Interactions between floodplain woodland and the freshwater environment

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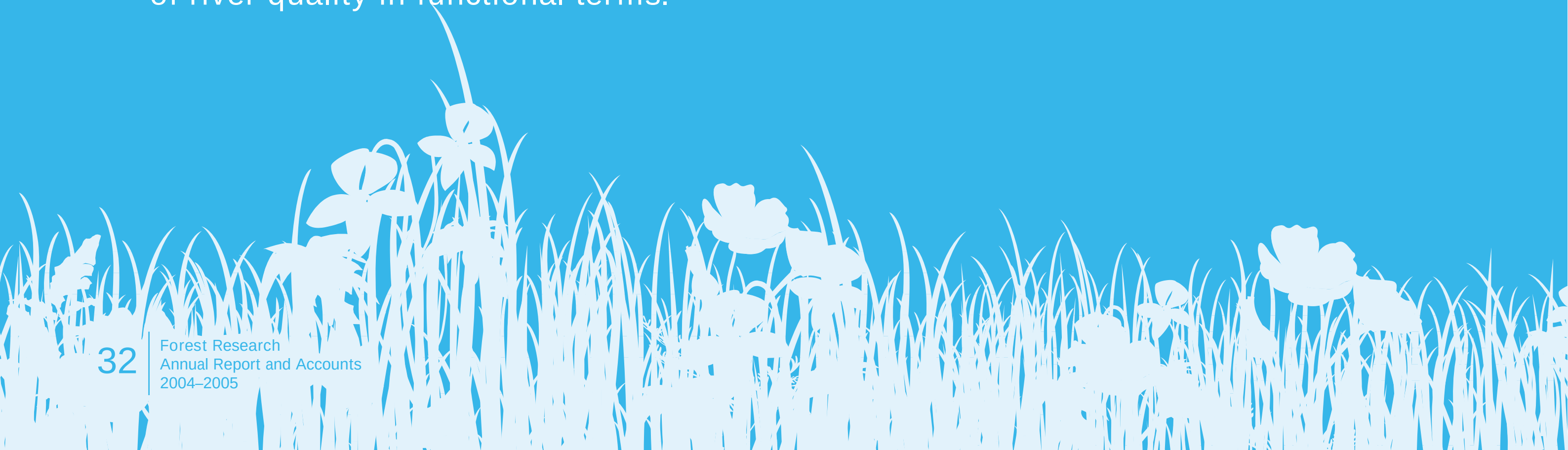
INTRODUCTION

Interest in the subject of floodplain woodland has expanded rapidly over the past 10–15 years. Attention initially focused on the high conservation value of this essentially lost habitat, with various groups embarking on a series of prominent site restoration schemes. This was followed by joint action to restore and create more wet woodlands, with specific targets set under the UK Biodiversity Action Plan. More recently, interest has shifted both nationally and internationally to consider the flood and pollution control functions of floodplain woodland.

Forest Research’s involvement began in 1995 with a scoping study to assess the possible benefits and risks of restoring floodplain woodland in lowland Britain (Kerr and Nisbet, 1996). This drew attention to the need for further research to better understand and help quantify these effects. Work on investigating the role of floodplain woodland in flood control started in the late 1990s under the Forest Hydrology Programme. The first study looked at opportunities for planting floodplain woodland to help alleviate flooding in the River Parrett catchment in southwest England (Nisbet and Broadmeadow, 2003). A number of sites were identified and one of these was selected in 2003 to model the hydraulic impact of establishing a floodplain woodland.

This article presents the results of the initial modelling work and describes new studies designed to test predictions in the field. A number of related research topics are also described, including an experiment to better quantify the influence of riparian woodland shade on stream water temperature, the development of eco-hydrological guidelines to protect wet woodland habitats, and the implementation of a diagnostic tool for assessing the ecological status of river quality in functional terms.



The hydraulic impact of floodplain woodland

The use of floodplain woodland as an aid to flood control has been discussed for many years. Some flood defence engineers have argued that floodplain woodland would only be able to exert a small effect on flood flows, while others have expressed concern that any backing-up of floodwaters could adversely affect local properties. The high degree of uncertainty associated with these and other potential impacts has precluded any significant floodplain woodland planting to date.

The main mechanism whereby floodplain woodland could aid flood defence is by slowing the downstream passage of a flood peak, resulting in a lower but longer duration event. Floodplain woodland has naturally carried out this role in the past and its removal has probably contributed to an increase in flooding severity.

The delaying effect on flood flows is mainly due to the contribution of vegetation roughness (see Figure 1). The nature of the vegetation is important because of the type of frictional effects it produces. Thus, trees create more of a physical barrier than bushes because the latter can flatten during high flows whereas trees do not. The spacing and layout of trees, smoothness of trunks, presence of lower branches, level of undergrowth and amount of dead wood on the woodland floor all have an effect. By varying these factors, woodland management and design can exert a strong influence on woodland roughness and thus on the capacity of floodplain woodland to impede flood flows.

Figure 1

Fallen logs, branches and leaf litter collect to form debris dams which act to hold back and slow down flood flows.

Since there will be a long time lag between the planting of floodplain woodland and any significant effect on flood flows, there is an urgent need for research to quantify the effectiveness of this type of woodland as a mechanism of flood defence. In particular, information is required about the actual flood storage potential of floodplain woodland, the extent to which woodland could retard different sized flood peaks, and how any flood attenuation effect could be maximised through woodland design, including location, shape, size, age and species choice. The rarity of floodplain woodland in the UK and lack of hydrological data means that research must first focus on hydraulic modelling. The following section describes the results of initial work aimed at modelling the hydraulic effects of floodplain woodland at a test site in southwest England.

Case study: Parrett Catchment

The River Parrett is 59 km long and its main tributaries include the Rivers Tone, Isle, Yeo and Cary. It drains an area of over 1690 km^2, comprising around 50% of the land area of Somerset. A number of towns face a serious and recurrent flooding problem and the catchment is the location of a wider study to formulate a strategy and integrated plan for improving flood management. A key objective of the strategy is to explore how new woodland could help to alleviate downstream flooding in towns like Bridgwater.

A reach on the River Cary, 300 m upstream of the Environment Agency's gauging station at Somerton (No. 52011, NGR ST 498 291), was chosen as the study site. This was one of a number of areas in the Parrett Catchment identified as being potentially suitable for floodplain woodland restoration (Nisbet and Broadmeadow, 2003). The modelled river reach extends for approximately 2.2 km and has the potential to be completely forested.

The catchment area to the gauging station is approximately 82.4 km^2 and the highest recorded flow is 13.65 m^3 s^{-1}. The estimated 1 in 100 year flood or 1% annual probability event (a.p.e.) is 15.2 m^3 s^{-1}, which defined the inflow boundary condition for the model simulations. Topographic data for the study reach were obtained from the Environment Agency in the form of 2 m resolution LiDAR data and 10 surveyed cross-sections of the channel. The channel is approximately 16 m wide and 2 m deep. The potential flooded area extended mostly over the north bank of the river, reaching a maximum width of approximately 400 m.

Model simulations

The principle effect of floodplain vegetation is to increase surface roughness. Most models use Manning's roughness coefficient *(n)* to represent the energy lost in water flowing across the floodplain. There are a number of methods for calculating Manning's *n* and separate values are required for the river channel and floodplain.

Three contrasting scenarios were considered for the model simulations. The first represented the present land cover of pasture, the second a complete cover of thick broadleaved woodland along the wider north bank of the floodplain, and the third, a 500 m length section comprising 50 ha of woodland in the centre of the floodplain. The latter scenario allowed both the upstream and downstream impact of the woodland to be evaluated. Manning's *n* values of 0.035 and 0.15 were selected from the work of Chow (1959) as being typical for the pasture and woodland covers, respectively. An example of the type of woodland with this roughness value is shown in Figure 2.

Figure 2

Typical woodland type that would give a Manning's *n* roughness of 0.15 during a flood with a water depth of 1.25 m (Acrement and Schneider, 1990).

Two models were selected to evaluate the effects of floodplain woodland on flood flows. The first involved the 1D model called HEC-RAS that was originally developed by the US Army Corps of Engineers and is widely used by flood defence engineers in the UK. The second was the River2D model developed by the University of Alberta in the USA (Ghanem *et al.*, 1995). Both models used the channel geometry from surveyed cross-sections and topographic data from a 2 m resolution LiDAR survey. The latter was used to generate 10 m interval topographic transects for the 1D model.

A selection of the 1D model results is presented in Figure 3. Figure 3a shows that the presence of woodland along the entire length of the reach increased the flood level by as much as 270 mm. This raised the volume of flood storage by 71% and led to a marked delay of 140 min in the downstream passage of the flood peak (Figures 3b and 3c).

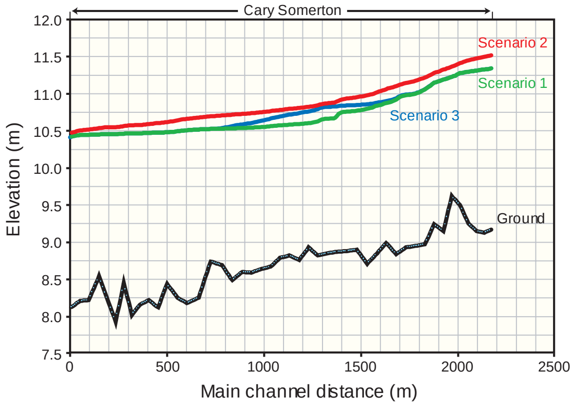
The central block of woodland had a similar but more localised effect on the flood level, which increased by 180 mm at the upstream edge. This led to a backing-up of water, with raised levels extending a distance of nearly 400 m upstream of the woodland. The effects on flood storage and flood peak travel time were much less than for the complete woodland cover, but still significant with 15% greater storage and a delay of 30 min, respectively.

The River2D model allowed a more detailed assessment of the effects of floodplain woodland on flood depth and water velocity. Figure 4a and b compares the profiles of these two parameters between the pasture and complete woodland scenarios. The effect of the woodland on flood depth was similar to the results of the 1D model, with a maximum increase of 190 mm. However, the horizontal extent of the flooding was relatively unchanged, probably because the topographical limit of the floodplain was already reached in many areas. The water velocity vectors show a reduction in flow velocity across a large part of the floodplain but especially in the upper end of the reach.

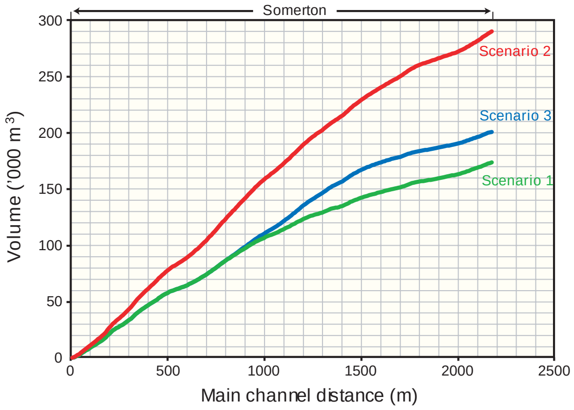
Figure 3

1D Model results.

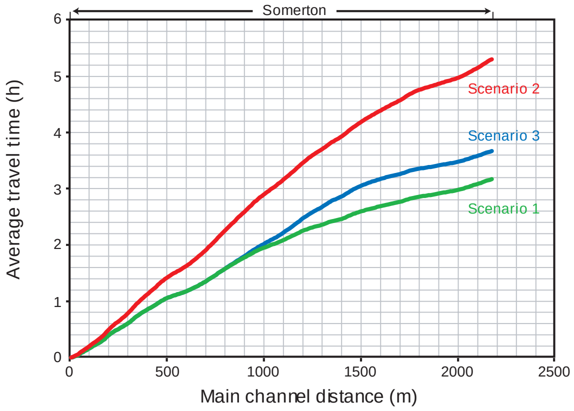
(a) Longitudinal profile displaying water and bed levels along the reach (wooded area for scenario 3 is located between 783 m and 1277 m).



(b) Flood storage volume with distance along the modelled reach.



(c) Average travel time for the downstream passage of the flood peak along the modelled reach.



Values for the woodland were generally in the range 0.04–0.07 m s^{-1} in the lower half and 0.14–0.3 m s^{-1} in the upper section, compared to 0.05–0.2 m s^{-1} and 0.15–0.5 m s^{-1} for the pasture, respectively. As expected, the velocity gradually decreased towards the outer edge of the flood.

The effect of the central block of woodland on flood depth is displayed in Figure 5. The results were similar to the 1D model with the water level raised by a maximum of 118 mm and a backwater effect that extended 300 m upstream of the woodland.

The magnitude of the predicted effects of both woodland scenarios is considered to be significant in flood management terms. For example, in the context of planning control, the Environment Agency regard a 50 mm rise in water level to be ‘significant’ in terms of the impact of building developments on the floodplain. The additional time generated by the predicted lag in the downstream progression of the flood peak would also be very valuable in terms of flood warning.

It is important to note that the size of the modelled floodplain woodland was relatively small in relation to the extent of the catchment of the River Cary. The 2.2 km reach comprised a total area of 133 ha of floodplain woodland in scenario 2, which is less than 2% of the total catchment area of 82 km^2. A much larger floodplain woodland or a series of similar sized woodlands in other parts of the catchment could therefore be expected to have an even greater response. Similarly, if this pattern was replicated across other tributary catchments it should be possible to exert a sizeable impact on flooding, even within a very large catchment such as the River Parrett.

A detailed analysis of the hydrographs of individual tributaries could identify where the restoration of floodplain woodland would exert the greatest benefit in terms of desynchronising sub-catchment contributions and therefore the size of the main flood peak. Desynchronisation, however, is likely to extend the flood hydrograph with possible

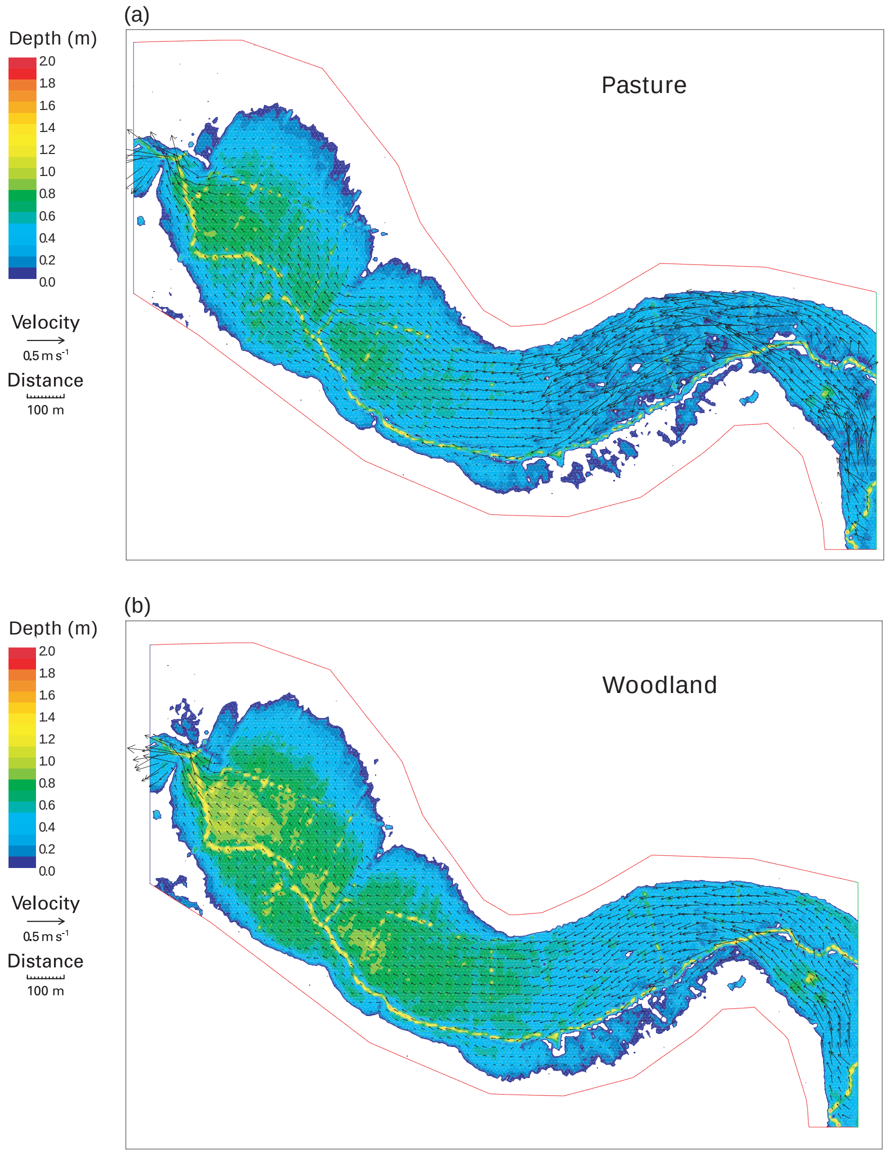


Figure 4

Plan view of flood depth and flow velocity: (a) assuming floodplain is covered by pasture (scenario 1); (b) for a complete cover of floodplain woodland on the north bank of the floodplain (scenario 2). Arrow length is proportional to velocity.

implications for longer duration or consecutive flood events. This concept is depicted diagrammatically in Figure 6.

The model predictions are based on using a roughness value associated with a dense stand of willows with limited amounts of dead wood on the woodland floor. It should be possible to create additional roughness by adopting management practices aimed at increasing levels of dead wood. Large woody debris forms a very important component of the roughness or flow resistance of both the floodplain and river channel, mainly arising from the formation of debris dams. The formation of multiple channels and pools typical of natural floodplain woodland could also be expected to enhance floodplain roughness and flood storage. The obstruction provided by individual trees and debris dams restricts water flow and contributes to scouring and channel development.

The backing-up of floodwaters upstream of a floodplain woodland could threaten local properties. Increased water levels of up to 190 mm were predicted to occur immediately above the forest. The implications of this factor need to be considered on a site by site basis guided by the results of modelling work.

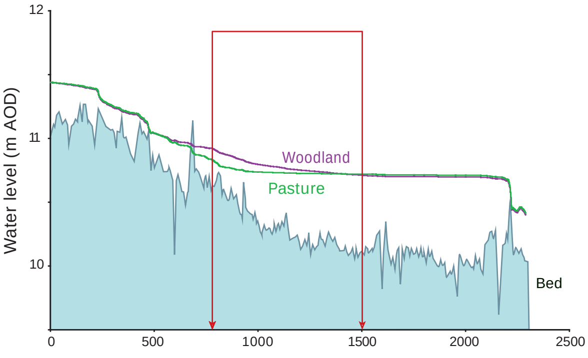


Figure 5

Longitudinal water surface profile along section of modelled river reach for scenario 3: woodland located between 790 and 1512 m.

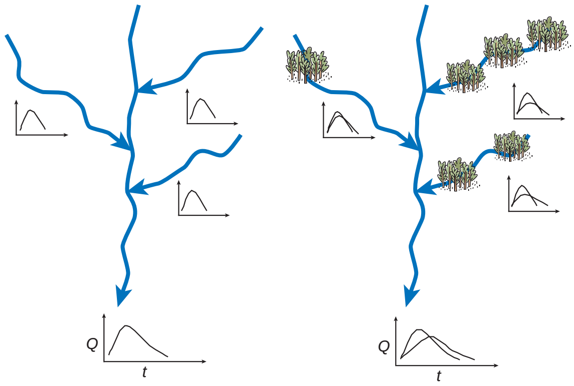


Figure 6

Conceptual diagram showing the cumulative effect of restoring floodplain woodland within a larger catchment on the flood hydrograph of individual tributaries and the main river. *Q*: river discharge; *t*: time.

Another potential threat posed by the restoration of floodplain woodland is the blockage of downstream structures such as bridges and culverts by woody debris. Further work is required to quantify the amount and nature of woody debris generated by floodplain woodland and the risk of this being washed out and moved downstream. Floodplain woodlands are thought to be reasonably retentive for large woody debris and it may be possible to enhance this function through management. One option could be to have a series of floodplain woodlands along a river system with the lowest one managed to maximise debris retention.

Conclusions

The findings of the initial modelling work suggest that there is considerable scope for using floodplain woodland as an aid to flood control. The scale of the modelled woodland was very small in relation to the size of the catchment, implying that a larger woodland block or a series of similar sized ones could exert a much greater downstream impact. In particular, if this pattern was replicated across other tributary catchments, it should be possible to influence flood flows even within very large catchments, such as the River Parrett.

A detailed analysis of the flood hydrograph would identify where the restoration of floodplain woodland would have the greatest benefit in terms of desynchronising sub-catchment contributions and therefore in attenuating the main flood peak. Desynchronisation, however, could extend the flood hydrograph with possible implications for longer duration or consecutive flood events.

Although it is very unlikely that floodplain woodland on its own would be able to provide complete protection for downstream towns or cities, it could make a valuable contribution alongside existing flood defences to tackling the increased risk of flooding associated with climate change. Similarly, it could have an important role to play in helping to manage smaller scale flooding problems where the high cost of constructing hard defences cannot be justified.

Future work

Work is under way to apply the models to other sites to test the transferability of the model predictions. One site involves Great Triley Wood near Abergavenny in south Wales. The small river that flows through this native floodplain woodland was instrumented at the beginning of 2005 to collect water level and velocity data during flood events. Although the site normally floods some 5 to 6 times per year, unfortunately, the relatively dry winter and spring have produced no events to date. Details of the instrumentation and layout are shown in Figure 7. Floodplain and channel cross-sections have been surveyed and measurements made to estimate the Manning’s roughness coefficient for

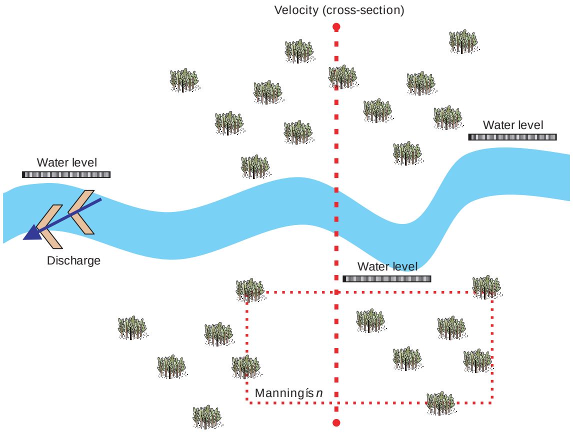


Figure 7

Conceptual diagram of floodplain woodland monitoring plot.

the floodplain woodland. The 1D model has been set up for the site and will be run for different sized flood events. In due course, these predictions will be compared to observations in order to test the performance of the model.

Three other sites have been selected on the River Laver, north of Ripon in Yorkshire. This is part of a much larger joint Defra/Environment Agency/English Nature/Forestry Commission pilot project to develop multi-functional approaches to flood risk management at the catchment scale. The sites are currently non-wooded but have been identified as holding some potential for converting to floodplain woodland. They will shortly be instrumented with water level recorders to provide baseline data for assessing future change. The intention is to set up both the 1D and 2D models for each site to investigate the potential impact of establishing several floodplain woodlands on flood flows in the River Laver and future flood risk in Ripon.

Investigating the influence of riparian shade on stream water temperature

One potentially adverse effect of climate warming is increased thermal stress for freshwater fish. Fish, and salmonids in particular, are very sensitive to changing temperature, with possible effects on the timing of spawning, fish growth rates and even survival. Salmonid fish require temperatures of between 5 and 15 °C for normal growth and rises above 21 °C can be lethal. Observations in recent years show that this tolerance limit can be significantly breached in smaller rivers during summer periods, especially in southern England.

Riparian woodland may have an increasingly important role to play in limiting such effects through the provision of shade, especially if climate warming continues as predicted. Judicious management of riparian woodland offers a means of maintaining water temperatures within a favourable range for salmonid fish and other sensitive freshwater fauna. A joint field study with Southampton University has recently been set up in the New Forest to evaluate the cooling effect of riparian shade. Ten sites with variable levels of shade on the Dockens Water and Ober Water have been instrumented to characterise the thermal regime and assess the effects of shading on streamwater temperature and on fish populations, including fish survival, growth rates and behaviour. The results will help to determine whether thermal stress poses a serious problem in small watercourses and if so, how riparian woodland management could help to protect the freshwater biota from future rises in water temperature.

Eco-hydrological guidelines for wet woodland

Wet woodland has been identified as a priority habitat requiring protection in the UK. The rarity and high conservation value of many wet woodlands has resulted in them being selected as Special Areas of Conservation (SACs) under the EU Habitats Directive. This designation requires all competent authorities to assess plans and projects that could affect the nature conservation value of these sites in order to ensure that their ecological integrity will not be adversely affected. Unfortunately, knowledge is lacking about the potential impact of a range of human activities, such as water abstraction, on the condition of these sites and on the specific ecological requirements of the wet woodland habitats and species. In particular, there is an urgent need to define scientifically robust eco-hydrological targets for the two Annex 1 wet woodland habitats: residual alluvial forests and bog woodlands.

As a first step, Forest Research was contracted by English Nature to provide an overview of the current state of the science relating to the eco-hydrological requirements of wet woodlands, and to scope out the direction of future research to facilitate ecological target setting.

The findings of this work have been written-up in a final report to English Nature (Barsoum *et al.*, 2005). Proposals for future work range from the need to better characterise and define the existing wet woodland resource to more in-depth studies to support the development, extension and testing of eco-hydrological targets.

Rivfunction

RIVFUNCTION is a pan-European research project which aims to develop and communicate a diagnostic tool for assessing the ecological status of river quality in functional terms. The method is based on litter decomposition and is widely applicable to national and regional agencies responsible for implementing the EU Water Framework Directive. The EU WFD explicitly recognises the importance of ecosystem function when defining the ecological status of aquatic systems. However, an effective assessment method does not exist currently. RIVFUNCTION seeks to fill this gap and provide a more complete assessment of ecological status, facilitating the development of improved water management policies. The objectives of the project are:

- To test whether leaf decomposition is a good indicator of functional integrity.
- To evaluate the response of leaf decomposition to eutrophication and riparian forest management.
- To develop an assessment tool, including methodology and threshold values for litter decay rates which define different ecosystem status classes.

The project is funded by the European Commission under the Fifth Framework Programme and involves 11 research partners from 8 countries. Field experiments are being conducted at 200 paired sites across 12 Ecoregions. Forest Research is primarily involved in translating the results into practice and promoting the use of the assessment tool amongst end users (Broadmeadow *et al.*, 2005).

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