SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: 15206
STSM title: Assessing the effectiveness of woodland creation for reducing agricultural diffuse pollution – developing value ranges to create look-up tables.
STSM start and end date: 04/09/2017 to 20/10/2017
Grantee name: Ignacio Pérez Silos

PURPOSE OF THE STSM:

The purpose of this STSM was to summarise current understanding of the effectiveness of woodland creation measures for reducing key diffuse pollutants (sediment, nitrate, phosphate, pesticides and Faecal Indicator Organisms). This was to be achieved through three tasks:

1. Review published literature on the impact of woodland planting on agricultural diffuse pollution, as well as capturing effects on runoff and temperature.
2. Extract numbers from the literature on observed changes to pollutant loads and concentrations resulting from tree planting, as well as record relevant contextual information on woodland measures (e.g. location, design and management of woodland).
3. Use these numbers to tabulate value ranges on the effectiveness of different woodland measures for reducing diffuse pollution in agrarian landscapes. Also record potential effects on water resources.

The provision of value ranges for the selected diffuse pollutants would help underpin the development of look-up tables by COST Action Working Group 2 for use by ecosystem function models (Deliverable 2.1). These tables would also contribute to the activities of Working Group 3 by directly informing the cost-effectiveness of woodland creation measures to improve water quality and provide other benefits (WG3 primary objective).

DESCRIPTION OF WORK CARRIED OUT DURING THE STSM

The focus of the STSM was on undertaking a desk-based review of the literature to identify as many case studies as possible on the interactions between woodlands, agricultural diffuse pollution and water quality. In total, 61 published papers (peer reviewed) between the years 1973 to 2017 were reviewed. The majority of the studies took place in North America and Europe (Fig. 1) and primarily generated empirical data from site-based experiments.

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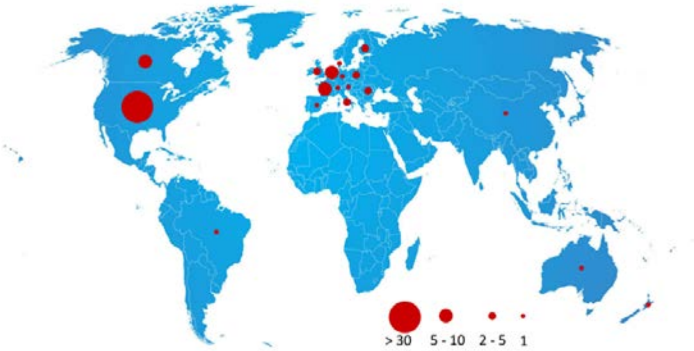


Fig. 1. Map of case studies

The review began with several articles provided by the host institution (Forest Research) on the effectiveness of woodland buffers for reducing agricultural diffuse pollution. Quantitative data on the ability of woodland measures to reduce diffuse pollutant loads or concentrations were extracted, as well as Meta data on relevant site factors, including on the design and management of the measures. Data were introduced into a structured database previously defined. Cited references were explored and new papers sought from a wider literature search, which sought balance in terms of targeting appropriate water quality and water quantity variables. In total, more than 100 papers were initially assessed, resulting in 61 papers being selected for detailed examination. Extracted data from these papers were captured in the Excel database (“Review_StudyCases.xls”).

Information collected:

Contextual information

Information was collected on the physiographic characteristics of the study area and on the nature of the trees/woodland present to allow the influence of these factors to be determined:

-*General features of the area:* Location, climate, previous land use, date and duration of the study, soils and geomorphology features, presence of effluents.

-*Specific tree plantation/woodland features:* Type of forest/plantation, origin, management objectives, age, main species, width, design-structural features, drainage area, drainage features, pest/disease issues.

Quantitative assessment of impacts on water quality and runoff

Quantitative data (concentrations, loads and yield/flow) for different water quality variables and runoff were extracted from the papers to determine the effectiveness of the woodland measures (contextual information) at reducing pollution impacts or changes to water quantity. To facilitate study comparisons, results were converted to % change between woodland and non-woodland treatments.

-*Water quality variables:* Sediments, nitrogen (nitrate and ammonium), phosphorous, pesticides, fecal indicator organisms, temperature.

-*Water quantity variables:* Runoff.

A second Excel database was built (‘Review_Data.xls’) to analyse the relationships between the contextual information and the water quality-quantity data. These data were structured by the different experimental-empirical treatments as follows:

-*Variable*: suspended solids, total sediments, nitrate, ammonium, phosphate, atrazine, daily maximun summer temperature (average), runoff depth and water volume.

-*Type of measurement*: concentration, load or only effectiveness.

-*Flow*: surface-subsurface water or groundwater.

-*Climate*: simulated rainfall, subtropical humid, oceanic, continental, Mediterranean, boreal or alpine

-*Type of forest/plantation*: hillside forest, riparian forest, shrubs, vegetated filter strips with trees or agroforestry.

-*Type of measure*: buffer along flow pathway or source area protection.

-*Origin*: natural (native in the area, non-afforested, non-restored or non-planted), restored (planted area under a restoration project or semi-natural plantations) or planted (any case involving land use change by planting trees, regardless of whether native or non-native species).

-*Width*

-*Tree age*: 0-3y, 3-15y, 15-30y or >30y.

-*Drainage*: Well, moderate or poorly drained.

-*Slope*: 0-3%, 3-6%, 6-9%, 9-15% or >15%.

-*Initial conditions*: Pre/before/impact measurement.
-*Final conditions*: Post/after/treatment measurement.
-*Effectiveness*: effectiveness of measure in terms of pollutant reduction achieved or % change.

Finally, provisional look-up tables (look-up_tables.xls) providing value ranges and effectiveness were built for each of sediment, nitrate (NO_3-N), ammonium (NH_4-N), phosphate (PO_4-P), atrazine, average daily maximum summer temperature and runoff depth. Insufficient data were found to support the construction of equivalent tables for other pesticides or for faecal indicator organisims. There were sufficient data to allow a separation by two contextual variables: climate and type of woodland/forest. The influence of width was also studied through linear correlation. Data on other contextual variables were scarce or scattered and so could only be used to explore outlier values or in a descriptive way.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

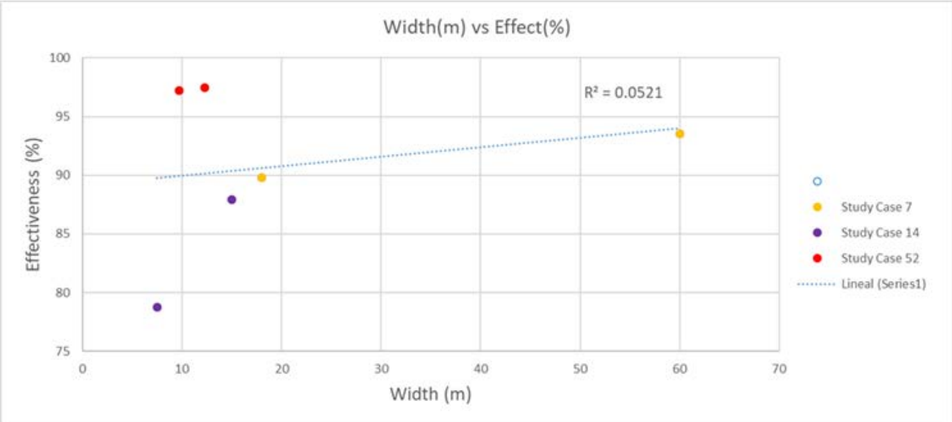
The main results obtained by the STSM are the provision of ranges of values for the selected diffuse pollutants. These data are provided in the form of a number of query tables, grouped by water quality or water quantity/physical variable. Furthermore, the tables are accompanied by narrative-based graphs describing the effects of key contextual factors such as width of the vegetated area/buffer, origin, etc. The original Excel files underpinning these summary tables, copies of reviewed papers plus final presentation on the results (presented at the PESFOR-W Croatia meeting, 17-19/10/17) are also provided to accompany this report.

The critical information of the query tables is outlined below:
-*Climate*: climate zone. Studies involving simulated rainfall treatments are listed separately as ‘Simulated rainfall’.
-*n*: number of studies.
-*max[initial]:* maximum value of the set of pre/before/impact concentration measurements.
-*min[initial]:* minimum value of the set of pre/before/impact concentration measurements.
-*Av.Effect(%):* average value (and range) in % for the effectiveness of the different treatments within a given climate zone. Positive values (green) show a reduction and negative values (red) show an increase in the pollutant concentration or load.
-*Q1, Q2, Q3:* the first, second (median) and third quartiles of the effectiveness (%) of the different treatments in a climate zone.
-*Type of plantation/forest:* hillside forest, riparian forest, shrubs, vegetated filter strips with trees or agroforestry.

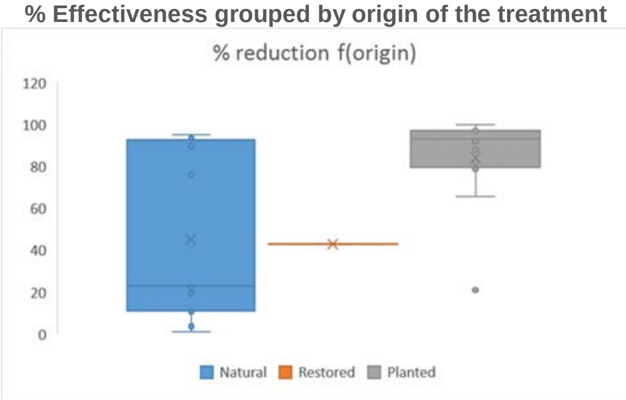
SUSPENDED SOLIDS (and total sediments)

Climate	n	max[Initial]	min[Initial]	Av. Effect.(%)	Q1	Q2	Q3	Type of plantation/forest	n	Av. Effect.(%)
	Concentration of Suspended Solids (mg/l)								Load of Total Sediments (kg/ha)	
Continental	4	72.6	7.6	27.6 [11.9 - 55.3]	18	22	32	Riparian woodland	3	89.4 [76.0 - 97.2]
									Concentration of Suspended Solids (mg/l)	
Oceanic	3	6480.0	104.9	75.4 [42.9 - 93.5]	66	90	92	Riparian woodland	n	Av. Effect.(%)
Simulated rainfall	4	10019.0	4433.0	90.3 [78.8 - 97.5]	86	93	97	Riparian woodland	2	83.4 [78.8 - 87.9]
								Shrub	2	97.4 [97.2 - 97.5]

Plot of study results (grouped by the same color) in which the effect of riparian woodland width was assessed



% Effectiveness grouped by origin of the treatment

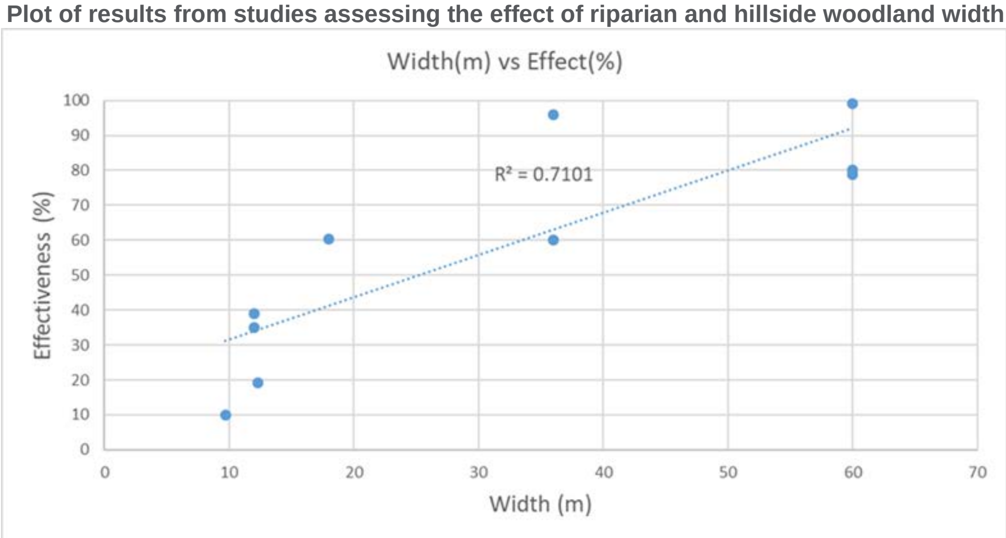


The majority of studies assessed the effect of riparian woodland, which was found to be the most effective for simulated rainfall treatments (average 90% reduction) and within the oceanic climate zone (average 75% reduction). Reductions appeared to be greatest when expressed as sediment loads rather than concentrations, indicating that riparian woodland is more effective at removing higher sediment concentrations. Although the correlation between width and effectiveness was very low ($r=0.05$; $p>0.05$), in the three study cases in which the width was included as an independent factor, the wider treatment was always the most effective. In relation to the origin of the measure (natural, restored or planted), it seems that the results for the planted treatments were less variable, implying that designed woodland measures were more effective.

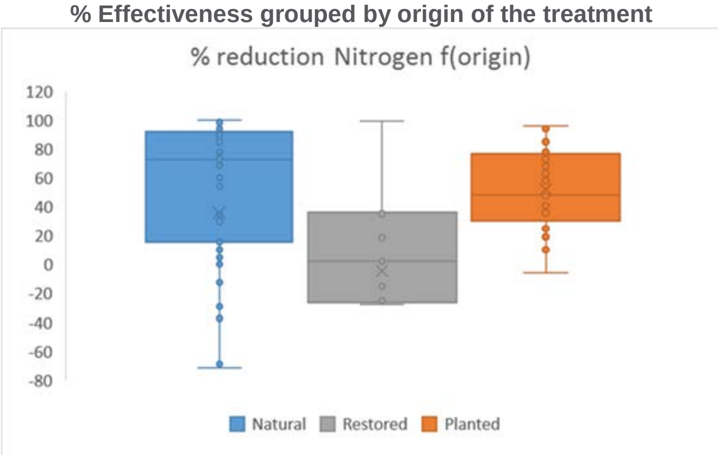
NITRATE- NO_3-N

Concentration of NO_3-N (mg/l) in surface runoff										
Climate	n	max[Initial]	min[Initial]	Av. Effect.(%)	Q1	Q2	Q3	Type of plantation/forest	n	Av. Effect.(%)
Continental	17	46.8	0.4	84.8 [18.4 - 100.0]	82	98	99	Hillside woodland	6	88.6 [64.0 - 100.0]
								Riparian woodland	9	79.8 [18.4 - 99.9]
								Shrub	2	96.0 [94.0 - 98.0]
Oceanic	8	32.5	0.1	74.2 [32.0 - 98.0]	60	77	95	Riparian woodland	7	73.9 [32.0 - 98.0]
								Shrub	1	76.0
Subtropical humid	13	13.5	1.3	82.5 [35.0 - 99.0]	80	92	96	Riparian woodland	10	89.7 [39.0 - 100.0]
								Shrub	3	58.3 [35.0 - 80.0]

Plot of results from studies assessing the effect of riparian and hillside woodland width



% Effectiveness grouped by origin of the treatment

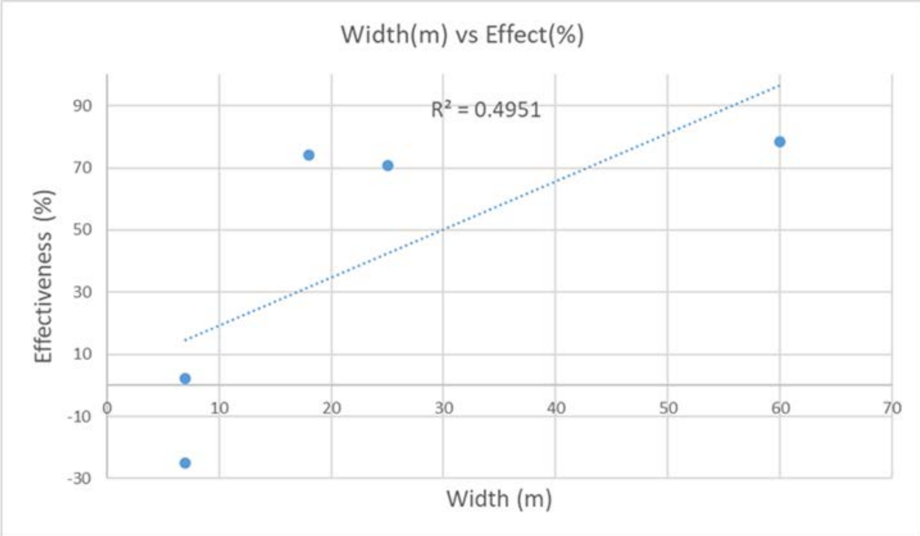


In terms of NO_3-N, the effectiveness of woodland buffers was very positive (more than 70% reduction in nitrate concentration achieved in all studied climates and types of forests (hillside woodland, riparian woodland and shrub). Furthermore, there was a highly positive relationship between buffer width and effectiveness ($r=0.71$; $p<0.05$). Natural riparian woodland appeared to be more effective at reducing nitrate compared to planted buffers, perhaps due to less dispersion. Restored woodland buffers were the least effective, probably due to the lower maturity/age of these treatment systems. However, it is important to keep in mind the smaller sample size (n=6) and variability in results for the restoration studies.

AMMONIUM- NH_4-N

Concentration of NH4-N (mg/l) in surface runoff											Concentration of ground water NH4-N (mg/l)							
Climate	n	max [Initial]	min [Initial]	Av. Effect.(%)	Q1	Q2	Q3	Type of plantation/forest	n	Av. Effect.(%)	n	max[Initial]	min[Initial]	Av. Effect.(%)	Q1	Q2	Q3	Type of plantation/forest
Oceanic	3	47.5	0.4	74.4 [70.7 - 78.3]	72	74	76	Riparian woodland	2	76.2 [74.1 - 78.3]	3	0.1	0.1	-89.2 [-265.3 - 35.1]	-151	-37	-1	Riparian woodland
								Shrub	1	70.7								
Continental	4	0.1	0.0	-22.2 [-68.7 - 2.8]	-36	-11	2.4	Riparian woodland										
Subtropical humid	1	0.3	0.3	72.9				Riparian woodland										

Plot of results from studies assessing the effect of riparian woodland width

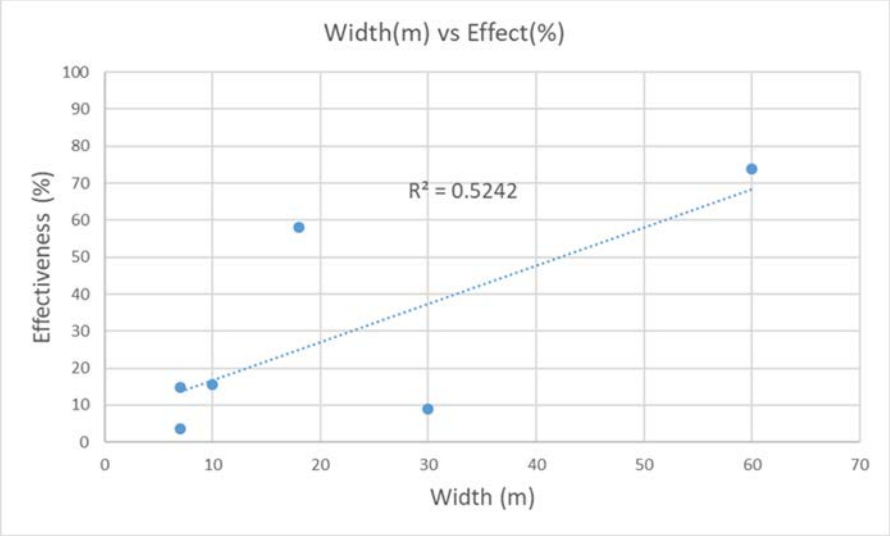


The results appear to suggest a great difference between the effectiveness of woodland buffers in oceanic/subtropical humid climates (although based on only one study for subtropical humid climate) compared to continental climates. However, the difference in response probably reflects the very low initial concentrations measured in the latter studies, with recorded increases in concentration representing very low absolute values. The same reason may explain the results for the groundwater studies. On the other hand, there appears to be a clear positive effect between the width of woodland and the level of reduction achieved.

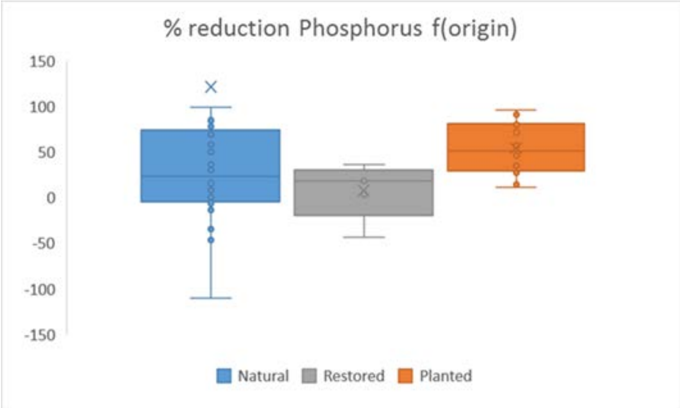
PHOSPHATE- PO_4-P

Climate	n	max[Initial]	min[Initial]	Av. Effect.(%)	Q1	Q2	Q3	Type of plantation/forest
			Concentration of PO_4-P (mg/l) in surface runoff					
Continental	4	0.3	0.0	15.8 [8.1 - 36.4]	7	12	20	Riparian woodland
Oceanic	4	0.7	0.0	39.1 [8.9 - 73.9]	14	37	62	Riparian woodland

Plot of results from studies assessing the effect of riparian woodland width



% Effectiveness grouped by origin of the treatment

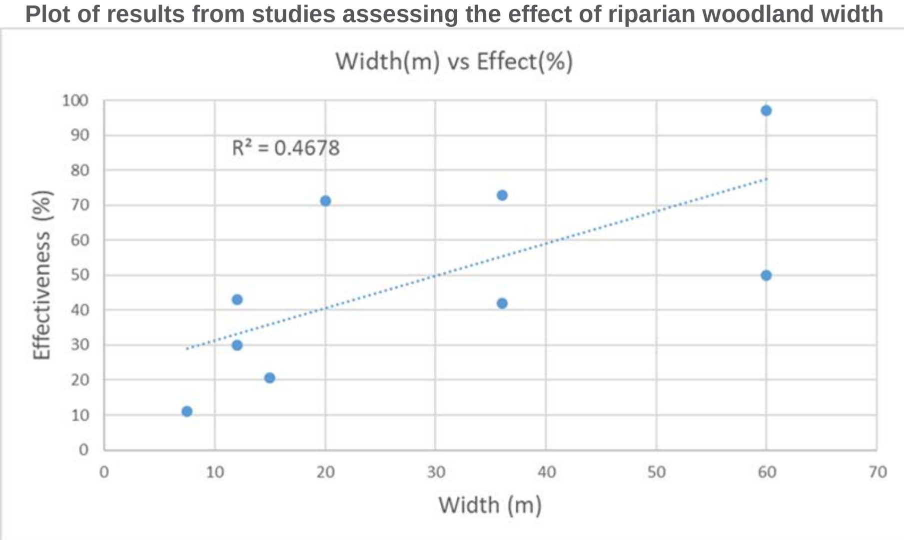


The results indicate that riparian woodland buffers are less effective at reducing PO_4-P compared to NO_3-N. Average reductions of nearly 40% were found for oceanic climates but only 16% for continental zones. There was a positive relationship between effectiveness and buffer width, while planted buffers appeared to be more reliable for reducing phosphate runoff compared to natural or restored woodland buffers.

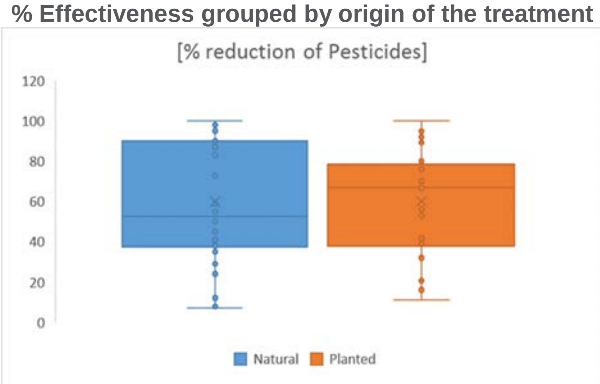
ATRAZINE

Concentration of Atrazine (µg/l) in surface runoff										
Climate	n	max[Initial]	min[Initial]	Av. Effect.(%)	Q1	Q2	Q3	Type of plantation/forest	n	Av. Effect.(%)
Continental	1	13.9		71.2				Hillside woodland		
Subtropical humid	7	12.7		61.4 [30.0 - 97.0]	43	50	84	Riparian woodland	4	76.9 [43.0 - 97.0]
								Shrub	3	40.7 [30.0 - 50.0]
Simulated rainfall	2	436.0		15.8 [11.0 - 20.6]				Riparian woodland		

Plot of results from studies assessing the effect of riparian woodland width



% Effectiveness grouped by origin of the treatment

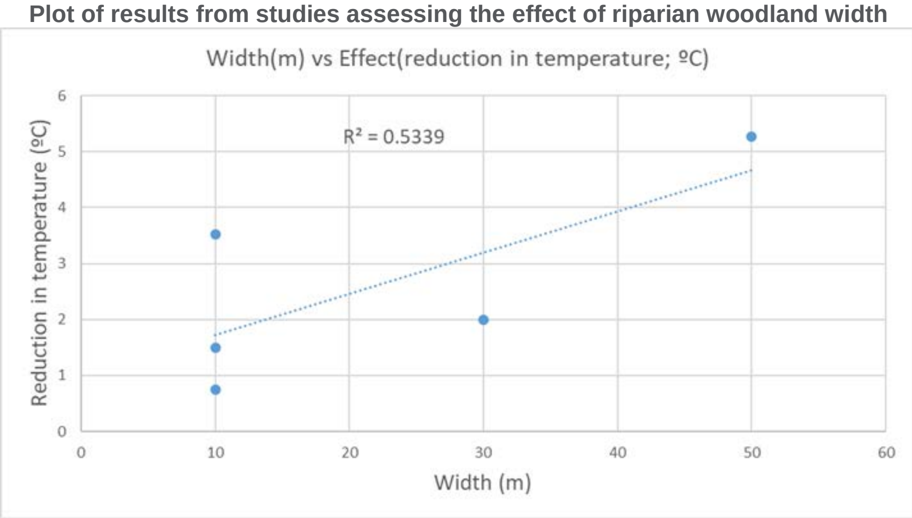


Results were only found for the pesticide Atrazine. Both hillside and riparian forests were effective at reducing concentrations in surface runoff (averaging 71% and 61%, respectively), although the assessment of the former was limited to a single study. Most studies were conducted in the subtropical humid climate zone, where riparian forest was found to be more effective at reducing atrazine than an equivalent shrub cover. There was a positive correlation between width of riparian forest and effectiveness ($r=0.47$; $p<0.05$), with simulated rainfall experiments indicating reduced effectiveness where inflowing concentrations of atrazine were very high. Natural and planted riparian forests appeared to have a similar ability to reduce atrazine in runoff.

AVERAGE OF THE DAILY MAXIMUM SUMMER TEMPERATURE

Average of the daily maximum summer temperature (ºC)								
Climate	n	max Initial ºC	min Initial ºC	Av. Effect.(ºC)	Q1	Q2	Q3	Type of plantation/forest
Continental	3	20.6	17.3	3.2 [0.8 - 5.3]				Riparian woodland
Oceanic	2	17.5		1.7 [1.5 - 2.0]				Riparian woodland

Plot of results from studies assessing the effect of riparian woodland width

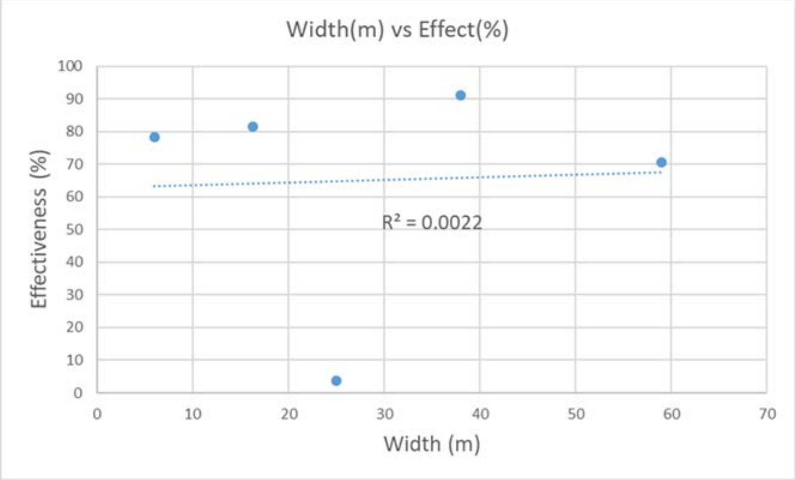


Riparian forest achieved a notable reduction (1.7 – 3.2 ºC) in stream temperature, which could have a marked effect in terms of preventing rises above thermal limits for fish. The cooling effect increased with the width of the riparian buffer.

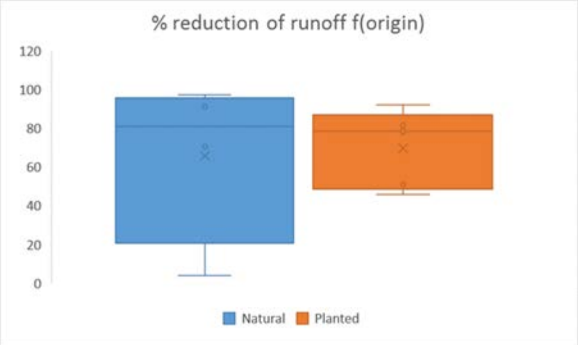
VOLUME OF SURFACE RUNOFF

Climate	n	max[Initial]	min[Initial]	Av. Effect.(%)	Q1	Q2	Q3	Type of plantation/forest	n	Av. Effect.(%)
				Volume of surface runoff (mm)						
Continental	3	340.0	97.0	58.8 [3.7 - 91.2]	43	81	86	Riparian woodland		
Subtropical humid	2	2300.0	68.0	74.4 [70.6 - 78.3]				Hillside woodland	1	70.6
								Vegetated filter strip	1	78.3

Plot of results from studies assessing the effect of riparian woodland width



% Effectiveness grouped by origin of the treatment



Based on a relatively small number of studies across two climatic zones, riparian and hillside forests appeared to be similarly effective (59-71%) at reducing surface water runoff. Surprisingly, forest width had no effect on runoff reduction, while natural forests showed greater variability in results compared to planted forests.

FUTURE COLLABORATIONS

I consider the review to be a good first step towards the development of look-up tables on the effectiveness of woodland creation measures for reducing key diffuse pollutants. More work is required to strengthen and extend the tabulated value ranges by expanding the literature search, in particular:

1) To seek more studies representative of the Mediterranean climate zone.
2) To seek more studies on the effects of hillside forest measures that target diffuse pollution sources. The reviewed papers were dominated by riparian buffer studies targeting pollution delivery pathways.
3) More sophisticated analysis of the data to try and isolate the effects of other key variables such as site hydrology, soil type, forest design and woodland management practices.

Overall, I believe that I have achieved the main objective of the STSM by delivering a tabulated set of value ranges for the effectiveness of different woodland measures for reducing diffuse pollution in agrarian landscapes. This forms a strong base for further development by the next STSM and Working Group 2, to which I remain willing to assist (e.g. by collaborating in writing up the review for publication, discussing next steps and in formulating the planned look-up tables).