
<tr><td>Treatment</td><td>14.1 (3.9)</td><td>18.5 (2.4)</td></tr>
</table>
Effect size (log ratio): 0.04 (SE 0.18)

Invertebrate abundance (number per m^2):
<table>
<tr><td></td><td>Downstream</td><td>Upstream</td></tr>
<tr><td>Control</td><td>254 (SD 156)</td><td>534 (SD 132)</td></tr>
<tr><td>Treatment</td><td>239 (SD 106)</td><td>1069 (SD 317)</td></tr>
</table>
Effect size (log ratio): -0.77 (SE 0.24)

(Both the effect sizes: the treatment downstream to upstream ratio(average downstream abundance divided by treatment average upstream abundance) divided by the control downstream to upstream ratio, logged and then averaged over the four seasons sampled)

Fish: no fish found at 2 out of 3 of the sites on both the control and treated streams. Fish were found on both the control and treated streams in the most downstream sites but only in very low abundances and details not given</td>
<td>Control stream near to limed stream but unclear how it was decided which to apply the intervention to, no indication that it was random.

In the control ground water was pumped into it in spring (possibly the time of highest run-off and hence acidification risk) to mitigate against effect of acidification on downstream fisheries. Therefore, the control is not an untreated control!

Stocking: not mentioned</td>
</tr>
<tr>
<td>Bjerkreim, Norway
Norwegian Survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Lake and Doser
Lake started autumn 1996 L Orsdalsvatn (12.3km^2) and Austrumdalsvatn (2.8km^2)
Lime doser implemented autumn 1997,
Dose: lakes limed annually. In 1998 and 1999 total 2200-2700 tonnes limestone powder added annually,
pH: Since 1998 target pH 6.2 - (15 Feb-31March), 6.4 (1April-31May), 6.0 rest of year
Replication: one river (before and after liming)</td>
<td>Fish:
Electro-fishing carried out three times in upstream direction, fish densities estimated by removal method and separately for fry and parr
Replication: 20 sites sampled along river. One year sampled prior to liming (1996) and 12 years since liming started (1997-2008).

Acid sensitive invertebrates:
Samples taken in spring and summer by kick sampling (Frost et al. 1971) and using a 30cm x 30cm opening landing net for approx. 2 mins per sample
Replication: 7 limed and 8 reference sites were studies. Sites were studied for 7 years (1998-2000, 2002, 04, 06, 08).</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Before</td><td>3.2</td><td>27.8</td><td>31.0</td></tr>
<tr><td>During</td><td>64.2 (SD 36.5)</td><td>26.6 (SD 4.8)</td><td>90.8 (SD 39.6)</td></tr>
<tr><td>Effect size (log ratio)</td><td>3.01 (SE 11.6)</td><td>-0.05 (SE 0.18)</td><td>1.07 (SE 1.29)</td></tr>
</table>
(effect size calculated as average after liming divided by average before liming and then logged)

Acid sensitive invertebrate abundance:
Mean abundance
<table>
<tr><td>Limed</td><td>68.4 (SD 32.7)</td></tr>
<tr><td>Reference</td><td>66.0 (SD 40.6)</td></tr>
<tr><td>Effect size (log ratio):</td><td>0.04 (SE 0.29)</td></tr>
</table>
(Effect sizes calculated as limed divided by control for each year, logged and then averaged)</td>
<td>No control rivers present for fish data.
Control data for the invertebrates were upstream sections and tributaries in the catchment. Rivers can vary naturally along their course.

Electro sampling depends on the height of the river.

Prior to liming a small encroachment/ barrier to migration was in the river

Stocking: River stocked with unfed fry, Salmon stocks lost from the river prior to liming</td>
</tr>
</table>

<table>
<tr>
<td>Degerman, Sweden
Degerman, E. and M. Appelberg (1992). "The response of stream-dwelling fish to liming." Environ Pollut 78(1-3): 149-155.</td>
<td>BA study
Wetland, Lake and doser liming in various combinations. The predominant method was lake liming for 11 streams, wetland for 6 and doser for 5.
pH: lowest measured pH increased after liming, however, the objective of avoiding pH below 6 was achieved in only half of the observed post liming years.
Replication: 22 limed and seven unlimed streams (6 of the limed streams are also in the main Swedish dataset).</td>
<td>Fish sampled by electrofishing

Replication: 1 to 7 stations sampled per stream. Unclear how many years sampling included or when sampled.</td>
<td>Fish diversity (number of species):
<table>
<tr><td></td><td>Before liming</td><td>After liming</td></tr>
<tr><td>Fish diversity</td><td>2.81</td><td>2.96</td></tr>
</table>
Wilcoxon, P=0.57 but unsure of number of observations this is over so can not calculate error in effect size.
Effect size (log ratio): 0.05

Fish abundance:
Overall abundance of fish and crayfish increased significantly after liming (Wilcoxon, P<0.007) but effect size not given.

Atlantic salmon was found in 10 limed streams, predominated at seven stations in three streams. In these three streams, salmon increased significantly after liming (ANOVA, P < 0.05)

Brown trout overall increased in abundance (ANOVA, P<0.01) but size of effect not given.</td>
<td>BA significance given for fish abundance but not effect size, details only given for selected rivers in order to make certain points, some rivers in dataset but not all.

Unclear how which streams to lime were chosen.

Stocking: not mentioned</td>
</tr>
<tr>
<td>Dogway, USA
Fish: Menendez, R., et al. (1996). "Chemical and fishery responses to mitigative liming of an acidic stream, Dogway Fork, West Virginia." Restoration Ecology 4(3): 220-233.
Invertebrates: Clayton, J. L. and R. Menendez (1996). "Macroinvertebrate responses to mitigative liming of Dogway Fork, West Virginia." Restoration Ecology 4(3): 234-246.</td>
<td>BACI study
Rotary drums, Continuous point application of limestone directly into the river
Dose: 10g/m^3. Liming started 4 years before last measurements.
pH: before liming 4.6 (4.4-5.0) after 6.3 (4.5-7.8)
Control 4.6 (4.3-4.8) to 4.6 (4.3-4.8)
Replication: only one stream limed, measured upstream and downstream of treatment (and with data before and after liming)</td>
<td>Invertebrates
Sampled during ice-free season (March, June, Sept) using a Surber sampler, area 0.1m2, net mesh 0.595mm, triplicate samples collected in riffle area, samples identified to lowest possible taxonomic level
Replication: 3 samples collected at each site, two sites upstream of the treatment point (controls) and two sites downstream of the treatment site. 3 years pre treatment (1986-89) and 4 yrs during treatment (1989-92)

Fish: sampled each year in late September or early October, multiple passes made through each station using 110volt AC generator with parallel wire electrodes. All habitats within station sampled thoroughly, after each run all fish processed and held until all sampling completed. Samples collected in 5 years (1989-93)</td>
<td>Invertebrate abundance:
<table>
<tr><td></td><td>Treated</td><td>Control</td></tr>
<tr><td>Pre-treatment (3 years)</td><td>16 (7)</td><td>16 (13)</td></tr>
<tr><td>Treatment (4 years)</td><td>55 (40)</td><td>109 (62)</td></tr>
</table>
Effect size (log ratio): - 0.70 (SE 0.2)
(number in treated and control streams averaged for each year then divided, this yearly ratio is then averaged for the pre and post treatment years. The post treatment average is the divided by the pre treatment, then the ratio logged)

Invertebrate diversity:
Number of macroinvertebrate taxa collected by quantitative samples (Standard deviation across years and streams).
<table>
<tr><td></td><td>Treated</td><td>Control</td></tr>
<tr><td>Pre-treatment</td><td>17.3 (SD 2.3)</td><td>14.7 (SD1.6)</td></tr>
<tr><td>Treatment</td><td>27 (SD 10.4)</td><td>23.4 (SD5.7)</td></tr>
</table>
Effect size (log ratio): -0.03 (SE 0.17)
(Average of the yearly post treatment ratio of number treated streams to number in control streams, divided by average pre treatment ratios, then logged).

Acid sensitive invertebrate diversity:
Number of acid sensitive invertebrate species:
<table>
<tr><td></td><td>Treated</td><td>Control</td></tr>
<tr><td>Pre treatment (3 yrs)</td><td>1</td><td>0</td></tr>
<tr><td>Treatment (4yrs)</td><td>13</td><td>1</td></tr>
</table>
Can not calculate a log ratio effect size as the control increased from zero.</td>
<td>Control was an upstream section of the treated river so treatment and control sites not fully independent. Also streams naturally change over their cause.

Water quality was poorer at the first sampling site above the treatment site than below the treatment site due to the influence of the Mauch Chunk strata - which outcrops in the watershed near the mouth of the stream

Dam built at treatment site may have impacted upstream movement of organisms

Stocking: of rainbow trout only downstream of dosing point but never high density, rainbow trout excluded from analysis.</td>
</tr>
</table>

<table>
<tr>
<td>Dogway cont.</td>
<td></td>
<td></td>
<td>Fish: No fish collected in before treatment sampling but data not presented in table and unclear if same level of sampling prior to treatment
Over 5 years of treatment average number of species was 6 (SD 0.7) and average density of all fish was 9.9 (SD 5.9) number per 100m^2
Averages do not include rainbow trout which was stocked and only present after stocking.</td>
<td></td>
</tr>
<tr>
<td>Esk, UK
Diamond, M., et al. (1992). "The effect of liming agricultural land on the chemistry and biology of the River Esk, north-west England." Environmental Pollution 78(1-3): 179-185.</td>
<td>BACI study
Catchment liming (10% of catchment limed)
Dose: Limed stream dosed twice with 3200t each powdered limestone, 1 year apart.
pH: Control had higher pH before and after treatment, both streams increased pH after treatment but treatment increased by more. pH after treatment 5.8
Replication: 1 limed stream and 1 control stream</td>
<td>Invertebrate diversity
Diversity (number of species) of stoneflies, mayflies, caddis and molluscus
Method of sampling not given
Replication: BA measured in treatment and control but does not say when sampled, number of samples or for how long before and after.
In methods suggests it may be 5 sites in each treatment but unclear</td>
<td>Invertebrate diversity (number of species):
<table>
<tr><td></td><td>limed</td><td></td><td>unlimed</td><td></td></tr>
<tr><td></td><td>before</td><td>after</td><td>before</td><td>after</td></tr>
<tr><td>stoneflies</td><td>3.79</td><td>4.08</td><td>3.67</td><td>4.91</td></tr>
<tr><td>mayflies</td><td>1.78</td><td>1.84</td><td>0.77</td><td>0.8</td></tr>
<tr><td>caddis</td><td>3.5</td><td>4.03</td><td>3.75</td><td>4</td></tr>
<tr><td>Mollusce</td><td>1.1</td><td>1.11</td><td>0.4</td><td>0.36</td></tr>
</table>
Effect size (log ratio): -0.32 (data not given to calculate error)</td>
<td>Limed streams were within areas of improved agricultural land whereas unlimed fields were not.
Very little difference in the pH after treatment of limed and unlimed sites. Unclear how control and intervention sites chosen- no indication of it being random

Stocking: not mentioned</td>
</tr>
<tr>
<td>Esko, Norway
Norwegian Survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Doser
One point doser since 1997
Dose controlled by twice monthly samples
2000-2008: 421-792 tons ($CaCO_3$ equivalent) per year
pH: Aim: 6.4 during 15/2-15/6, pH 6.2 in the rest of the year. 2004 -2008 pH above the doser avg. 6.1 (range 5.2 – 6.5); below the doser avg. 6.6 (range 5.3 – 7.4)
Replication: one river (before and after liming)</td>
<td>Fish:
Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately

Replication: 4 stations sampled each year. Samples taken 2 years prior to liming (1995-96), 12 years during liming (1997-2008).</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Before</td><td>3.5 (SD 5.0)</td><td>27.5 (SD 21.1)</td><td>31.1 (SD 16.1)</td></tr>
<tr><td>During</td><td>34.1 (SD 16.5)</td><td>40.6 (SD 13.0)</td><td>74.7 (SD 22.4)</td></tr>
<tr><td>Effect size (log ratio)</td><td>2.26 (SE 0.50)</td><td>0.39 (SE 0.02)</td><td>0.88 (SE 0.05)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>Fish stocks are also affected by the Myster Power station that came into operation in 1987. Also, escaped farmed salmon have made up a large proportion of the salmon catch during regular fishing at start of liming period.
No independent control river

Stocking occurred annually since 1998 (salmon), pevious trials with eggs occurred 1990-1992 and possibly stocking of 51000 young salmon (smolts) annually prior to that, stocking increased over time</td>
</tr>
<tr>
<td>Flekke, Norway
Norwegian Survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Doser, with additional lake liming and point application of shell sand in some tributaries. Dosed since 1998
Dose: 1st 4 yrs 1600-1900tons, 2001-2008 764-1184 t of $CaCO_3$, lake liming last done in 2003 with 120tonnes</td>
<td>Fish:
Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Before</td><td>14.4 (SD 4.2)</td><td>30.0 (SD 3.0)</td><td>44.4 (SD 1.7)</td></tr>
<tr><td>During</td><td>70.3 (SD 27.9)</td><td>14.0 (SD 3.9)</td><td>84.3 (SD 28.7)</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table></td>
<td>No independent control river

Stocking: Since 2002 definitively been significant level of stocking and 50% of fish caught are from stock in some places.</td>
</tr>
</table>

<table>
<tr>
<td>conc….
Flekke, continued.</td>
<td>pH: target 6.2pH throughout the year
Before liming pH avg. 5.4 (range 5.3-5.8), During liming pH avg.6.2 (range 5.3 – 6.8)
Replication: one river (before and after liming)</td>
<td>Replication: 3 stations sampled each year within salmon bearing reach. Samples taken 3 years prior to liming (1995-97), 11 years during liming (1998-2008).</td>
<td>
<table>
<tr><td>Effect size (log ratio)</td><td>1.58 (SE 0.48)</td><td>-0.76 (SE 0.09)</td><td>0.64 (SE 0.16)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)
</td>
<td></td>
</tr>
<tr>
<td>Fifteen Mile Brook, Canada
Lacroix, G. L. (1996). "Long-term enhancement of habitat for salmonids in acidified running waters." Canadian Journal of Fisheries and Aquatic Sciences 53: 283-294.</td>
<td>BACI study
Directly application
gravel distributed over 8 areas to form bars
Dose: 220t in first application (1987) with an additional 100t applied 4 years later (1991) of dolomitic limestone
pH: Mean ph in control before treatment 5.5, After treatment average min in control was 4.7 and in limed section was 5.0 (range 4.5 – 6.3)
Replication: One limed stream sampled, area upstream of the limed section was the control</td>
<td>Fish abundance
Electrofishing carried out in October and August each year, density measured by sequential removal method. Sites enclosed by barrier nets, electrofished, at least 4 catches were made to calculate density, areas fished included pools and riffles and were 500-700m2
Replication: One site sample above and below the treatment. One years sampled prior to treatment (1987; 2 samples), and 7 years post first treatment (1988-94), (3 years after the second liming) (14 samples)</td>
<td>Fish abundance
<table>
<tr><td></td><td>limed</td><td>control</td></tr>
<tr><td>Pre treatment</td><td>0.38 (0.31)</td><td>0.74 (0.09)</td></tr>
<tr><td>During/post treatment</td><td>0.29 (0.16)</td><td>0.13 (0.06)</td></tr>
</table>
Effect size (log ratio): All 0.93 (SE 0.7)
Salmon 1.78 (SE 1.88)
Trout 0.73 (SE 0.85)
(ratio of limed to control calculated for each year, then averaged over the pre treatment and during/post treatment years. These averages then divided (post/during divided by pre treatment) and then logged)</td>
<td>The limestone beds also provided gravel beds for spawning habitat for the fish

Control is upstream on the limed river – not fully independent and rivers can vary naturally along their length (although before data was taken to quantify this).

Stocking: not mentioned</td>
</tr>
<tr>
<td>First Fork, USA
and
Shavers Fork, USA
Both:
Clayton, J. L., et al. (1998). "Application of Limestone to Restore Fish Communities in Acidified Streams." North American Journal of Fisheries Management 18(2): 347-360.]

Cont…</td>
<td>BACI
Direct application of limestone sand or gravel at one point in the river applied once per year for 2 years (1992-1993)
Dose: between 63 and 252t per year.
pH: Control 4.4 before and after treatment, Treatment avg. 4.8 before treatment, avg. 5.7 after (range after 5.5-6)
Replication: 5 tributaries of Shavers Fork of the cheat river. Shavers Fork group - 4 close together; 1 control and 3 limed. Fifth stream, First Fork, was further upstream and was measured both upstream and downstream of point liming application.</td>
<td>Fish diversity and abundance: Surveyed by electro-fishing in June for community structure and in late August for abundance/population size estimate using Moran-Zippen removal method (Moran 1982).

Replication: One sample per river each year. One year pre liming (1991) and 4 years during/post liming (1992 – 1995) for the Shavers fork group and 3 years during/post liming for First fork.</td>
<td>Fish diversity (number of species):

<table>
<tr><td>Shavers Fork group:</td><td>Pre (1yr)</td><td>Post (4 yrs)</td></tr>
<tr><td>Control (1 stream)</td><td>1</td><td>1.3 (SD 0.5)</td></tr>
<tr><td>Limed (3 Streams)</td><td>1</td><td>4.2 (SD 1.0)</td></tr>
</table>
Effect size (log ratio):1.2 (SE 0.1)
(average number of species in treated each year divided by the number of spp. in the control, logged then averaged).

<table>
<tr><td>First Fork</td><td>Pre (1yr)</td><td>Post (3 yrs)</td></tr>
<tr><td>Control</td><td>6</td><td>6.7 (2.1)</td></tr>
<tr><td>Limed</td><td>8</td><td>8.3 (1.2)</td></tr>
</table>
Effect size (log ratio): -0.03 (0.23)
(average ratio of treatment to control sections after treatment divided by the ratio before treatment then logged).</td>
<td>Shavers Fork – only one control but 3 treatment streams

Unclear how treatment and control streams were chosen. Control for the First Fork is upstream section – streams can naturally vary along their length.

Not bias in study but potential bias in evaluation in splitting study into two – however each more related to own control

Stocking: no stocking occurred.</td>
</tr>
</table>

<table>
<tr>
<td>First Fork continued</td>
<td></td>
<td></td>
<td>Fish abundance (biomass kg/ha)
<table>
<tr><td>Shavers Fork group:</td><td>Pre (1yr)</td><td>Post (4 yrs)</td></tr>
<tr><td>Control (1 stream)</td><td><0.1</td><td><0.1</td></tr>
<tr><td>Limed (3 Streams)</td><td><0.1</td><td>17.9 (SD 9.7)</td></tr>
</table>
Effect size (log ratio): 5.2 (SE 31.2)
(the log of the ratio of treated streams to control stream, were the abundance was <0.1 it was taken to be 0.1 for calculations).
<table>
<tr><td>First Fork:</td><td>Pre(1yr)</td><td>Post (3 yrs)</td></tr>
<tr><td>Control</td><td>7.5</td><td>5.3 (5.3)</td></tr>
<tr><td>Treatment</td><td>9.7</td><td>13.8 (5.2)</td></tr>
</table>
Effect size (log ratio): 1.4 (SE 1.3)
(average ratio of treated to control after treatment divided by the ratio before treatment then logged)</td>
<td></td>
</tr>
<tr>
<td>Frafjordelva, Norwegian Survey
Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Doser (and one lake)
Dose: varied, Two dosers installed since 1995 and one lake limed since 1998. Largest dose applied in 2001: 959 ton ($CaCO_3$ eqivalent), Between 2004 and 2008, 579 to 760 applied in total (across both dosers and lake)
pH: aim pH> 6.0 (1 / 6 - 14 / 2), pH 6.2 (15 / 2 -31 / 3), pH 6.4 (1 / 4 - 31 / 5).
1996-2008, avg. pH 6.4, min 5.7, max 7.1
Replication: one river (before and after liming)</td>
<td>Fish:
Electrofishing not carried out before liming so only record of angling catch extracted.

Replication: Angling effort unclear, reports for 20 years prior to liming (1975-1994) and 14 (1995-2008) years during.</td>
<td>Fish abundance (Weight in kg):
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Before</td><td>55.6 (SD 22.1)</td><td>152 (SD 104)</td><td>202 (SD 103)</td></tr>
<tr><td>During</td><td>557 (SD 322)</td><td>147 (SD 75)</td><td>703 (SD 344)</td></tr>
<tr><td>Effect size (log ratio)</td><td>2.36 (SE 0.90)</td><td>-0.03 (SE 0.22)</td><td>1.25 (SE 0.28)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>Angling effort may not have been uniform through time, was not scientifically or systematically collected.
No independent control river.

Stocking occurred in the 1980s as well as today, increase in recent years but precise changes over time not clear, nor whether there as an increase as soon as liming started. River had lost all salmon prior to liming.</td>
</tr>
<tr>
<td>Herrmann, Sweden
Herrmann, J. and B. S. Svensson (1995). "Resilience of macroinvertebrate communities in acidified and limed streams." Water, Air, and Soil Pollution 85(2): 413-418.</td>
<td>BACI study
Doser or Lake liming
Limed streams either dosed by an in stream doser or lake liming
Dose: type of liming varied between limed streams. Details of dose not given, sites limed for 8 to 11 years prior to sampling.
pH: Treatment streams: 1981 (before liming) min 4.2-5.3, 1994 min 4.6-6.2; Control streams 1981 min 4.8 to 5.5, 1994 5.6-6.2
Replication:
5 Reference streams and 10 Limed streams</td>
<td>Invertebrate:
Kick samples during 10mins with handnet (mesh size 0.7mm)

Replications: samples taken at end April, mid August, end Oct each year but only combined data is given. One year sampled (2 to 5 years) before start of liming (1981), and one year surveyed (8 to 11 years) after liming started (1994).</td>
<td>Invertebrate diversity
<table>
<tr><td></td><td>Pre liming</td><td>Liming</td></tr>
<tr><td>Limed</td><td>96</td><td>142</td></tr>
<tr><td>Reference</td><td>60</td><td>84</td></tr>
</table>
Effect size (log ratio): 0.06

Acid sensitive taxa
<table>
<tr><td></td><td>Pre liming</td><td>Liming</td></tr>
<tr><td>Limed</td><td>2</td><td>4</td></tr>
<tr><td>Reference</td><td>11</td><td>17</td></tr>
</table>
Effect size (log ratio): -0.26
(no replication to allow the calculation in the errors in the effect size)</td>
<td>Sites chosen because they were all in a small area and so likely to be similar.
Before information taken from an earlier published survey and two surveys probably done by different people, although same method used.
Most streams limed since 1st survey - unclear why none-limed streams were not chosen to be limed

Stocking: not mentioned</td>
</tr>
</table>

<table>
<tr>
<td>Jørpelandselva, Norwegian Survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Lake liming several lakes in the catchment of the river limed. 1995-2005 13 to 19 lakes limed, 2005 reduction in liming effort, only 9 lakes limed.
Dose: dose decreased by 35% when the number of limed lakes decreased (in 2005). Dose decreased by a further 4% despite no reduction in the number of lakes limed in 2006-2007. In 2008 at total of 164tons (100% $CaCO_3$ equivalent).
pH: before liming ‘acidic’; after liming 5.7 to 6.6
Replication: one river (before and after liming)</td>
<td>Fish:
Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately

Replication: 7 stations sampled each year within river. Samples taken 2 years prior to liming (1993-4), 10 years during liming (1996-2001,2003-06,2008)</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><th></th><th>Salmon</th><th>Trout</th><th>Both</th></tr>
<tr><td>Before</td><td>13.6 (SD 7.9)</td><td>17.3 (SD 9.9)</td><td>30.9 (SD 17.8)</td></tr>
<tr><td>During</td><td>18.2 (SD 9.5)</td><td>14.0 (SD 5.0)</td><td>32.3 (SD 11.5)</td></tr>
<tr><td>Effect size (log ratio)</td><td>0.29 (SE 0.51)</td><td>-0.21 (SE 0.27)</td><td>0.04 (SE 0.31)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>River used to be blocked to migratory fish due to a hydropower station. A new fish ladder was built in 1998 allowing upstream migration

No independent control river

Stocking of salmon with unfed fry</td>
</tr>
<tr>
<td>Kvina, Norway Norwegian survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Doser (some lakes in the catchment also limed)
Main liming by 3 dosers located along the river. Limed since 1993
Dose: Between 2004 and 2008 the total annul dose ranged from 2525 to 4967 tons (100% $CaCO_3$ equivalent).
pH: aim: pH 6.2 (15/2-31/3), pH 6.4 (1/4-31/5), pH 6.0 (1/6-14/2). Before liming pH 4.5 – 5.2, 2001-08: pH 5.5-7.0
Replication: one river (before and after liming)</td>
<td>Fish:
Electrofishing not carried out before liming so only record of angling catch extracted.

Replication: Angling effort unclear, reports from 5 years (trout)(1971-1975) and 2 years (salmon)(1971,1974) over 20 years prior to liming and data from the year immediately prior to liming (1993); data from 15 years during liming reported (1994 - 2008).</td>
<td>Fish abundance (Weight in kg):
<table>
<tr><th></th><th>Salmon</th><th>Trout</th><th>Both</th></tr>
<tr><td>Before (year immediately before liming)</td><td>108</td><td>100</td><td>208</td></tr>
<tr><td>During</td><td>1488 (SD 1118)</td><td>248 (SD 106)</td><td>1705 (SD 1366)</td></tr>
<tr><td>Effect size (log ratio)</td><td>0.91 (SE 1.07)</td><td>2.34 (SE 6.81)</td><td>1.88 (SE 3.41)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>Salmon caught before 1998 were largely escaped farmed salmon not wild salmon

No independent control river

Stocking: no stocking occurred after liming, No stocking since 1990</td>
</tr>
<tr>
<td>Larsson, Sweden Larsson et al (1999) Biologiska effekter i kalkad skog. Årsrapport 1998. Effektuppföljning av Skogsstyrelsens program för kalkning och vitaliseringsgödsling av skogsmark, IVL Svenska Miljöinstitutet AB</td>
<td>CI
Catchment liming, limed since 1991/1992
Dose: dose varied depending on limed stream.
pH: Stated that 1st year increased pH was seen but effect faded, after three to four year. Streams had different pH before liming. pH at time of sampling (mean min) limed 4.8 (0.6), control 4.7 (0.5)
Replication: 5 paired control and reference streams</td>
<td>Benthic fauna collected in April Collected by kick sampling, method M42 - using metal strainer diameter 16cm, aperture 0.5mm, in flowing steam strainer held downstream of sample, otherwise moved up and down thought disturbed sediment.
Replication: 30 samples along a stretch of 50m, 3 samples of different depth every 5m, each sample - 0.2m^2 in 5 seconds. Sampling method not quantitative. Samples collected in 1998.</td>
<td>Invertebrates:
<table>
<tr><th></th><th>Diversity (number of taxa)</th><th>Abundance (number organisms)</th></tr>
<tr><td>Limed</td><td>12.2 (SD 4.0)</td><td>289 (SD 17.9)</td></tr>
<tr><td>Reference</td><td>10.4 (SD 3.4)</td><td>287 (SD 108)</td></tr>
</table>
Effect size (log ratio); abundance: 0.08 (SE 0.19)
Diversity: 0.15 (SE 0.13)
(the ratio of treated divided by control for each paired streams, logged and then averaged)</td>
<td>Dams were present in limed streams but not reference streams but were avoided to allow comparison, ponds likely to have different fauna
Streams can dry up in summer, making assessment less accurate and pH tolerant taxa likely to dominate.
Control and treatment streams close to each other but unclear how the decision of which one to lime was made.
Stocking: not mentioned</td>
</tr>
</table>

<table>
<tr>
<td>Laural Branch, USA
Eggleton, M. A., E. L. Morgan, et al. (1996). "Effects of liming on an acid-sensitive southern Appalachian stream." Restoration Ecology 4(3): 247-263.</td>
<td>BACI study
Doser – continuous point application,
Dose: total limestone applied over 18 months approx. 8.2 tons
pH: River was already nearly at its target pH of 6.5 and 94% of samples at upstream site were >6.2,
Replication: one limed stream and one control stream.
Treatment stream measured both upstream and downstream of the doser.</td>
<td>Fish – Sampled in Nov. by backpack electrofishing units, population estimates made by three-pass depletion data;
Replication: one sample in control stream; treated stream:1 upstream of doser 2 downstream.
3 years sampled pre treatment (1986-1989) and 2 years during treatment (1989-90).

Invertebrates –samples taken in May, Aug and Nov by a Surber sampler (270 µm mesh) with sampling statified by habitat,
Replication: 5 replicate samples taken per site. 2 sites sampled in reference stream and in treatment stream 2 upstream and 3 downstream sites sampled.
3 years sampled pre treatment (8 samples) and first 18 months of treatment sampled (5 samples).</td>
<td>Fish abundance
Autumn population sizes of rainbow trout (Oncorhynchus mykiss)<table><tr><td></td><td>Limed</td><td>Control</td></tr><tr><td>Pre liming</td><td>86. 7 (SD 29.2)</td><td>70.3 (SD 44.0)</td></tr><tr><td>During liming</td><td>34 (SD 14.0)</td><td>38 (SD 5.7)</td></tr></table>Effect size (log ratio): -0.48 (SE 0.33)
Invertebrate abundance:
Number of macrobenthic organisms per 100m^2<table><tr><td></td><td>Limed</td><td>Control</td></tr><tr><td>Pre liming</td><td>1.3 (0.8)</td><td>1.0 (SD 0.4)</td></tr><tr><td>During liming</td><td>1.5 (SD 1.1)</td><td>1.0 (SD 0.6)</td></tr></table>Effect size (log ratio): 0.12 (SE 0.15)
(both effect sizes - ratio of averaged treated to average control each year, averaged for before and during treatment and divide (during divided by before) then logged)</td>
<td>Control and limed stream chosen to be similar but unclear exactly how it was decided which stream to lime.

Two control years were 'dry', two treatment years 'wet',

Also two upstream tributaries are possibly effected by lime in road fill

Stocking: no stocking or fishing in experimental area, fish stocked downstream of experimental sites but stocked fish distinct and none collected upstream</td>
</tr>
<tr>
<td>Lingdell, Sweden
Lingdell, P. E. and E. Engblom (1995). "Liming restores the benthic invertebrate community to "pristine" state." Water, Air, and Soil Pollution 85(2): 955-960.</td>
<td>BACI
Catchment, Lake and Doser,
8 catchment, 2 lake and 2 doser limed.
Dose: All limed steams pooled, and greater details of liming not given. Post liming samples taken 9 years after 1st liming. pH: pH in limed streams went from 4.9(0.3) to 6.0(0.5), controls remained relatively constant 4.8 (0.4) to 4.6 (0.5)
Replication: 12 limed streams in total and 4 reference streams.</td>
<td>Invertebrates: benthic animals collected in autumn, Sampled using handnet (16cm diameter, 1mm mesh), Taxa identified to spp, genus or family depending on group and ease of identification

Replication: 30 qualitative kick samples covering 6m2 taken in 50m long sampling site in a riffle Samples taken in the year immediately before liming (1984) and another sample taken 9 years after liming started (1993).</td>
<td>Invertebrate diversity (number of taxa)<table><tr><td></td><td>Before</td><td>After</td></tr><tr><td>Limed</td><td>34.3 (8.1)</td><td>41.5 (8.2)</td></tr><tr><td>Reference</td><td>30 (16.7)</td><td>30 (8.5)</td></tr></table>Effect size (log ratio): 0.19 (SE 0.09)
(effect size calculated as mean limed after liming divided by mean in the reference after liming, then this ratio divided by the ratio for before liming).</td>
<td>Limed streams limed since 1984 but not clear level or frequency of liming

Unclear why rivers chosen or why limed rivers limed.

Stocking: Stocking not mentioned.</td>
</tr>
</table>

<table>
<tr>
<td>Liscomb River, Canada:
Watt, W. D., G. J. Farmer, et al. (1983). "Studies on the Use of Limestone to Restore Atlantic Salmon Habitat in Acidified Rivers." Lake and Reservoir Management, (special issue on EPA/N Am Lake Mgt Soc Lake and Reservoir Mgt 3rd Conf, Knoxville, TN) 1(1): 374-379.</td>
<td>CI study
Direct application
Gravel applied directly into stream as a one-off dose
Dose: total 180 tons limestone gravel applied. Unclear length of time between lime application and measurements
pH: mean pH of river 4.9 – unclear impact of liming on pH
Replication: Samples from one treated stream with samples above and within area of a stream spread with limestone gravel</td>
<td>Fish abundance
Fish caught be electrofishing (exact details not given)
Replication: Two sites upstream of treatment and 5 sites within the treatment area, all sampled on one occasion (1982).</td>
<td>Fish abundance
<table>
<tr><th></th><th>Number of fry and par per 100m^2</th></tr>
<tr><td>Upstream (2 sites)</td><td>8.2</td></tr>
<tr><td>Within (5 sites)</td><td>51.6</td></tr>
</table>
Effect size (log ratio): 1.8
The variance in the measurements at the upstream and within sites are not given so the error in the effect ratio cannot be calculated</td>
<td>The variance is not given so error and variance can not be assessed or calculated.

No before (baseline) data is given

Control is upstream on the limed river and rivers can vary naturally along their length. Fewer samples taken from upstream.

Stocking: not mentioned</td>
</tr>
<tr>
<td>Little Stoney Creek, USA
Downey, D. M., C. R. French, et al. (1994). "Low cost limestone treatment of acid sensitive trout streams in the Appalachian Mountains of Virginia." Water, Air, & Soil Pollution 77(1-2): 49-77.</td>
<td>CI study
Direct point application of limestone sand into stream but naturally spread out to a max final distance of 151m
Dose: Limestone applied each September for 3 years, a total of 105tons.
pH: Mean pH Upstream dosing 5.7 (SD 0.4), downstream 6.8 (SD 0.4)
Replication: One stream sampled both above and below the dose.</td>
<td>Invertebrates:
Aquatic insects sampled using Carle sampler
Replication: one sample above and below the treatment site each year. All three years during which treatment was applied were sampled (1989-1991).

Fish:
100yrd sections sampled using a backpack electroshocker and a three pass depletion method</td>
<td>Invertebrate diversity and abundance:
Diversity (total number of taxon found)
<table>
<tr><td>Taxa richness</td><td>1989</td><td>1990</td><td>1991</td></tr>
<tr><td>Above</td><td>15</td><td>20</td><td>20</td></tr>
<tr><td>Below</td><td>12</td><td>20</td><td>22</td></tr>
</table>
Abundance (total number of organisms found):
<table>
<tr><td># of organisms</td><td>1989</td><td>1990</td><td>1991</td></tr>
<tr><td>Above</td><td>260</td><td>280</td><td>906</td></tr>
<tr><td>Below</td><td>253</td><td>292</td><td>804</td></tr>
</table>
Effect size (log ratio), Diversity: -0.04(SE 0.09)
Abundance: -0.03 (SE 0.05)
(log of the below divided by the above value, averaged over the years)

Fish:
No quantitative data given for fish abundance.
Statement of no definitive response of brook trout, population increases for Blacknose dace and Longnosed dase, fanfail darter, and mottled sculpin recolonized areas of the stream.
Brook trout responded dramatically to the liming of an acidity tributary to the main stream. Prior to limestone treatment, the pH was too low to support healthy fish populations. Following liming, qualitative sampling revealed an immediate colonization of this stream. No trout or other fish species were observed upstream from the liming site.</td>
<td>Only control is on the same river as the treated section so not fully independent of it. Control upstream and rivers can vary naturally along their course.

No before (baseline) data given

No quantitative data on fish abundance.

Stocking: not mentioned</td>
</tr>
</table>

Llyn Brianne, UK
Acid sensitive invertebrates:
Bradley, D. C. and S. J. Ormerod (2002). "Long-term effects of catchment liming on invertebrates in upland streams." Freshwater Biology 47(1): 161-171
Invertebrates:
Communication from the study author Steve Ormerod,
Fish:
Weatherley, N. S., et al. (1992). "The biological response of acidic streams to catchment liming compared to the changes predicted from stream chemistry." Journal of Environmental Management 34(2): 105-115

BACI study
Catchment liming of inlets into a lake.
Source areas (2 streams), Whole catchment (1 stream)
Dose: All catchments dosed once (25 to 9t per ha $CaCO_3$ powder)
pH: pH increased in limed streams (from an average of 5.1 to 6.2)

Replication: 3 limed streams and 3 control streams for invertebrate data but no fish in one limed and control stream before or after data so only 2 lime and 2 control streams included in fish data.

Invertebrates:
Sampled once a year in April by 3 min kick sample (2 mins in mid channel riffles, 1 min a stream margin)
Species identified to lowest feasible taxonomic level.
18 taxa classed as acid sensitive taxa due to acid tolerance levels

Replication: one sample each year. 3 years sampled pre liming (1985-1987) and 10 years post liming (1988-1998) for acid sensitive species. For all invertebrates pre-liming 3 or 4 years sampled depending on stream and 1 to 2 years sampled post liming.

Fish:
Monitored every yr by quantitative electro fishing (usually in October)
Replication: one sample each year in each stream. 4 years sampled pre liming (1984-1987) and 2 years sampled post liming (1988-1989).

Acid sensitive invertebrate abundance and diversity: Mean over years and sites (SD – between years which was larger than the within year variation reported)

limed	# species	Abundance (# organisms per sample)
Pre (3 yrs)	1.2 (0.5)	6 (4)
Post (9 yrs)	3.1 (1.1)	50 (75)
acid		
Pre (3 yrs)	2.1 (1.0)	19 (8)
Post (9 yrs)	2.0 (0.8)	26 (19)

Species Effect size (log ratio): 1.8 (SE 3.9)
Abundance Effect size (log ratio): 0.62 (SE 0.42)
(both are the average of the yearly pre treatment ratio of treated to untreated divided by the average of the yearly post treatment ratio, then logged)

Invertebrate abundance and diversity Mean over years and sites (SD – between years which was larger than the within year variation reported)

limed	# taxa	Abundance (# organisms per sample)
Pre (3 yrs)	17 (2)	347 (217)
Post (10 yrs)	17 (4)	243 (144)
acid		
Pre (3 yrs)	20 (1)	185 (250)
Post (10 yrs)	17 (4)	355 (250)

taxa Effect size (log ratio): 0.05 (SE 0.28)
Abundance Effect size (log ratio): 0.06 (SE 0.11)
(both are the average of the yearly pre treatment ratio of treated to untreated divided by the average of the yearly post treatment ratio, then logged)

Fish abundance: mean number trout per $100m^2$ (se)

		Pre (4 years)	Post (2 years)
Limed	C2	7 (25)	115 (21)
	C5	17	156 (115)
Control	C1	18 (111)	120 (68)
	C4	25 (54)	67 (33)

Effect size (log ratio) : 1.01 (SE 0.9)
(log of the average pre-post liming ratio for the limed sites divided by the average pre-post liming ratio for the control sites)

It is unclear exactly how streams were chosen. The author states that the streams were "matched as far as logistically possible".

May have had reduced effect after 9 yrs, application not repeated.

Stocking: not mentioned

<table>
<tr>
<td>Loch Fleet, UK
Milner, A. G. P. and R. J. Aston (1995). "Pre- and post-liming aquatic communities and trout diets." Chemistry and Ecology 9(3-4): 193-205
(Fish:- Turnpenny, A. W. H., J. M. Fleming, et al. (1995). "The brown trout population at Loch Fleet eight years after liming." Chemistry and Ecology 9(3-4): 179-191.)</td>
<td>BA study
Catchment liming (varied through catchment)
Dose: total of 445t limestone applied in autumn of one year with unspecified amount extra applied the next year.
pH: pH increased from approx. 4.5 to 6.6
Replication: the inlet and outlet of the lake whose catchment was limed were measured. Will not be independent samples.</td>
<td>Invertebrate abundance using modified Surber Sampler and quadrate covering 0.09m2 of stream bed. Sampled in the Spring, summer and autumn of teach year.
Fish abundance recorded.
Replication: Three samples taken per stream on each occasion. Pre-liming sampled in 6 seasons (from summer 1984 - spring 1986), post liming pre-stocking sampled in 3 seasons (summer 1986 - spring 1987) and post liming pre stocking sampled in 7 seasons (summer 1987-summer 1990)</td>
<td>Invertebrate abundance (mean number per m^2 (SE))
<table>
<tr><td colspan="2">Inlet stream</td></tr>
<tr><td>A: pre-liming</td><td>2300 (600)</td></tr>
<tr><td>B: postliming, pre stocking</td><td>5000 (1500)</td></tr>
<tr><td>C: post-liming and stocking</td><td>2000 (300)</td></tr>
<tr><td colspan="2">Outlet stream</td></tr>
<tr><td>A: pre-liming</td><td>4100 (1400)</td></tr>
<tr><td>B: postliming, pre stocking</td><td>7100 (2200)</td></tr>
<tr><td>C: post-liming and stocking</td><td>4100 (1500)</td></tr>
</table>
Effect size (log ratio): 0.67 (SE 0.17)
(Pre to post liming pre stocking, average of logged response ratios)

Fish: survived and increased after stocking.
But no stocking prior to liming so can not distinguish increase due to liming and increase due to stocking</td>
<td>Waterfall below study site – possible barrier to decolonisation

No control

Stocking: Fish stocked 2 years after liming, no fish prior to stocking.</td>
</tr>
<tr>
<td>Lygana, Norway
Norwegian Survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Doser and lake
liming started 1991, with first doser installed and some lakes limed. In 2000 second doser started
Dose: 2004-08 total 1763-3073 metric tones 100% $CaCO_3$ equivalent applied per year.
pH: Aim 15/2-31/3: pH 6.2, 1/4-31/5: 6.4, 1/6-14/2: pH 6.0, 2001-09: Above doser pH 4.4-5.9, Below doser pH 5.7-7.0
Replication: one river (limed section and a unlimed control tributary)
For the invertebrates: 6 limed and 6 reference sites (upstream of dosing or in tributaries).</td>
<td>Fish: Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately
Replication: Electrofishing only started after liming started. However, since 1994 an unlimed tributary also surveyed. 9 sampling points on main river (limed) and 2 on tributary (control). Sites surveyed for 15 years (1994-2008).

Invertebrates: Samples taken in spring and summer by kick sampling (Frost et al. 1971) and using a 30cm x 30cm opening landing net for approx. 2 mins per sample
Replication: Sampled in the spring and autumn of one year (2008).</td>
<td>Fish abundance (number per $100m^2$):
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Limed</td><td>33.5 (SD 28.3)</td><td>30.3 (SD 16.5)</td><td>63.8 (SD 29.4)</td></tr>
<tr><td>Control</td><td>1.74 (SD 3.13)</td><td>28.9 (SD 15.0)</td><td>30.7 (SD 16.4)</td></tr>
<tr><td>Effect size (log ratio)</td><td>2.96 (SE 3.23)</td><td>0.05 (SE 0.21)</td><td>0.73 (SE 0.24)</td></tr>
</table>
(Effect size calculated as from average of the limed river divided by the average for the control tributary and then logged)

Invertebrate abundance (number of organisms per sample).
<table>
<tr><td></td><td>Limed</td><td>Control</td></tr>
<tr><td>Spring</td><td>582 (SD 282)</td><td>433 (SD 116)</td></tr>
<tr><td>Autumn</td><td>1290 (SD 1652)</td><td>1622 (SD 2012)</td></tr>
</table>
Effect size (log ratio): 0.03 (SE 0.37)</td>
<td>Until 2001 liming was done to mitigate for brown trout which are thought to be less sensitive than salmon.

Control sites were upstream sections and /or tributaries in the catchment. Rivers can vary naturally along their course.

Stocking: No stocking of salmon or trout fry after 1990 so all juveniles must be natural recruitment</td>
</tr>
<tr>
<td>Lysevassdraget, Norwegian Survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2

Cont.</td>
<td>BA study, Norwegian survey
Doser and lake liming
Doser started in 2000 and lake liming in 1999
Dose: 2004-2008 73 to 253 tonne (100% $CaCO_3$ equivalent) used per year
pH: aim: pH 6.2 (15/2-31/3), pH 6.4 (1/4-31/5), pH 6.0 (1/6-14/2)</td>
<td>Fish: Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately
Replication:10 stations sampled each year within river. Samples from 5 years prior to liming (over 7 years; 1993-1999) and from 8 years during liming (2001- 2008)</td>
<td>Fish abundance (number per $100m^2$):
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Before</td><td>7.6 (SD 4.1)</td><td>32.1 (SD 14.8)</td><td>39.7 (SD 18.1)</td></tr>
<tr><td>During</td><td>24.4 (SD 6.9)</td><td>14.6 (SD 5.2)</td><td>39.0 (SD 8.7)</td></tr>
<tr><td>Effect size (log ratio)</td><td>1.16 (SE 0.30)</td><td>-0.78 (SE 0.30)</td><td>-0.02 (SE 0.18)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>Control sites were upstream sections and tributaries in the catchment. Rivers can vary naturally along their course.

Stocking: no stocking present</td>
</tr>
</table>

<table>
<tr>
<td>Lysevassdraget continued</td>
<td>In 2008 Avg pH 6.36, min 5.96, Max 6.71
Replication: one river (before and after liming)</td>
<td>Invertebrates: Samples taken in spring and summer by kick sampling (Frost et al. 1971) and using a 30cm x 30cm opening landing net for approx. 2 mins per sample
Replication: 5 limed sites were sampled and 3 reference sites (upstream and unlimed tributaries). The year prior to liming was sampled (1999) and 3 samples were taken in 7 years during liming (2002, 06, 08).</td>
<td>Acid sensitive invertebrate abundance (number of organisms per sample)
<table>
<tr><td></td><td>Limed</td><td>Control</td></tr>
<tr><td>Before</td><td>1.4</td><td>2.4</td></tr>
<tr><td>During</td><td>16.3 (SD 9.9)</td><td>10.1 (SD 2.3)</td></tr>
</table>
Effect size (log ratio): 1.14 (SE 1.57)
(Effect sizes calculated as limed divided by control for each year, logged and then averaged)</td>
<td></td>
</tr>
<tr>
<td>Mandalsvassdraget, Norwegian Survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2
Also acid sensitive invertebrates:
Hindar, A. (2006) Liming of River Mandalselva: A Success Story. Proceedings of the Acid Rain MitigationWorkshop, Bedford Institute of Oceanography.</td>
<td>BA study, Norwegian survey
Doser and Lake
3 large dosers in main river and 6 smaller dosers in side rivers, also liming of several lakes in the catchment
Dose: limed since 1996. 2004 - 2008 4813 to 7025 metric ton limestone (100%$CaCO_3$ equivalent) used in the dosers, and 93-107 ton used in 13-18 lakes, about 5000 metric tons used per year
pH: aim: pH 6.2 (15/2- 144), pH 6.4 (15/4-31/5), pH 6.0 rest of year. Typical range pH before was 4.6 to 5.5 after 6 to 6.5. There was some recovery prior to liming

Replication: one river (before and after liming)</td>
<td>Fish: Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately
Replication:18 stations sampled each year within river. Two years sampled prior to liming (1995, 1996) and 11 years during liming (1997-2008).

Invertebrates Samples taken in spring and summer by kick sampling (Frost et al. 1971) and using a 30cm x 30cm opening landing net for approx. 2 mins per sample
Replication: 9 limed and 6 un-limed reference stations. One sample taken per year, 1 year sampled before liming (1996) and 9 years during treatment (1997-2005).</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Before</td><td>0.10 (SD 0.14)</td><td>14.8 (SD 6.9)</td><td>55.0 (SD 18.4)</td></tr>
<tr><td>During</td><td>50.5 (SD 21.9)</td><td>14.5 (SD 7.0)</td><td>55.0 (SD 18.4)</td></tr>
<tr><td>Effect size (log ratio)</td><td>6.0 (SE 145)</td><td>-0.02 (SE 0.35)</td><td>1.31 (SE 0.84)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)

Acid sensitive invertebrate abundance (number of organisms per sample)
<table>
<tr><td></td><td>Limed</td><td>Control</td></tr>
<tr><td>Before</td><td>18.6</td><td>5.7</td></tr>
<tr><td>During</td><td>35.4 (SD 13.9)</td><td>11.0 (SD 4.8)</td></tr>
</table>
Effect size (log ratio): 0.13 (SE 0.59)
(Effect sizes calculated as limed divided by control for each year, logged and then averaged)</td>
<td>Only edge of river can be electrofished - area depends on water flow so variation between years should be regarded with caution
Large dam present within the river
No control river present for fish data. Control data for the invertebrates were upstream sections and tributaries in the catchment. Rivers can vary naturally along their course.
Stocking: river stocked with salmon eyed eggs, fry and smolts. Stocked fish 1 to 16% of salmon caught by electrofishing
In 2004 released 91 000 fry; in 2005 - 31300 fry and in 2006 - 6000 salmon and 200 000 eggs</td>
</tr>
</table>

<table>
<tr>
<td>Maryland, USA
Greening, H. S., et al. (1989). An Evaluation of Stream Liming Effects on Water Quality and Spawning of Migratory Fishes in Maryland Coastal Plain Streams: 1988 Results, Final Report AD-89-5, Maryland Department of Natural Resources Chesapeake Bay Research and Monitoring Division, Annapolis, MD</td>
<td>CI study
Continuous doser - Automated slurry doser, doser had been in operation for 2 years at time of sampling.
Dose: Exact dose unclear.
pH: Upstream of doser mean 6.5, Min 5.6, Max 6.7, Downstream of doser mean 6.7, min 6.1, max 7.5
Replication: One dosed and one control stream, matched pair. (additional data on one dosed and undosed streams but streams not matched/similar)</td>
<td>Fish diversity and abundance; Abundance and presence of Yellow Perch, White Perch, Alewife and Blueback Herring recorded.
Spawning populations of migratory fish monitored continuously for 3.5 months in spring as they moved upstream using Maine fyke nest with square Dakota mouth openings fitted with 5cm mesh wings stationed to block entire width of stream.
Replication: each stream sampled once (1988)</td>
<td>Fish abundance and diversity:
<table><tr><th>Site</th><th># Species</th><th>Total number fish collected</th></tr><tr><td>Dosed</td><td>3</td><td>80</td></tr><tr><td>Not dosed</td><td>3</td><td>88</td></tr></table>Diversity Effect size (log ratio): 0
Abundance Effect size (log ratio): -0.10
(no replication to allow error calculation)</td>
<td>No replication so not enough data to determine the level of error in the effect size.
No before (baseline) data present.

Unclear how control and treatment streams chosen. Data extracted from pair of neighbouring streams, relatively matched but still unclear if were differences and how treated chosen.

Stocking: not mentioned</td>
</tr>
<tr>
<td>Mountain Run, USA
Hudy, M., D. M. Downey, et al. (2000). "Successful Restoration of an Acidified Native Brook Trout Stream through Mitigation with Limestone Sand." North American Journal of Fisheries Management 20(2): 453-466.</td>
<td>BACI study
Point application of limestone sand
Dose: two applications 100m apart, total of 36.3 metric tons all applied at one time
pH: 5.2 before and increased by nearly 1pH
Replication: One stream with a circumneutral tributary as the control</td>
<td>Invertebrates:
Measured in the spring, in each section one riffle area with relatively fast current and one riffle area with slower current sampled with kick net (500µm). Taxa identified to family
Replication: 3 sections measured below the treatment and 1 in the control, 1 year measured before treatment (1993) and 3 years after (1995-1997).

Fish:
Sampled by electrofishing in July each year, population estimates were made using mark-recapture or three-pass depletion methods
Replication: One year measured before treatment and 4 years after.</td>
<td>Invertebrate diversity (Number of taxa)
<table><tr><th></th><th>Pre-treatment (1 year)</th><th>Post-treatment (3 years)</th></tr><tr><td>Treatment</td><td>7.7 (3.5)</td><td>11.6 (1.6)</td></tr><tr><td>Control (circumneutral)</td><td>11</td><td>20.3 (5.3)</td></tr></table>Effect size (log ratio): -0.22 (SE 0.93)
(effect size calculate by first calculating the ratio of pre to post treatment for each section then averaging treated and control. The treated average was then divided by the control then logged)

Fish abundance (number per 100m^2):
<table><tr><th></th><th>Pre-treatment (1 year)</th><th>Post-treatment (4 years)</th></tr><tr><td>Treatment</td><td>0.9 (SD 1.6)</td><td>21 (SD 12)</td></tr><tr><td>Control (circumneutral)</td><td>0</td><td>12 (SD 18)</td></tr></table>Can not measure log ratio effect size as control increased from zero.</td>
<td>Only control data is for a circumneutral tributary, rather than an acid site and control is linked to main stream so it is not completely independent.

Before liming there were already differences as you went downstream

Stocking: Stocking occurred after liming.</td>
</tr>
<tr>
<td>Nyberg, Sweden
Nyberg, P., M. Appelberg, et al. (1986). "Effects of liming on crayfish and fish in Sweden." Water, Air, & Soil Pollution 31(3): 669-687.</td>
<td>BA study
Lake or river, no details on level and type just given as lake or river
Dose and pH: Details not given
Replication : three rivers with before and after data
(4 additional rivers with no before data)</td>
<td>Fish densities:
Details of sampling not given Two of the rivers also included in the Swedish database but no before data given there.
Replication: unclear if there was replication within rivers within years. Storån 1yr before (1979), 2 yrs after (1981, 1983) sampled. Brodalsbäcken: 3 yrs before (1971, 78, 81), 2 year after (1982, 83). Högvadså: 3 years before (1975-77), 5yrs after (1978-82).</td>
<td>Fish abundance: Total number of salmon and trout per 100m^2
<table><tr><th>River</th><th>Before</th><th>After</th><th>Effect size</th></tr><tr><td>Högvadsån (Lake liming and Doser)</td><td>72.7 (SD 62.9)</td><td>60.4 (SD 26.7)</td><td>-0.18 (SE 0.46)</td></tr><tr><td>Brodalsbäcken (Doser and lake liming)</td><td>40.9 (SD 43.8)</td><td>20.8 (SD 0.7)</td><td>-0.68 (SE 1.32)</td></tr><tr><td>Storån (Lake liming)</td><td>106</td><td>227 (194, 260)</td><td>0.76</td></tr></table>(effect size the average for after divided by the average for after, then logged)</td>
<td>Full details of liming not given

Very little replication/no replication.

No control rivers present.

Stocking: not mentioned.</td>
</tr>
</table>

<table>
<tr>
<td>Ogna, Norway
Norwegian Survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2

Acid sensitive invertebrate:
Fjellheim, A. and G. G. Raddum (1992). "Recovery of acid-sensitive species of ephemeroptera, plecoptera and trichoptera in river audna after liming." Environmental Pollution 78(1): 173-178.</td>
<td>BA study, Norwegian survey
Doser and Lake liming.
Lake liming in 3 lakes and dosers in main river, tributary and powerstation outlet, all started in 1991.
Dose: dose varied between years, doser dose controlled by water flow. In 1999- 2008 dose was 151 to 389 metric tons (100% $CaCO_3$ equivalent) per year.
pH: aim: 6.2 (15 Feb.- 31 March), pH 6.4 (1 April - 31 May). The rest of the year, pH 6.0.
Average yearly min prior to liming 5.1, post liming 6.1
Replication: one river (before and after liming)</td>
<td>Fish: Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately
Replication: 8 to 16 stations sampled per year for electrofishing. Six years sampled prior to liming (1983-1988; but no sampling in two years immediately prior to liming), 18 years sampled during liming (1991-2008).

Invertebrates: Samples taken in spring and summer by kick sampling (Frost et al. 1971) and using a 30cm x 30cm opening landing net for approx. 2 mins per sample
Replication: 6 limed and 4 reference sites (upstream of dosing or on non-dosed tributaries) Samples taken over 4 years (1991-1994)</td>
<td>Fish abundance (number per $100m^2$):
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Before</td><td>18.7 (SD 8.4)</td><td>19.0 (SD 6.4)</td><td>37.7 (SD 82.5)</td></tr>
<tr><td>During</td><td>76.1 (SD 27.5)</td><td>6.4 (SD 2.9)</td><td>82.5 (SD 28.0)</td></tr>
<tr><td>Effect size (log ratio)</td><td>1.41 (SE 0.54)</td><td>-1.09 (SE 0.20)</td><td>0.78 (SE 0.29)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)

Acid sensitive invertebrate diversity (number of sensitive species in benthic samples)
<table>
<tr><td></td><td>Limed</td><td>Control</td></tr>
<tr><td>During</td><td>30.0 (SD 12.4)</td><td>29.1 (SD 38.8)</td></tr>
</table>
Effect size (log ratio): 1.27 (SE 1.89)
(Effect sizes calculated as limed divided by control for each year, logged and then averaged)</td>
<td>There has been a reduction in previously significant agricultural run-off during the time of liming.

No control river present for fish data.
Control data for the invertebrates were upstream sections and tributaries in the catchment. Rivers can vary naturally along their course.

Stocking: no stocking after the start of liming</td>
</tr>
<tr>
<td>Olofsson, Sweden
Olofsson, E., E. Melin, et al. (1995). "The Decline of Fauna in Small Streams in the Swedish Mountain Range." Water Air and Soil Pollution 85(2).</td>
<td>BA study.
Dose: Details of liming unclear
pH: lowest 1980-90: 4.1-4.3; lowest 1994: 6.1
Replication: data from two limed streams.</td>
<td>Benthic invertebtares: quantitatively with metal frame and 1mm sieve (specific details not given)
Replication: Three years sampled post acidification, pre liming (1980, 86, 90) but only one year sampled after liming started (1994). Liming started 1991</td>
<td>Invertebrate abundance:
<table>
<tr><td></td><td>Stream 1</td><td>Stream 2</td></tr>
<tr><td>Pre acidificiation (1976)</td><td>3400</td><td>2700</td></tr>
<tr><td>Post acidification pre liming (1980-1990)</td><td>112-510
Average 351</td><td>320-550
mid point 435</td></tr>
<tr><td>Post liming</td><td>1580</td><td>1360</td></tr>
</table>
Effect size (log ratio): 1.32 (SE 0.25)</td>
<td>Full details of liming not given
Very little replication/no replication.

No unlimed controls.

Stocking: not mentioned</td>
</tr>
<tr>
<td>Parasites, Canada.
Cone, D. K., D. J. Marcogliese, et al. (1993). "Metazoan parasite communities of yellow eels (Anguilla rostrata) in acidic and limed rivers of Nova Scotia." Canadian Journal of Zoology/Revue Canadienne de Zoologie 71(1): 177-184.</td>
<td>CI study
Lake liming – application over the ice in winter,
Dose: lake limed annually with calcite limestone since start of liming (1986) but dose not given.
pH: control over 3 years4.6-4.7, limed over 3 yrs 6.3-6.4
Replication: One limed and one control river sampled.</td>
<td>Diversity of parasites within eels. 30 eels collected each year from each river, then dissected to identify the parasites they contained.

Replication: 30 eels sampled from each river. Samples collected for 3 years (1988-1991) from 3 years post first liming</td>
<td>Invertebrate diversity
Diversity of parasites, number of parasitic species present

Acidic 2.7 (SD 1.5)
Limed 4.3 (SD 2.1)
Effect size (log ratio): 0.54 (SE 0.72)
(logged ratio of number in limed to control sites, averaged over the 3 years of sampling)</td>
<td>Parasites – may not be representative of other invertebrates.

No before (baseline) data

Unclear how limed and control rivers chosen.

Stocking: not mentioned</td>
</tr>
</table>

<table>
<tr>
<td>Pottsville, USA
Hartman, K. J., et al. (2007). "Evidence of stock-recruit relationships for Appalachian brook trout." Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 61: 40-45.</td>
<td>CI
Direct point application of sand in river (probably)
Dose: applied by West Virginia Department of Environmental Protection, methods suggest limestone sand place directly in river but details of liming unclear, including dose and length of time limed.
pH: Mean pH of limed 4.9-6.2, control 5.1- 5.7
Replication: 5 treated streams and 5 controls</td>
<td>Invertebrate abundance; Benthic macroinvertebrates collected in spring by kick-net samples,

No usable fish data presented

Replication: 3 replicate samples per stream section, all collected at same time (2006).</td>
<td>Invertebrate abundance (benthic invertebrate mean biomass):
Limed streams mean: 0.103 (SD 0.085)
Range 0.017-0.207
Control streams: mean 0.049 (SD 0.027)
Range 0.027 – 0.094

Effect size (log ratio): 0.74 (SE 0.52)</td>
<td>pH in some limed streams worse than control streams.

Control streams had lower road density

Unclear how limed and unlimed streams chosen both in this study and during decision to lime some streams.

Stocking: not mentioned</td>
</tr>
<tr>
<td>Rødneelva, Norwegian Survey
Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Lake and Doser
Lake liming of three lakes at the top of basin (since 1996) and river doser at the top of the salmon bearing stretch (since 1997)
Dose: varied between years.
pH: aim: pH 6.2 (15.feb. - March 31), pH 6.4 (1 April - 31 May). The rest of the year, pH 6.0.
1976-1995 pH 4.4-6.4,
1996 – 2008 pH 5.2-8.3
Replication: one river (before and after liming)</td>
<td>Fish: Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately

Replication:
8 sites sampled per year. 8 years sampled in the 11 years prior to liming (1985-1995), 12 years sampled during liming (1996-2008).</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><th></th><th>Salmon</th><th>Trout</th><th>Both</th></tr>
<tr><td>Before</td><td>20.9 (SD 13.4)</td><td>50.4 (SD 12.1)</td><td>71.3 (SD 24.1)</td></tr>
<tr><td>During</td><td>66.3 (SD 44.0)</td><td>31.3 (SD 14.4)</td><td>97.6 (SD 47.7)</td></tr>
<tr><td>Effect size (log ratio)</td><td>1.15 (SE 1.48)</td><td>-0.48 (SE 0.56)</td><td>0.31 (SE 0.92)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>No unlimed control river

Stocking: of both fed and unfed salmon fry above salmon bearing stretch but stopped in 1999</td>
</tr>
<tr>
<td>Shavers Fork, USA
See first fork</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sokndalselva, Norwegian Survey
Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2

Cont.</td>
<td>BA study, Norwegian survey
Lake liming started in 1989
Dose: liming gradually increased in 1990s since 1996 all four branches of the watercourse limed, 2004 to 2008 yearly dose varied between 673 and 970 metric tons 100% $CaCO_3$ equivalent).
pH: pH aim 6 thought the year. Before liming pH:4.8 -6.1; 1989-1998 pH 4.9-7.2 and since river fully limed (1999) to 2008 pH 5.8 -6.9
Replication: one river (before and after liming)</td>
<td>Fish:
Electrofishing not carried out before liming so only record of angling catch extracted.
Replication: Trout catch recorded 20 years prior to liming (1969-1988) and 20 years during liming (1989-2008), salmon catch recorded for 8 years in the 20 years prior to liming (1969-70, 74-79) and recorded for 15 years in the 20 years post liming (1993-2008).</td>
<td>Fish abundance (weight in kg):
<table>
<tr><th></th><th>Salmon</th><th>Trout</th><th>Both</th></tr>
<tr><td>Before</td><td>5.6 (SD 12.6)</td><td>292.8 (SD 116.2)</td><td>319.2 (SD 121.4)</td></tr>
<tr><td>During</td><td>1595 (SD 910)</td><td>288.8 (SD 175.6)</td><td>1852 (SD 907)</td></tr>
<tr><td>Effect size (log ratio)</td><td>5.66 (SE 47.1)</td><td>-0.01 (SE 0.16)</td><td>1.76 (SE 0.83)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>No unlimed control river for fish data.
Control data for the invertebrates were upstream sections and tributaries in the catchment. Rivers can vary naturally along their course.

Unclear how angling effort has varied through the years.

Stocking: no stocking occurred.</td>
</tr>
</table>

<table>
<tr>
<td>Sokndalselva, continued</td>
<td></td>
<td>Invertebrates:
Samples taken in spring and summer by kick sampling (Frost et al. 1971) and using a 30cm x 30cm opening landing net for approx. 2 mins per sample
Replication: 4 reference sites and 6 limed sites. Six years sampled during liming from 10 to 20 years after the start of liming (1998, 2002, 02,04, 06,08)</td>
<td>Acid sensitive invertebrate abundance (number of sensitive organisms in benthic samples)
<table><tr><td></td><td>Abundance</td></tr><tr><td>Limed</td><td>48.1 (SD 10.4)</td></tr><tr><td>Control</td><td>13.2 (SD 10.4)</td></tr></table>Effect size (log ratio): 1.29 (SE 0.33)</td>
<td></td>
</tr>
<tr>
<td>Swedish Database, Database from the Swedish national liming program
Includes rivers:
Limed; Enån, Lillån (Ga järnvägsbron), Enångersån, Källsjöån, Haraldsjöån, Svanån, Stridbäcken, Rökeå, Skuggälven, Blankan Hovgårdsån, Ådalsån Strönhultsån, Arån, Storselsån, Ljungaån, Sällevadsån, Hästgångsån
Discontinued limed; Hammarbäcken Häggingån Djursvasslan Örvallsbäcken
Reference; Havssvalgsbäcken Lillån-Bosgårdsån Laxbäcken Vingån Lillån (E4), Musån Trollbäcken Tangån Sörjabäcken Härån Hörlingeån Bastuån Morån Lillån (Gnyltån) Ejgstån Hornsjöbäcken Stråfulan Gnyltån</td>
<td>CI
Doser, Lake and Catchment
Different rivers have different combinations of liming methods.
Dose: all rivers regularly limed for long time periods
pH: limed rivers average pH 6.1 to 6.9.
Replication:
Covers 17 limed, 4 discontinuded limed, and 18 reference rivers of various levels of pH
Effect size calculated on the 17 limed rivers and the 8 acid reference rivers (pH<6).</td>
<td>Invertebrates:
Benthic invertebrates were sampled using the M42 method. The M42 method is a kick method in which each sample is a composite sample of 30 subsamples each consisting of 5 sec kicking within an area of 0.2 m2 and the invertebrates were collected in a hand-held net with 1 mm mesh size. The abundance measure is individuals per sample.
Replication: Samples were taken in spring and autumn 2005 and in autumn 2006-2009

Fish
Fish were caught by electrofishing
Replication: each river was sampled at 2-6 sub-sites once per year
Fish were surveyed between 1996 and 2009 but only the 2005 -2009 data was used as it was the most complete (some rivers had one years data missing but not multiple years).</td>
<td>Invertebrates:
<table><tr><td>Diversity (number taxon per sample):</td><td>Mean</td><td>SD</td></tr><tr><td>Limed</td><td>57.22</td><td>9.938</td></tr><tr><td>Limed discontinued</td><td>45.98</td><td>12.18</td></tr><tr><td>Reference (pH<6)</td><td>36.22</td><td>10.51</td></tr><tr><td>Reference (pH>6)</td><td>55.17</td><td>9.768</td></tr></table><table><tr><td>Abundance (number per sample)</td><td></td><td></td></tr><tr><td>Limed</td><td>1666</td><td>825.6</td></tr><tr><td>Limed discontinued</td><td>1369</td><td>725.8</td></tr><tr><td>Reference (pH<6)</td><td>1954</td><td>1304</td></tr><tr><td>Reference (pH>6)</td><td>1609</td><td>700.8</td></tr></table>Effect size (log ratio): Diversity: 0.46 (SE 0.11)
Abundance: -0.16 (SE 0.22)
(average of the limed streams to the acid reference streams)

Fish:
<table><tr><td>Abundance (number per m^2):</td><td>Mean</td><td>SD</td></tr><tr><td>Limed</td><td>0.23</td><td>0.13</td></tr><tr><td>Limed discontinued</td><td>0.20</td><td>0.13</td></tr><tr><td>Reference (pH<6)</td><td>0.09</td><td>0.11</td></tr><tr><td>Reference (pH>6)</td><td>0.35</td><td>0.23</td></tr></table><table><tr><td>Diversity (number species)</td><td>Mean</td><td>SD</td></tr><tr><td>Limed</td><td>2.45</td><td>1.08</td></tr><tr><td>Limed discontinued</td><td>2.13</td><td>1.21</td></tr><tr><td>Reference (pH<6)</td><td>1.82</td><td>0.98</td></tr><tr><td>Reference (pH>6)</td><td>2.90</td><td>0.84</td></tr></table>Effect size (log ratio): Diversity: 0.30 (SE 0.23)
Abundance: 1.04 (SE 0.48)
(average of the limed streams to the acid reference streams)</td>
<td>No before data available.
Which rivers to lime chosen by liming program not experimentally or randomly

Bias in Swedish data for number of species in river
Very variable number of spp between sites on different rivers, and only few sites per river - unlikely to be comprehsive surveys of all spp present in the rivers so bias on the number of spp
Potential problem as number will depend on the diversity between and within the sites surveyed as well as the underlying diversity in the river
Nearly 10 fold difference in area surveyed in different sites min 70m, max 631</td>
</tr>
</table>

<table>
<tr>
<td>Tovdalsvassdraget, Norwegian Survey
Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Doser and lake liming,
Doser started 1996. 5 main dosers and smaller doser on tributary. Also 2 main lakes limed along with some smaller lakes. Largest lake limed in 1996, 97, 99 and every years since 2001
Dose: Varied yearly, between 2004-2008, 4466 and 6407 metric tons 100% $CaCO_3$ equivalent dosed per year.
pH: before dosing (1980-96) 4.7-6.3; after (1997-2008) 5.8- 6.9.
Replication: one river (before and after liming)</td>
<td>Fish: Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately

Replication: 14 stations sampled per year.
One year sampled immediately prior to liming (1995), 12 years sampled during liming (1997-2008).</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><th></th><th>Salmon</th><th>Trout</th><th>Both</th></tr>
<tr><td>Before</td><td>0</td><td>19.7</td><td>19.7</td></tr>
<tr><td>During</td><td>19.9 (SD 15.4)</td><td>28.2 (SD 10.5)</td><td>48.1 (SD 16.2)</td></tr>
<tr><td>Effect size (log ratio)</td><td>NA</td><td>0.36 (SE 0.54)</td><td>0.89 (SE 0.83)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>No unlimed control river
Salmon ladder put into a waterfall in 2003 and increase in catch in 2004, salmon could get further upstream.
Only close to shore can be electrofished and so varied with water flow and height.

Stocking: fry stocked in 1997, from 2000 annual distribution of eyed eggs – fry from egg planning made up 20-64% of catch in 2000-2003</td>
</tr>
<tr>
<td>Uskedalselva, Norwegian Survey
Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Doser and coarse lime directly into the main river. One doser in the main river since 2002
Dose: 2002-2008, 42 to 85 metric tons 100% $CaCO_3$ equivalent applied each year in total.
pH: was between 5.6 and 6.7 in 2006, to 2008. pH goal of 6.2 not achieved during smelting period.
Replication: one river (before and after liming)</td>
<td>Fish: Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately

Replication: Six stations sampled each year.
One year sampled prior to liming (2001) and 7 years during liming (2002-2008).</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><th></th><th>Salmon</th><th>Trout</th><th>Both</th></tr>
<tr><td>Before</td><td>7.1</td><td>26.9</td><td>34</td></tr>
<tr><td>During</td><td>25.4 (SD 12.0)</td><td>35.2 (SD 11.8)</td><td>60.6 (SD 19.6)</td></tr>
<tr><td>Effect size (log ratio)</td><td>1.28 (SE 1.70)</td><td>0.27 (SE 0.46)</td><td>0.58 (SE 0.59)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>Landslide in 2005 impeded migration of salmon upstream.

No unlimed control river

Stocking: not mentioned.</td>
</tr>
<tr>
<td>Vegårvassdraget, Norwegian Survey
Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Doser and Lake liming.
Lake liming in one lake (since 1985) and two dosers (since 1987 and 1996, older doser was replaced in 1999).
The largest doser started in 1996 nearest salmon bearing stretch. Sampling from before and after the main doser installed in 1996
Dose: 2004-2008 at doser 95 - 322 metric ton (in 100%$CaC0_3$ equivalent) (total all dosing 261-463tonn)
pH: aim: 15/2-31/3: pH 6.2, 1/4-30/6: pH 6.4, 1/7-14/2: pH 6.0. Actual of river 1996-2008 below doser pH5.8 – 7.2; above doser pH 4.7 -7.
Replication: one river (before and after liming)</td>
<td>Fish: Electro fishing done as per the standard for the Norwegian survey.
Replication: 9 stations surveyed on the river. Samples taken one year before the main river doser was installed (1995) and for 13 years during dosing (1996-2008).</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><th></th><th>Salmon</th><th>Trout</th><th>Both</th></tr>
<tr><td>Before</td><td>23.0</td><td>28.1</td><td>51.1</td></tr>
<tr><td>During</td><td>48.0 (SD 19.4)</td><td>26.7 (SD 11.3)</td><td>74.7 (SD 23.8)</td></tr>
<tr><td>Effect size (log ratio)</td><td>0.74 (SE 0.85)</td><td>-0.05 (SE 0.42)</td><td>0.38 (SE 0.47)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>No unlimed control river
Before data, liming was already occurring but just at a lower rate and further upstream.
Hydroelectric plant built was a barrier to migration, fish ladder built in 1976 but extended when power plant was modernised in later years. A fish ‘lift’ was also added to the site of an older ironworks in 2006.

Stocking: Level of stocking unclear prior to 2000 since 2000 stocking has occurred every year of either fry or roe.</td>
</tr>
</table>

<table>
<tr>
<td>Vikedal
Norwegian Survey for fish and acid sensitive invertebrate abundance data.
AlsoInvertebrate diversity data from: Fjellheim, A. and G. G. Raddum (2001). "Acidification and liming of River Vikedal, western Norway. A 20 year study of responses in the benthic invertebrate fauna." Water Air and Soil Pollution 130(1-4): 1379-1384.</td>
<td>BA study, Norwegian survey
Doser
One doser in the main river since 1987, additional doser in tributary added in 1994
Dose: for main doser controlled by pH measurements 700m downstream of doser.
pH: In first 3 years only in operation during snow melt and dosed to ph of 5.5 to 5.7, 1990-1993 river limed to pH 6.2 from 15th Feb to 1st June, Since 1994 limed to minimum pH of 6.5 during late winter and spring snowmelt.
pH before liming included depressions down to 4.9, since liming continuously pH stable near target and down to 5.5 only during short periods of high water discharges
Replication: one river (before and after liming)</td>
<td>Fish: Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately
Replication: 9 to 17 stations sampled each year. 6 years sampled prior to liming (1981-86) and 22 years during liming (1987-2008).

Invertebrates:
Ephemeroptera, Plecoptera and Trichoptera sampled by qualitative benthic kick sampling in Spring and Autumn.
Replication: One limed and one control station sampled in one year prior to liming (1982) and one year during liming (1999).

Acid sensitive invertebrates:
Samples taken in spring and summer by kick sampling (Frost et al. 1971) and using a 30cm x 30cm opening landing net for approx. 2 mins per sample
Replication for abundance: 3 control and 9 limed sites were surveyed annually over 20 years (1987-2007).
Replication for diversity: Two reference and five limed sites were sampled over 14 years (1987-1994).</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Before</td><td>30.8 (SD 9.4)</td><td>19.3 (SD 6.7)</td><td>50.1 (SD 13.5)</td></tr>
<tr><td>During</td><td>57.1 (SD 30.9)</td><td>12.0 (SD 7.1)</td><td>69.2 (SD 29.2)</td></tr>
<tr><td>Effect size (log ratio)</td><td>0.62 (SE 0.39)</td><td>-0.48 (SE 0.19)</td><td>0.32 (SE 0.23)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)

Invertebrate diversity (number of species of Ephemeroptera, Plecoptera and Trichoptera per sample):
<table>
<tr><td></td><td>Control</td><td>Limed (since 1987)</td></tr>
<tr><td>Before (1982)</td><td>12</td><td>14</td></tr>
<tr><td>During (1999)</td><td>25</td><td>29</td></tr>
</table>
Effect size (log ratio): -0.01 (no replication to allow error calculation)

Acid sensitive invertebrate diversity (average number of sensitive species):
<table>
<tr><td>Limed</td><td>12.7 (SD 10.9)</td></tr>
<tr><td>Control</td><td>0.41 (SD 0.57)</td></tr>
</table>
Effect size (log ratio): 3.43 (SE 3.84)
(calculated from averages not individual yearly differences as in some years there was zero in the control).
Abundance (average number of acid sensitive benthic organisms per sample):
<table>
<tr><td>Limed</td><td>22.1 (SD 13.4)</td></tr>
<tr><td>Control</td><td>8.6 (SD 8.0)</td></tr>
</table>
Effect size (log ratio): 1.45 (SE 0.68)
(average of logged ratio of limed to control for each year).</td>
<td>No unlimed control river for fish data.
Control data for the invertebrates were upstream sections and tributaries in the catchment. Rivers can vary naturally along their course.

Changes in angling regulations since start of liming, salmon fishing prohibited for three years (1989-1991) and season shortened thereafter (since 1992)

Acid tributary enters river just below doser and may cause toxic mixing zone.

Stocking: of both Salomon and brown trout fry from 1960's till 1986, no stocking from 1987 onwards.</td>
</tr>
<tr>
<td>Vosges, France
Baudoin, J-M (2007) Biodiversité et fonctionnement de cours d'eau forestiers de tête de bassin : Effet de l'acidification anthropique et d'une restauration</td>
<td>BACI study
Catchment liming - by helicopter evenly over catchment, Crushed limestone applied to sandstone and granite areas
Dose: average dose 2.5 tonns per hectera
pH: Sandstone: Limed - pH before 4.3, after 4.6, control 4.6; Granite: pH limed before 5.1, after 5.6, control 4.9
Replication: 2 groups of paired limed and control streams, one on sandstone and one on granite.</td>
<td>Benthic invertebrates
Diversity, number of taxa
Invertebrates collected from bags of leaves (beech) left for decomposition experiments, invertebrates separated by 0.125mm sieve and identified to highest taxonomic level possible, generally species but higher were this was not possible
2 months between last liming and first sampling.
Replication: one total given for before (in 2003) and after liming (in 2004) in each stream.</td>
<td>Invertebrate abundance
<table>
<tr><td></td><td colspan="2">Sandstone</td><td colspan="2">Granite</td></tr>
<tr><td></td><td>limed</td><td>acid</td><td>limed</td><td>acid</td></tr>
<tr><td>before</td><td>21</td><td>17</td><td>22</td><td>18</td></tr>
<tr><td>after</td><td>17</td><td>19</td><td>18</td><td>20</td></tr>
</table>
Effect size (log ratio): -0.31 (SE 0.01)
(log of ratio of after to before treatment for limed divided by ratio for acid, and then averaged across two groups)</td>
<td>One of the limed streams still below a pH of 5 after liming

Unclear how limed and control streams chosen.

Stocking: not mentioned</td>
</tr>
</table>

<table>
<tr>
<td>Vosso, Norway
Norwegian Survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA study, Norwegian survey
Doser and Lake
One doser in operation 1994-2005
Shell-sand placed directly into tributaries 1994-2003
Lakes limed annually. One lake limed since 1993, with an additional two limed annually since 1997, a total of four since 1999.
Dose: Doser dose controlled by water flow
pH: aim: 6.2 (15/2-31/3), 6.4 (1/4-31-5), 6.0 (1/6-14/2)
pH average annual min prior to liming 6.0 (SD 0.1), post liming, 6.1 (SD 0.1). Max pH prior 6.5 (SD 0.1), post 6.6 (SD 0.1)
Replication: one river (before and after liming)</td>
<td>Fish: Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately

Replication: 3 stations sampled in the main river, 3 stations upstream of main doser and 4 stations sampled in tributary.
3 years sampled prior to liming (1991-1993) and 10 years during liming (1994 – 2004).</td>
<td>Fish abundance (number per 100m^2):
<table>
<tr><td></td><td>Pre treatment</td><td>Treatment</td><td>Effect size (log ratio)</td></tr>
<tr><td>Salmon</td><td></td><td></td><td></td></tr>
<tr><td>Main river</td><td>46 (SD 31)</td><td>17 (SD 13)</td><td>-1.0 (SE 0.1)</td></tr>
<tr><td>Upstream</td><td>73 (SD 24)</td><td>37 (SD 12)</td><td>-0.7 (SE 0.4)</td></tr>
<tr><td>Tributary</td><td>18 (SD 13)</td><td>20 (SD 14)</td><td>0.1 (SE 0.1)</td></tr>
<tr><td>Trout</td><td></td><td></td><td></td></tr>
<tr><td>Main river</td><td>37 (SD 11)</td><td>50 (SD 23)</td><td>0.3 (SE 0.1)</td></tr>
<tr><td>Upstream</td><td>11 (SD 5)</td><td>54 (SD 23)</td><td>1.6 (SE 0.2)</td></tr>
<tr><td>Tributary</td><td>65 (SD 31)</td><td>75 (SD 33)</td><td>0.1 (SE 0.1)</td></tr>
<tr><td>Both</td><td></td><td></td><td></td></tr>
<tr><td>Main river</td><td>82 (SD 34)</td><td>67 (SD 27)</td><td>-0.2(SE0.04)</td></tr>
<tr><td>Upstream</td><td>84 (SD 29)</td><td>91 (SD 31)</td><td>0.1 (SE0.04)</td></tr>
<tr><td>Tributary</td><td>83 (SD 34)</td><td>95 (SD 40)</td><td>0.1 (SE 0.1)</td></tr>
</table>
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Combined effect size (log ratio)</td><td>-0.52 (SE 0.56)</td><td>(SE 0.78)</td><td>0.00 (SE 0.18)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged, Combined affect size calculated by averaging across three sites)</td>
<td>No unlimed control river for fish data.Control data for the invertebrates were upstream sections and tributaries in the catchment. Rivers can vary naturally along their course.
Salmon ladder that was built in the 1950s was restored in the late 1980s allowing greater movement of salmon upstream.
Since 1992 the salmon in the river have been protected.
Stocking: Extensive stocking started in 1990 with annual release of salmon fry (and sometimes smolts)
Stocked fish included in abundances reported.
Escaped farmed salmon also present in the area.
Possibly trout also stocked.</td>
</tr>
<tr>
<td>West Virginia (-Dogway), USA
McClurg, S. E., J. T. Petty, et al. (2007). "Stream ecosystem response to limestone treatment in acid impacted watersheds of the allegheny plateau." Ecological Applications 17(4): 1087-1104.</td>
<td>CI study
Point application of limestone 8 treated streams reported in study but one Dogway studied for invertebrates in greater detail in separate study.
Dose: Of 7 included streams 6 were limed yearly by point source applications of limestone sand into the river and 1 was limed by continuously by a hydropowered limestone doser. Exact doses not reported.
Length of liming varied from 2 to 20 years.
pH: Average pH streams (SD); acid control: 4.9 (0.1), limed 6.8 (0.4)
Replication: 4 control streams and 8 treated streams for fish, 7 treated streams for invertebrates.</td>
<td>Invertebrates
Sampled in May using modified Hess sampler (0.1m2, 250µm mesh net) within targeted riffle habitat
samples identified to order, genera or family depending
Replication: 5 randomly selected locations sampled in each study reach, at one time in 2005
The invertebrates of one stream (Dogway) included in its own study with before data So is excluded from the effect size of this study

Fish: July 2003 using one-pass electrofishing procedue modified from EPA-EMAP protocols
Replication: one sample per stream (taken in 2005)
(Two streams – First Fork and one of the Shavers Fork group fish abundance was also recorded in separate studies, however, separate data is not included in this study so effect size still included this these river)</td>
<td>Invertebrate abundance and diversity:
(SD in brackets)
<table>
<tr><td></td><td>Diversity (Number of taxon)</td><td>Abundance (number per m^2)</td></tr>
<tr><td>Control streams (4)</td><td>16.8 (SD 2.5)</td><td>2040 (SD 1009)</td></tr>
<tr><td>Treated streams (7)</td><td>17.1 (SD 4.4)</td><td>1168 (SD 1079)</td></tr>
</table>
Effect size (log ratio): Diversity 0.02 (SE 0.14)
Abundance: -0.56 (SE 0.43)
Acid sensitive invertebrate abundance and diversity:
(SD in brackets)
<table>
<tr><td></td><td>Diversity (Number of taxon)</td><td>Abundance (number per m^2)</td></tr>
<tr><td>Control streams (4)</td><td>0 (SD 0)</td><td>0 (SD 0)</td></tr>
<tr><td>Treated streams (7)</td><td>3.1 (SD 3.1)</td><td>540 (SD 531)</td></tr>
</table>
Effect size (log ratio): Diversity 0.02 (SE 0.14)
Abundance: -0.56 (SE 0.43)
Fish:
<table>
<tr><td></td><td>Diversity (# of species)</td><td>Abundance (biomass, g/ m^2)</td></tr>
<tr><td>Control streams (4)</td><td>2 (SE 0.7)</td><td>0.1 (SE 0.02)</td></tr>
<tr><td>Treated streams (8)</td><td>6 (SE 1.3)</td><td>1.3 (SE 0.25)</td></tr>
</table>
Effect size (log ratio):
Diversity: 1.1 (SE 0.3) Abundance: 2.6 (SE 1.0)</td>
<td>There is no baseline data reported for the streams

Controls were selected to match pre-treatment condition of limed streams reducing the risk of baseline differences. However, limed streams were part of a state liming program already in operation and it was unclear how it was decided which streams to lime.

Unclear how specific sites for sampling in each reach were chosen

There were more control streams than treatment streams.

The exact length of dosing is not reported.

Stocking: not mentioned</td>
</tr>
</table>

<table>
<tr>
<td>Whetstone Brook , USA
Invertebrates: Simmons, K. R. and K. Doyle (1996). "Limestone treatment of Whetstone Brook, Massachusetts .3. Changes in the invertebrate fauna." Restoration Ecology 4(3): 284-292.</td>
<td>BACI
Doser
Continuous point application within the river
Dose: 56tonnes limestone applied over 3 years of dosing
pH: pH just below doser increased from mean of 5.86 (SE 0.06) to 6.62 (SE 0.06)
Replication: one river limed, control sites upstream of doser</td>
<td>Invertebrates – Samples collected May, August and October each year. Samples collected with Surber sampler (0.1m^2 with 500µm mesh), within riffle habitat, samples collected by gently scrubbing all substrate with a brush in area delimited by sampler down to 5cm depth.
Replication: 6 samples taken at each station using random sampling methods, 2 sampling stations upstream of doser and 4 downstream, each 80m long. Sampled for 3 years pre liming (1986-8; 9 samples) and 3 years post (1989-91; 9 samples).

Fish: Sampled in late Sept or early Oct each year by removal via multiple passes with a backpack DC electrofishing unit, at least 3 runs per station, block seines placed at upstream and downstream boundaries of stations to contain fish during sampling. May and June also samples taken for species composition
Replication: One sample per year per station, 2 sampling stations upstream of doser and 4 downstream, each 80m long. Sampled for 4 years pre treatment (1985-88) and 3 years post (1989-91).</td>
<td>Invertebrates:
Abundance (number of specimens caught per m^2)
<table>
<tr><td></td><td>Pre-treatment</td><td>Treatment</td></tr>
<tr><td>Control</td><td>2500 (SD 500)</td><td>2340 (SD 1660)</td></tr>
<tr><td>Treatment</td><td>1990 (SD 690)</td><td>1660 (SD 570)</td></tr>
</table>
Effect size (log ratio): -0.04 (SE 0.27)
Diversity (number of taxa per sample)
<table>
<tr><td></td><td>Pre-treatment</td><td>Treatment</td></tr>
<tr><td>Control</td><td>61.8 (SD 3.6)</td><td>53.2 (SD 3.7)</td></tr>
<tr><td>Treatment</td><td>62.5 (SD 4.2)</td><td>64.1 (SD 8.0)</td></tr>
</table>
Effect size (log ratio): 0.17 (SE 0.07)
(For both effect sizes: treatment period divided by the pre treatment for each station then averaged across treatment and control sites. Treatment averaged divided by control average then logged).
Fish:
Diversity (number of species)
<table>
<tr><td></td><td>Pre-treatment</td><td>Treatment</td></tr>
<tr><td>Control</td><td>2.8 (SD 1.0)</td><td>2.0 (SD 0)</td></tr>
<tr><td>Treatment</td><td>3.3 (SD 0.5)</td><td>2.7 (SD 0.6)</td></tr>
</table>
Abundance (average number of fish collected per year per sampling station)
<table>
<tr><td></td><td>Pre-treatment</td><td>Treatment</td></tr>
<tr><td>Control</td><td>23.8 (SD 10.6)</td><td>19.7 (SD 8.0)</td></tr>
<tr><td>Treatment</td><td>26.7 (SD 6.4)</td><td>22.6 (SD.4)</td></tr>
</table>
Abundance (average number of brown trout collected per year)
<table>
<tr><td></td><td>Pre-treatment</td><td>Treatment</td></tr>
<tr><td>Control</td><td></td><td></td></tr>
<tr><td>Treatment</td><td></td><td></td></tr>
</table>
Effect size (log ratio) diversity: 0.02 (SE 0.27)
Abundance: -0.01 (SE 0.27)

(the treatment divided by the control for each year, then averaged for the pre-treatment years and treatment years. The average for the treatment divided by the average for the pre-treatment and logged)</td>
<td>Fewer control samples than treatment samples.

Control upstream section of treated river, not fully independent.

Stocking: No stocking or angling</td>
</tr>
</table>

<table>
<tr>
<td>Wye, UK
Merrix, F., et al. (2006). "The effects of low pH and palliative liming on beech litter decomposition in acid-sensitive streams." Hydrobiologia 571(1): 373-381.</td>
<td>CI study
Catchment liming in source areas
Dose: a total of 750t $CaCO_3$ applied by the time of sampling, liming had started 2 years prior to sampling.
pH: pH of limed higher, mean in study (SD); limed 5.0(0.3), acid 4.6 (0.7)
Replication: 3 limed streams and 3 unlimed control streams.</td>
<td>Invertebrate diversity (number of taxon) collected by kick sampling of 4 min duration in mid stream riffles and 2 min in stream margins ie 6 min per site with standard FBA pond nets (frame 230X250mm, mesh size 900µm)

Replication: one sample per stream (in 2005).</td>
<td>Invertebrate diversity (number of taxa):
<table>
<tr><td>Treatment</td><td>land use</td><td>total # taxa</td></tr>
<tr><td>Limed</td><td>Rough pasture</td><td>223</td></tr>
<tr><td>Limed</td><td>Coniferous forest</td><td>48</td></tr>
<tr><td>Limed</td><td>Coniferous forest</td><td>131</td></tr>
<tr><td>Acidic</td><td>Improved grassland</td><td>280</td></tr>
<tr><td>Acidic</td><td>Coniferous forest</td><td>45</td></tr>
<tr><td>Acidic</td><td>Coniferous forest</td><td>435</td></tr>
</table>
Effect size (log ratio): -0.63 (s.e. 0.74)
(number averaged for limed and acidic, then limed divided by acidic and then logged)</td>
<td>No baseline (before) data given,
Unclear how control and intervention sites chosen- no indication of it being random,

Stocking: not mentioned</td>
</tr>
<tr>
<td>Yndesdalsvassdraget, Norwegian survey Direktoratet for naturforvaltning, 2009. Kalking i laksevassdrag. Effektkontroll i 2008. Notat 2009-2</td>
<td>BA, Norwegian Survey
Doser and Lake
1991-2003 annual full liming of Yndesdal lake
1994 onwards continuous doser at Ostavatn
Dose: No data before liming but data before and after continuous doser
pH: aim >6.2 on salmon bearing stretch throughout the year
2002-08: pH 5.9 – 7 except for one reading of 4.9.
Above doser pH 4.6 to 5.7
Replication: one river (before and after continuous dosing)</td>
<td>Fish surveyed by electro-fishing, Three passed made with repeated withdrawal, fish density calculated using Bohlin et al (1989) for fry and par separately
Replication: samples from 3 year prior to (continuous doser) liming (1991-1993), 14 years during liming (1994 -2008)</td>
<td>Fish abundance (number of fry and par per $100m^2$):
Salmon bearing stretch:
<table>
<tr><td></td><td>Salmon</td><td>Trout</td><td>Both</td></tr>
<tr><td>Pre treatment (3 years)</td><td>1.9 (SD 2.1)</td><td>81.4 (SD 21.2)</td><td>83.3 (SD 21.2)</td></tr>
<tr><td>Treatment (14 years)</td><td>35.2 (SD 27.2)</td><td>39.6 (SD 14.7)</td><td>74.8 (SD 34.6)</td></tr>
<tr><td>Effect size (log ratio)</td><td>2.92 (SE 7.72)</td><td>-0.72 (SE 0.15)</td><td>-0.11 (SE 0.19)</td></tr>
</table>
Above salmon bearing stretch, only trout
<table>
<tr><td>Pre treatment (3 years)</td><td>31.7 (SD 5.8)</td></tr>
<tr><td>Treatment (14 years)</td><td>49.5 (SD 10.6)</td></tr>
<tr><td>Effect size (log ratio)</td><td>0.44 (SE 0.06)</td></tr>
</table>
(Effect size calculated as average after liming divided by average before liming and then logged)</td>
<td>Many more years after treatment surveyed than before treatment

No unlimed control river

Before data already some liming being carried out

Stocking: not mentioned</td>
</tr>
</table>

B2. Articles not used in the quantitative review:

Study/Report	**Reason for not including in quantitative analysis** **Report finding and rivers covered**
Norwegian reports not used in quantitative review.	
Hesthagen, T. and B. M. Larsen (2003). "Recovery and re-establishment of Atlantic salmon, Salmo salar, in limed Norwegian rivers." Fisheries Management and Ecology 10(2): 87-95.	No extra data to Norwegian survey report; 21 rivers covered
Haraldstad, O., D. Matzow, et al. Strategies for re-establishing Atlantic salmon (Salmo salar) in two limed rivers in southern Norway, Directorate of Nature Management.	No extra data on liming to Norwegian survey; River Tovdalselva and Mandalselva
Larsen, B. M. and T. Hesthagen (1995). "The effects of liming on juvenile stocks of Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) in a Norwegian river." Water Air and Soil Pollution 85(2): 991-996.	Smaller time series than Norwegian survey report; Vikedalselva
Larsen, B. M., O. T. Sandlund, et al. (2007). "Invasives, Introductions and Acidification: The Dynamics of a Stressed River Fish Community." Water, Air, & Soil Pollution: Focus 7(1-3): 285-291.	No pre-liming data or controls; River Litlana, tributary to river Kvina
(NASCO), North Atlantic Salmon Conservation Organization (NASCO) and Conserving and restoring wild Atlantic salmon, Restoration and Enhancement of Salmon Habitat Focus Area Report Norway North Atlantic Salmon Conservation Organization, Conserving and restoring wild Atlantic salmo.	Salmon abundance in all limed rivers combined, individual data available in other papers; Paper reports an increase in catch in all limed rivers.
Norwegian survey report on Arendal	No clear before data (and no control sites) - Lime dosing stated to be by lake and doser but not clear when doser started – whether it was before or after lake dosing; River Arendal
Poléo, A. B. S. (2005). Acid Rain 2005, SESSION 11 , Effects on aquatic biota Acid rain 2005, 7th international conference on acid deposition	names of rivers not given fish - trout trends over all rivers over time, may be usefull for double checking results but no new primary data
Raddum, G. G. and A. Fjellheim (2003). “Liming of River Audna, Southern Norway: A Large-scale Experiment of Benthic Invertebrate Recovery.” Ambio 23(3): 230-234.	Only accumulative number of invertebrates over time not average in each year; river Audna
Rosseland, B. O. and A. Hindar (1988). “Liming of lakes, rivers and catchments in Norway.” Water, Air, & Soil Pollution 41(1): 165-188.	No extra data to other studies presented; Audna
Sandoy, S. and A. J. Romundstad (1995). “Liming of acidified lakes and rivers in Norway – An attempt to preserve and restore biological diversity in the acidified regions.” Water Air and Soil Pollution 85(2): 997-1002.	No extra data to other studies included; river Audna
Walseng, B., R. M. Langaker, et al. (2001). "The River Bjerkreim in SW Norway - Successful chemical and biological recovery after liming." Water Air and Soil Pollution 130(1-4): 1331-1336	No extra data to Norwegian survey; Bjerkreim
Westling, O., T. Zetterberg, et al. (2007). "Recovery of Acidified Streams in Forests Treated by Total Catchment Liming." Water, Air, & Soil Pollution: Focus 7(1): 347-356.	Effect of liming in isolation not recorded; Wood ash also applied to all treated sites and a small obstruction/ barrier to fish removed at the same time as liming which allowed trout to fully enter stream for the first time. Catchment liming - Limed applied by helicopter and tractor over one winter, 52 tons applied to discharge areas (3.8 tons/ha) and 15530 tons applied to recharge areas (10.6 tons/ha) 1 limed stream, 1 control Statement of Brown trout started to successfully reproduce in limed stream but not present in control stream. Data shows increase in trout abundance post liming
Swedish studies/reports:	
Ahlström, J. and M. Johansson (2010) Monitoring the Effects of Acidification and Liming on Water Quality in a Boreal Stream: The River Stridbäcken in Northern Sweden. In: Conservation Monitoring in Freshwater Habitats, 231-244	Data covered by main Swedish database; river Stridbacken
Kullberg, A. and R. C. Petersen (1987). "Dissolved organic carbon, seston and macroinvertebrate drift in an acidified and limed humic stream." Freshwater Biology 17(3): 553-564.	Data covered by main Swedish database; river Fyllean
Bengtsson, B., W. Dickson, et al. (1980). "Liming Acid Lakes in Sweden." Ambio 9(1): 34-36.	Data covered by main Swedish database; Hogvadsan river - report of increase
Bergquist, B. and M. Dahlberg (2009). Fisksamhällen i kalkade IKEU-vattendrag och okalkade	Data covered by main Swedish database; Storselsan, Stridbacken, Aran, Adalsan,

referensvattendrag (kapitel 2b:4 i Utvärdering av IKEU 1990-2006 - Syntes och förslag). (Fishing communities in limed IKEU-water and unlimed reference streams), Naturvårdsverket, Stockholm, Rapport 6302:474-499.	Djursvasslan, Kallsjoan, Enangersan, Enan, Haraldsjoan, Skuggalven, Svanan, Hastganagsan, Ljungaan, Sallevadsan, Hovgardsan, Lillan, Blankan, Stronhultsan, Rokea
Dahlberg, M. and B. Bergquist (2003). "Provfiskeresultat år 2002. IKEU-programmets vattendrag och Miljöövervakningens referensvattendrag. (Test fishing results in 2002. IKEU program streams and environmental monitoring reference streams.)." Fiskeriverket, Finfo 2003:10.	Data covered by main Swedish database; Rivers included in sent database
McKie, B., P. O. Hoffsten, et al. (2006). Compilation and analysis of benthic macroinvertebrate data collected IKEU-streams., Inst. för tillämpad miljövetenskap, Stockholms universitet, Stockholm, ITM-rapport 150.	Data covered by main Swedish database; Storselsån, Arån Arålund, Ådalsån Lyckemyran (D), Källsjöån Källsjöklack, Enångersån V. Lövås, Haraldssjöån Sandån Övre, Skuggälven, Hästgångsån Hästgången, Lillån G:a Järnvägsbron, Blankan Ryerna, Hovgårdsån Munkhättan, Strönhultsån G. Kvarnen Covered by data sent
McKie, B. G., Z. Petrin, et al. (2006). "Mitigation or disturbance? Effects of liming on macroinvertebrate assemblage structure and leaf-litter decomposition in the humic streams of northern Sweden." Journal of Applied Ecology 43(4): 780-791.	Data covered by main Swedish database;
Krogerstrom, L. **(**1988) "Salmon Spawning Again in Limed River**"** Acid Mag. (journal of the Swedish environmental protection agency), 7: 10	Data covered by main Swedish database; Ätran River and its main tributary – River Hogvadsn. Report that salmon had returned to the Ätran River and its main tributary – River Hogvadsn which is included in the main dataset
Reizenstein, M., Holmgren, K. and Bergquist, B. (2005) Befintlig information om fisk och kraftor I nya IKEU-objekt, Sammanstallning av ett specialprojekt 2005. (Existing information on fish and crayfish in new IKEU object) *PM 2005-12-27 Fiskeriverket, Sötvattenslaboratoriet*	No additional controls rivers to the main database, some additional limed rivers but contains less information on these rivers so hard to integrate into the main database and would create systematic differences between the treated and control sites.
Other studies	
(2005). Mitigation of soil and water acidification Acid Rain 2005, 7th International conference on acid deposition Prague, Czech Republic.	no extra data
Arnold, D. E., W. D. Skinner, et al. (1988). "Evaluation of Three Experimental Low-Technology Approaches to Acid Mitigation in Headwater Streams." Water, Air, and Soil Pollution WAPLAC 41(1-4): 385-406.	Soda ash application in one stream by a streamside dissolution tank. Samples only taken over 60 days and method stated to be ineffective as a liming application method, as soda ash cohered into a solid mass in tank. No significant change in invertebrates observed but data hard to read off graph – appears data may only have been taken over three hours, axis not labelled.
Brown, D. J. A., G. D. Howells, et al. (1988). "Loch Fleet - a research watershed liming project." Water, Air, and Soil Pollution 41(1-4): 25-41.	Loch fleet statement of change with liming, no data given, data available in other papers about site.
Burns, J. C., Harriman R., Morrison B. R. and Quine C. P. (1984)"The Loch Dee Project-a Study of the Ecological Effects of Acid Precipitation and Forest Management on an Upland Catchment in South-West Scotland. 1. Preliminary Investigations" Fisheries Management: 15 (4) 145-167.	Application of limestone into some catchments into a loch for mitigating acidification as part of a long term acidification and forestry project. No monitoring data from the limed stream from after the lime was applied.
Gasper, D. C. "New Opportunities: New Native Brook Trout Streams, A New Wilderness Stream Restoration – Liming"	No extra data to Menendez, et al. (1996) and Clayton and Menendez (1996). Cranberry river, south fork, Dogway fork,
Howells, G., T. R. K. Dalziel, et al. (1992). "Loch fleet: liming to restore a brown trout fishery." Environmental Pollution 78(1-3): 131-139.	Loch Fleet statement of increased spawning post liming but not data
Keener, A. L. and W. E. Sharpe (2005). "The Effects of Doubling Limestone Sand Applications in Two Acidic Southwestern Pennsylvania Streams." Restoration Ecology 13(1): 108-119.	Earlier study on single application included. Bear Run
Kreček, J. and Z. Horická (2001). "Degradation and recovery of mountain watersheds: the Jizera Mountains, Czech Republic." Unasylva (English ed.) 52(207): 43-49.	Multiple interventions – cannot distinguish effect of liming from data given.
Lacroix, G. L. (1992). "Mitigation of low stream ph and its effects on Salmonids." Environmental Pollution 78(1-3): 157-164.	Update of paper included in the review. Lacriox (1996)
Marcogliese, D.J. and Cone, D.K. (1997) "Parasite communities as indicators of ecosystem stress." Parassitologia, 39 (3), 227-232	Relevant data covered by Cone (1993)
Masters, Z., I. Peteresen, et al. (2007). "Insect dispersal does not limit the biological recovery of streams from acidification." Aquatic Conservation: Marine and Freshwater Ecosystems 17(4):	Llyn Brianne insect dispersal and recolonisation ability after liming, abundance and diversity covered by other papers

375-383.	
Messant, D., J. Bock, et al. (2008). "Restoration of two acidified sloping catchments in the Vosges by amendment with calcium-magnesium." RenDez-Vous Techniques(22): 3-12.	No primary data but statement trout increased post liming, was no trout before liming and after liming stocked trout survived
Ormerod, S. J. and I. Durance (2009). "Restoration and recovery from acidification in upland Welsh streams over 25 years." Journal of Applied Ecology 46(1): 164-174.	Ordination data, earlier data (with first 9 years post liming) used instead; Bradley and Ormerod 2002
Rundle, S. D., N. S. Weatherley, et al. (1995). "The effects of catchment liming on the chemistry and biology of upland Welsh streams: Testing model predictions." Freshwater biology. Oxford 34(1): 165-175.	Llyn Brianne – Data included in Bradley and Ormerod 2002
Scarr, A. (1997). “Lime dosing to restore the upper Tywi = : Dogni calch i adfer blaenau'r afon Tywi.” Hwlffordd, Adran yr Amgylchedd. Environment Agency report	Information contained within later paper.
Simon, K. S., M. A. Simon, et al. (2009). "Variation in ecosystem function in Appalachian streams along an acidity gradient." Ecological applications : a publication of the Ecological Society of America 19(5): 1147-1160.	Sites already included with earlier data - gives later data for invert shredders but not all invertebrates or fish.
Swierczynski, M. and G. Matlawski (1992). "An attempt on neutralize acidified mountain waters on example of the investigated streams: The Czerwien, Myja and Podgorna." Acta Ichthyologica et Piscatoria 22(1): 75-95.	Difference in invert diversity in traps with and without chalk added not actually difference with and without chalk added to the stream, not the treatment we actually want to test
Weatherley, N. S. and S. J. Ormerod (1990). "The constancy of invertebrate assemblages in soft-water streams: implications for the prediction and detection of environmental change." Journal of Applied Ecology 27(3): 952-964.	Acidic index of streams and change with liming but no extra data on abundance and diversity to other studies on Llyn Brianne.

List of articles by author:

(2005). Mitigation of soil and water acidification Acid Rain 2005, 7th International conference on acid deposition Prague, Czech Republic.

(2006). Proceedings of the Acid Rain Mitigation Workshop, Bedford Institute of Oceanography.

North Atlantic Salmon Conservation Organization (NASCO), Restoration and Enhancement of Salmon Habitat Focus Area Report Norway North Atlantic Salmon Conservation Organization, Conserving and restoring wild Atlantic salmo.

Ahlström, J. and M. Johansson (2010). Monitoring the Effects of Acidification and Liming on Water Quality in a Boreal Stream: The River Stridbäcken in Northern Sweden. Conservation Monitoring in Freshwater Habitats: 231-244.

Arnold, D. E., W. D. Skinner, et al. (1988). "Evaluation of Three Experimental Low-Technology Approaches to Acid Mitigation in Headwater Streams." Water, Air, and Soil Pollution WAPLAC 41(1-4): 385-406.

Baudoin, J. M. and F. Guerold (2007). Biodiversity and functioning of forested headwater streams: effect of acidification and restoration. Universite Paul Verlaine, Metz: 258

Bengtsson, B., W. Dickson, et al. (1980). "Liming Acid Lakes in Sweden." Ambio 9(1): 34-36.

Bergquist, B. and M. Dahlberg (2009). Fisksamhällen i kalkade IKEU-vattendrag och okalkade referensvattendrag (kapitel 2b:4 i Utvärdering av IKEU 1990-2006 - Syntes och förslag). (Fishing communities in limed IKEU-water and unlimed reference streams), Naturvårdsverket, Stockholm, Rapport 6302:474-499.

Bradley, D. C. and S. J. Ormerod (2002). "Long-term effects of catchment liming on invertebrates in upland streams." Freshwater Biology 47(1): 161-171.

Brown, D. J. A., G. D. Howells, et al. (1988). "Loch Fleet - a research watershed liming project." Water, Air, and Soil Pollution 41(1-4): 25-41.

Clayton, J. L., E. S. Dannaway, et al. (1998). "Application of Limestone to Restore Fish Communities in Acidified Streams." North American Journal of Fisheries Management 18(2): 347-360.

Clayton, J. L. and R. Menendez (1996). "Macroinvertebrate responses to mitigative liming of Dogway Fork, West Virginia." Restoration Ecology 4(3): 234-246.

Cone, D. K., D. J. Marcogliese, et al. (1993). "Metazoan parasite communities of yellow eels (Anguilla rostrata) in acidic and limed rivers of Nova Scotia." Canadian Journal of Zoology/Revue Canadienne de Zoologie 71(1): 177-184.

Dahlberg, M. and B. Bergquist (2003). "Provfiskeresultat år 2002. IKEU-programmets vattendrag och Miljöövervakningens referensvattendrag. (Test fishing results in 2002. IKEU program streams and environmental monitoring reference streams.)." Fiskeriverket, Finfo 2003:10.

Degerman, E. and M. Appelberg (1992). "The response of stream-dwelling fish to liming." Environ Pollut 78(1-3): 149-155.

Diamond, M., D. Hirst, et al. (1992). "The effect of liming agricultural land on the chemistry and biology of the River Esk, north-west England." Environmental Pollution 78(1-3): 179-185.

Downey, D. M., C. R. French, et al. (1994). "Low cost limestone treatment of acid sensitive trout streams in the Appalachian Mountains of Virginia." Water, Air, & Soil Pollution 77(1-2): 49-77.

Eggleton, M. A., E. L. Morgan, et al. (1996). "Effects of liming on an acid-sensitive southern Appalachian stream." Restoration Ecology 4(3): 247-263.

Fjellheim, A. and G. G. Raddum (1992). "Recovery of acid-sensitive species of ephemeroptera, plecoptera and trichoptera in river audna after liming." Environmental Pollution 78(1): 173-178.

Fjellheim, A. and G. G. Raddum (1995). "Benthic animal response after liming of three South Norwegian rivers." Water, Air, and Soil Pollution 85(2): 931-936.

Fjellheim, A. and G. G. Raddum (2001). "Acidification and liming of River Vikedal, western Norway. A 20 year study of responses in the benthic invertebrate fauna." Water Air and Soil Pollution 130(1-4): 1379-1384.

Gasper, D. C. New Opportunities: New Native Brook Trout Streams, A New Wilderness Stream Restoration - Lining, Fish Biologist WV DNR - Retired 4 Ritchie Street Buckhannon, WV 26201.

Greening, H. S., A. J. Janicki, et al. (1989). An Evaluation of Stream Liming Effects on Water Quality and Spawning of Migratory Fishes in Maryland Coastal Plain Streams: 1988 Results, Final Report AD-89-5, Maryland Department of Natural Resources Chesapeake Bay Research and Monitoring Division, Annapolis, MD.

Haraldstad, O., D. Matzow, et al. Strategies for re-establishing Atlantic salmon (Salmo salar) in two limed rivers in southern Norway, Directorate of Nature Management.

Hartman, K. J., M. B. Adams, et al. (2007). "Evidence of stock-recruit relationships for Appalachian brook trout." Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 61: 40-45.

Herrmann, J. and B. S. Svensson (1995). "Resilience of macroinvertebrate communities in acidified and limed streams." Water, Air, and Soil Pollution 85(2): 413-418.

Hesthagen, T. and B. M. Larsen (2003). "Recovery and re-establishment of Atlantic salmon, Salmo salar, in limed Norwegian rivers." Fisheries Management and Ecology 10(2): 87-95.

Howells, G., T. R. K. Dalziel, et al. (1992). "Loch fleet: liming to restore a brown trout fishery." Environmental Pollution 78(1-3): 131-139.

Hudy, M., D. M. Downey, et al. (2000). "Successful Restoration of an Acidified Native Brook Trout Stream through Mitigation with Limestone Sand." North American Journal of Fisheries Management 20(2): 453-466.

Keener, A. L. and W. E. Sharpe (2005). "The Effects of Doubling Limestone Sand Applications in Two Acidic Southwestern Pennsylvania Streams." Restoration Ecology 13(1): 108-119.

Kreček, J. and Z. Horická (2001). "Degradation and recovery of mountain watersheds: the Jizera Mountains, Czech Republic." Unasylva (English ed.) 52(207): 43-49.

Kullberg, A. and R. C. Petersen (1987). "Dissolved organic carbon, seston and macroinvertebrate drift in an acidified and limed humic stream." Freshwater Biology 17(3): 553-564.

Lacroix, G. L. (1992). "Mitigation of low stream ph and its effects on salmonids." Environmental Pollution 78(1-3): 157-164.

Lacroix, G. L. (1996). "Long-term enhancement of habitat for salmonids in acidified running waters." Canadian Journal of Fisheries and Aquatic Sciences 53: 283-294.

Larsen, B. M. and T. Hesthagen (1995). "The effects of liming on juvenile stocks of Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) in a Norwegian river." Water Air and Soil Pollution 85(2): 991-996.

Larsen, B. M., O. T. Sandlund, et al. (2007). "Invasives, Introductions and Acidification: The Dynamics of a Stressed River Fish Community." Water, Air, & Soil Pollution: Focus 7(1-3): 285-291.

Larsson, P.-E., C. Akselsson, et al. (1998). Biologiska effekter i kalkad skog. Arsrapport 1998, Effektuppfoljning av Skogsstyrelsens program for kalkning och vitaliseringsgodsling av skogsmark, IVL svenska Miljoinstitutet AB.

LeFevre, S. R. and W. E. Sharpe (2002). "Acid stream water remediation using limestone sand on bear run in southwestern Pennsylvania." Restoration Ecology 10(2): 223-236.

Lingdell, P. E. and E. Engblom (1995). "Liming restores the benthic invertebrate community to "pristine" state." Water, Air, and Soil Pollution 85(2): 955-960.

Marcogliese, D. J. and D. K. Cone (1997). "Parasite communities as indicators of ecosystem stress." Parassitologia 39(3): 227-232.

Masters, Z., I. Peteresen, et al. (2007). "Insect dispersal does not limit the biological recovery of streams from acidification." Aquatic Conservation: Marine and Freshwater Ecosystems 17(4): 375-383.

McClurg, S. E., J. T. Petty, et al. (2007). "Stream ecosystem response to limestone treatment in acid impacted watersheds of the allegheny plateau." Ecological Applications 17(4): 1087-1104.

McKie, B., P. O. Hoffsten, et al. (2006). Compilation and analysis of benthic macroinvertebrate data collected IKEU-streams., Inst. för tillämpad miljövetenskap, Stockholms universitet, Stockholm, ITM-rapport 150.

McKie, B. G., Z. Petrin, et al. (2006). "Mitigation or disturbance? Effects of liming on macroinvertebrate assemblage structure and leaf-litter decomposition in the humic streams of northern Sweden." Journal of Applied Ecology 43(4): 780-791.

Menendez, R., J. L. Clayton, et al. (1996). "Chemical and fishery responses to mitigative liming of an acidic stream, Dogway Fork, West Virginia." Restoration Ecology 4(3): 220-233.

Merrix, F., B. Lewis, et al. (2006). "The effects of low pH and palliative liming on beech litter decomposition in acid-sensitive streams." Hydrobiologia 571(1): 373-381.

Messant, D., J. Bock, et al. (2008). "Restoration of two acidified sloping catchments in the Vosges by amendment with calcium-magnesium." RenDez-Vous Techniques(22): 3-12.

Milner, A. G. P. and R. J. Aston (1995). "Pre- and post-liming aquatic communities and trout diets." Chemistry and Ecology 9(3-4): 193-205.

Nyberg, P., M. Appelberg, et al. (1986). "Effects of liming on crayfish and fish in Sweden." Water, Air, & Soil Pollution 31(3): 669-687.

Olofsson, E., E. Melin, et al. (1995). "The Decline of Fauna in Small Streams in the Swedish Mountain Range." Water Air and Soil Pollution 85(2): 419-424

Ormerod, S. J. and I. Durance (2009). "Restoration and recovery from acidification in upland Welsh streams over 25 years." Journal of Applied Ecology 46(1): 164-174.

Ormerod, S. J., N. S. Weatherley, et al. (1990). "Restoring acidified streams in upland Wales: a modelling comparison of the chemical and biological effects of liming and reduced sulphate deposition." Environmental pollution 64(1): 67-85.

Poléo, A. B. S. (2005). Acid Rain 2005, SESSION 11 , Effects on aquatic biota Acid rain 2005, 7th international conference on acid deposition

Raddum, G. G. and A. Fjellheim (2003). "Liming of River Audna, Southern Norway: A Large-scale Experiment of Benthic Invertebrate Recovery." Ambio 23(3): 230-234.

Reizenstein, M., K. Holmgren, et al. (2005). "Befintlig information om fisk och kräftor i nya IKEU-objekt. Sammanställning av ett specialprojekt 2005." Fiskeriverkets sötvattenslaboratorium Drottningholm PM 2005-12-27. .

Rosseland, B. O. and A. Hindar (1988). "Liming of lakes, rivers and catchments in Norway." Water, Air, & Soil Pollution 41(1): 165-188.

Rundle, S. D., N. S. Weatherley, et al. (1995). "The effects of catchment liming on the chemistry and biology of upland Welsh streams: Testing model predictions." Freshwater biology 34(1): 165-175.

Sandoy, S. and A. J. Romundstad (1995). "Liming of acidified lakes and rivers in Norway - An attempt to preserve and restore biological diversity in the acidified regions." Water Air and Soil Pollution 85(2): 997-1002.

Scarr, A., P. Edwards, et al. (2002). Acid waters remediation and long term monitoring in Wales, Environment Agency.

Scarr, A. (1997). Lime dosing to restore the upper Tywi = : Dogni calch i adfer blaenau'r afon Tywi. Hwlffordd, Adran yr Amgylchedd. Environment Agency

Simmons, K. R., P. G. Cieslewicz, et al. (1996). "Limestone treatment of Whetstone Brook, Massachusetts .2. Changes in the brown trout (Salmo trutta) and brook trout (Salvelinus fontinalis) fishery." Restoration Ecology 4(3): 273-283.

Simmons, K. R. and K. Doyle (1996). "Limestone treatment of Whetstone Brook, Massachusetts .3. Changes in the invertebrate fauna." Restoration Ecology 4(3): 284-292.

Simon, K. S., M. A. Simon, et al. (2009). "Variation in ecosystem function in Appalachian streams along an acidity gradient." Ecological applications: a publication of the Ecological Society of America 19(5): 1147-1160.

Swierczynski, M. and G. Matlawski (1992). "An attempt on neutralize acidified mountain waters on example of the investigated streams: The Czerwien, Myja and Podgorna." Acta Ichthyologica et Piscatoria 22(1): 75-95.

Turnpenny, A. W. H., J. M. Fleming, et al. (1995). "The brown trout population at Loch Fleet eight years after liming." Chemistry and Ecology 9(3-4): 179-191.

Walseng, B., R. M. Langaker, et al. (2001). "The River Bjerkreim in SW Norway - Successful chemical and biological recovery after liming." Water Air and Soil Pollution 130(1-4): 1331-1336.

Watt, W. D., G. J. Farmer, et al. (1983). "Studies on the Use of Limestone to Restore Atlantic Salmon Habitat in Acidified Rivers." Lake and Reservoir Management, (special issue on EPA/N Am Lake Mgt Soc Lake and Reservoir Mgt 3rd Conf, Knoxville, TN) 1(1): 374-379.

Weatherley, N. S. and S. J. Ormerod (1990). "The constancy of invertebrate assemblages in soft-water streams: implications for the prediction and detection of environmental change." Journal of Applied Ecology 27(3): 952-964.

Weatherley, N. S. and S. J. Ormerod (1992). "The biological response of acidic streams to catchment liming compared to the changes predicted from stream chemistry." Journal of Environmental Management 34(2): 105-115.

Westling, O. and T. Zetterberg (2007). "Recovery of Acidified Streams in Forests Treated by Total Catchment Liming." Water, Air, & Soil Pollution: Focus 7(1): 347-356.