THE ECOLOGY AND MANAGEMENT OF RIPARIAN TREES IN THE NRA ANGLIAN REGION

Draft Final Report
December 1993

Dr. David Harper
Director, Ecology Unit
Department of Zoology
University of Leicester

National Rivers Authority
Anglian Region
R&D Operational Investigation 527
Project Leader: Peter Barham

National Rivers Authority, Anglian Region
Kingfisher House,
Orton Goldhay,
Peterborough
PE2 OZR

Tel: 0733-371811
Fax: 0733-xxxxxx

First Published 1993

Dissemination status

Internal: Released to Regions
External: Restricted

Statement of Use

This document records the results of a study of the ecology and management of riparian trees and recommends management options to the NRA .

Research Contractor

This document was produced under OI contract 527 by:

Dr D M Harper
Ecology Unit
Department of Zoology
University of Leicester
Leicester LE1 7RH
Tel: 0533-523346
Fax: 0533-523330

NRA Project Leader

The NRA's Project Leader for OI Contract 527 was:

Mr Peter Barham - Anglian Region

Additional copies of this document may be obtained from
Anglian Region R&D Co-ordinator

CONTENTS

KEYWORDS

trees	shrubs	flowering plants	aquatic invertebrates	organic debris
riparian zone	floodplain	mammals	birds	fish

EXECUTIVE SUMMARY

1. The literature review emphasises three main areas in which trees are valuable – in flood defence, in ecology and in landscape:-

- Tree roots confer stability upon riverbanks under certain circumstances. The degree of protection depends upon many factors such as the species, age and state of the tree, and its location in relation to the water level.

- Trees drive the ecological production of small natural streams (typically first and second-order streams) through leaf-fall. Although this process is seasonal, leaf availability is continuous because leaf debris is retained within the stream system for approximately a year as a consequence of debris dams formed by coarse woody material (branches and logs) which slow down discharge and flushing of this detrital food. They are important habitats and components of habitat for invertebrate and vertebrate inhabitants of the riparian zone.

- Trees form an important part of human beings' perception of what is 'natural' and 'valuable' in river corridor landscapes.

2. Practical investigations were made into the abundance and distribution of trees by aerial photographic analysis, a catchment-wide field survey, and a short survey of the rural/urban fringe:-

- The photographic study (the photographs held in County Council Planning Departments), examined the relation between riparian trees (including shrubs) and those of hedgerows and woodlands in the floodplain in seven flodplain sections of the great Ouse catchment. It found that the density of riparian trees is generally as high or higher than hedgerow trees and, although only higher than woodland trees in three study areas, was probably of greater ecological importance in all seven study areas since so much woodland was conifer plantation (e.g. Little Ouse floodplain). The number of floodplain trees overall was strongly correlated with land use, with fewer trees in more arable floodplains.

- The field study examined the detail of tree distribution in eighteen, 1 km stretches of corridor within the Great Ouse catchment covering all river sizes and underlying geologies, with a smaller supplementary survey of seventeen 500m stretches concentrating upon the rural-urban fringes along the middle part of the Great Ouse

(Bedford-Huntingdon). The most dominant trees are species of willow, with hawthorn, ash, elder and alder sub-dominant. The density of mature trees varied from none to 120 /km, a range so great that an average would be meaningless. Lowest tree cover, (as would be expected), occurred in the fenland reaches whilst highest cover occurred in headwater streams. There was also considerable range in landcape aspect, from Great Ouse reaches where mature trees occurred with little shrub cover to the Kym which was almost entirely shrub-dominated. Thirty seven species were found, including alien (eg. laburnum) and non-riparian (eg. horse chestnut) species. Very few species show signs of healthy natural regeneration, indicating that a continuous long-term planting policy should be developed. Species assemblages corresponded loosely with natural phytosociological alliances in the rural but not the urban/suburban catchment, where exotics disrupted any pattern.

- There was no connection between tree species or tree density with the richness of flowering plant species. The latter is probably more strongly controlled by bank morphology and the management of the riparian zone and adjacent land.

3. Additional subject-specific surveys were carried out on different second- and third-order streams:

- A study of the bird community of river stretches with and without riparian trees emphasised the value of a wooded riparian corridor to non-aquatic birds, and showed that the value is enhanced where the linear corridor was 'reinforced' by small areas (<1 ha) of scrub or thicket. This is a valuable conclusion which can be taken forward into planning tree-planting schemes.

- A study of the ecological value of organic debris in two first/second-order streams surrounded by agricultural land, one with riparian woody and one with non-woody vegetation showed that only the wooded has geomorphological characteristics driven by debris dams. The other contains some litter-retaining features associated with emergent vegetation stems and overhanging or trailing terrestrial grasses. In the absence of woody vegetation however, the invertebrate community has a similar structure (shredder-dominated) based upon inputs of grass debris if first order and macrophyte debris if second-third order. The taxonomic richness of woody and open streams appears similar, although the taxonomic composition is different.

- Studies of the invertebrate communities in 'functional habitats' in a larger river section emphasised the distinctiveness of habitats dependent upon trees – leaf litter, in-stream woody debris and tree roots – as refuges for high population densities of shredders (e.g. the shrimp *Gammarus*) and predators (e.g the dragonfly *Agrion*).

RECOMMENDATIONS

1. A positive policy towards native riparian and floodplain trees should be established, with a long-term (i.e. decades) perspective and a rolling programme of native species plantings which improve the ecological and landscape importance of our riparian tree community and rectify the present situation of inadequate juvenile stock in almost all species.

2. Policy towards tress should be guided overall by a catchment-scale approach, recognising the major natural functions of trees which change downstream:-

- In first and second order streams, where leaf-fall is the primary energy source for stream organisms, trees and shrubs should be allowed as much as possible to overhang the river channel and to contribute debris to it, both leaf and branch; such debris should be removed only when obvious flooding risk is caused, never as a means of 'tidying-up' the river channel.

- In larger, middle-order streams, mature trees have more of a shading value which provides cover for fish and suppresses in-chanel vegetation growth. The optimum performance of these functions is achieved if the trees are on south banks, spaced to give about 50% channel shading. Management should be directed towards this optimum.

- In many lowland reaches, mature (often single) trees also have very important landscape and wildlife value due to their size and dsistinctiveness. This should be retained and increased by a) pollarding mature trees as many are over-tall and becoming unstable, and b) appropriate new plantings of native standard trees, well-spaced with high quality protective fencing.

3. The following principles should be applied on all occasions involving tree management:

- Any trees lost should be replaced with native species, even if not in the same location. Mature trees should be replaced with standards, scrub with whips.

- Where it is not possible to plant in the riparian zone and compensatory plantings are made elsewhere as part of a larger management project, a target area for this should be 1 ha, 0.75 ha minimum. This is just above the threshold area value for species richness of birds in small patches of woodland.

- Liaison should always be established with appropriate County Council Planning officials and local FWAG groups and County Wildlife Trusts, in order to maximise the varied opportunities for grant-aid in tree-planting schemes.

- Species chosen should be native to the U.K., and appropriate to the site characteristics (important ones are soil type, wetness and distance from water's edge).

4. Riparian maintenance requirements, though governed by byelaws, are often interpreted in different ways by individual district engineers. Practice within Central area could benefit from the following general concepts, wherever possible:-

- Patches of scrub are valuable feeding stations and nesting habitat for birds and should be retained where there are no negative effects (eg. rabbit tunnelling risk).

- Discontinuous riparian tree cover (see 1. above) is better than continuous and, unless single-standard landscape planting is undertaken, patches of mixed native species should be established with some connection to the water's edge for shelter of birds and mammals from distubance. The concept of frequent triangular-shaped patches of tree/shrub, with the apex at the water's edge, is a useful one.

- Trees planted without animal-proofing have low long-term survival value; the need for protection should always be considered as highly as the need for tree-planting.

- Trees form one component of the overall ecological value of riparian zones, and where particular management requirements exclude trees, policy should be directed towards maximising the variety of other riparian functional habitats, such as grassland of different height and structure.

ACKNOWLEDGEMENTS

This project was carried out over its two-year duration with a number of assistants and students. The first part of the desk survey and correspondence with conservation bodies and County Councils was carried out by Maureen Parsons and completed by Gaynor Evans. The aerial photgraphic analysis was carried out by Francis Witkowski as part of his M.Sc. dissertation. Field survey throughout the catchment was carried out by Deborah Kemp-McCarthy assisted by Lucy Parkin, and on the rural/urban fringe by Jacqueline Crabb as part of her M.Sc. project. The survey of bird communities was done by Tony Balbi towards his B.Sc. Human & Environmental Sciences, and those of organic debris by Amanda Jones, Clare Cudmore and Jasper Ellis as part of their B.Sc. Biological Sciences dissertations. Literature reviews were initiated by Andy Smart and carried through by students in the Natural Resource Management M.Sc. Data analyses were completed and the final text was assembled with me by Gaynor Evans.

Assistance in the preliminary stages was provided by staff at the County Council Planning Departments and the County Wildlife Trusts which cover the Great Ouse catchment; English Nature, County FWAGs and the Ministry of Agriculture offices. NRA officers, particularly the conservation staff and the three Central Area District Engineers were very helpful in discussions. Peter Barham provided a valuable overview throughout the project and he, together with Geoff Brighty, contributed to a first draft of the text.

INTRODUCTION

Project Objectives

The primary objective of this Operational Investigation was to provide guidelines for the management of riparian trees. The project was initiated because increasing concern about riparian conservation over the past decade had firstly led to an environmentally sympathetic approach to land drainage and flood defence works, and secondly made the financing of conservation works possible within the capital programme. This environmentally sympathetic approach amongst flood defence engineers has inevitably been interpreted in a wide variety of ways by different individuals, and broad guidelines were needed for conservation of existing trees and shrubs during river management operations. Conservation works have, since 1989 or thereabouts, included tree-planting schemes of various sizes, and some guidelines were also needed for this pro-active approach to riparian vegetation.

The detailed objectives were as follows:

- To review the scientific literature on the ecology of riparian trees in order to produce broad conclusions about their role in the overall ecology of rivers so that recommendations produced would have a scientific basis.

- To survey the tree and flowering plant communities within the Central District of the Anglian Region of NRA in order to determine the frequency and abundance of the species of riparian trees and shrubs present.

- To carry out investigative work, where gaps appeared to exist in our information, upon the role of riparian trees in the ecology of the river.

- To ascertain from local authorities and conservation bodies in the Central Area, information held about riparian trees and policies towards them.

Outline legal background to tree management and conservation

Legislation directed towards the control of water resources within England and Wales has placed increasing emphasis on the need for conservation and more sympathetic river management over recent decades. The 1968 Countryside Act required water resource managers to 'have regard' for conserving 'natural beauty and amenity' during engineering operations. The 1973 Water Act which instigated the replacement of the many River Boards by ten Regional Water Authorities used similar terminology:

'water authorities ... shall have regard to the desirability of preserving natural beauty, of conserving flora, fauna and geological or physiographical features of speciel interest ...' (1973 Water Act)

This Water Act instructed the individual Water Authorities to carry out a number of duties relating to the practicalities of water supply, flood control and land drainage. Conservation was considered to be a 'desirable' option and was not among these duties.

Under the 1975 Conservation of Wild Creatures and Wild Plants Act, provision was made for the protection of named species. The Water Authorities however were exempted from having to comply with this Act whilst undertaking statutory duties.

Legislation relating to the functions and duties of the Water Authorities was consolidated in the 1976 Land Drainage Act. This also empowered them to produce byelaws necessary for the protection of drainage installations (for example, from tree planting and fence erection). Any obligation that the Authorities might have towards conservation and landscape preservation was conveyed as 'due regard ... to the interests of fisheries'.

The 1981 Wildlife and Countryside Act bought about a change in the original wording of the 1973 Water Act relating to conservation responsibilities. Water Authorities were now required to;

'exercise their functions ... as to further the conservation and enhancement of natural beauty and the conservation of flora, fauna ...where consistent with other duties' (1981 Wildlife and Countryside Act)

Furthermore, the Authorities had to consult with the Nature Conservancy Council prior to work on sites that had been notified for their special interest.

The 1989 Water Act replaced the Water Authorities by ten newly established water companies (PLCs) and the National Rivers Authority. The PLCs were made responsible for water supply and recovery and the NRA undertook a wide range of other regulatory and statutory duties; water resources, environmental quality and pollution control, flood defence, fisheries, conservation, navigation and recreation. The NRA is presently comprised of eight regional groups, each corresponding to an area served by one or more former regional Water Authority.

This Water Act imposes a specific duty upon the NRA to promote the interests of conservation;

'without prejudice to its other duties, under this section, it shall be the duty of the Authority, to such extent as it considers desirable, generally to promote the conservation and enhancement of the natural beauty and amenity of inland and coastal waters and of land associated with such waters...the conservation of flora and fauna which are dependent on an aquatic environment and the use of such waters and land for recreational purposes.'

A distinct recreational duty is also imposed upon the NRA requiring the recognition of three factors prior to the formulation or consideration of any statutory function or function of the PLCs. First the Authority is to have regard to the desirability of preserving for the public any freedom of access to areas of woodland, mountains, moor, heath, down, cliff or foreshore and other places of natural beauty. Second, it is to have regard to the desirability of maintaining the availability to the public of any facility for visiting or inspecting any building, site or object of archeological, architectural or historic interest. Third it is to take into account any effect which the proposals would have on public freedom of access or the availability of a facility of this kind.

The Water Resources Act 1991 is the most recent act, consolidating previous legislation relating to conservation. Its relevant sections are Section 2, linking the conservation of 'flora and fauna', and 'natural beauty and amenity' with the promotion of recreation, whilst Section 16 links them with the freedom of public access. There is thus a general trend in the legislation towards strengthening pro-active conservation operations of the NRA in addition to re-active work.

This general conservation legislation does not specifically refer to trees, and the only separate provision for trees is by tree preservation orders under 1990 Town & Country Planning Act. More specific legislation covering species and sites of conservation importance is embodied in the 1981 Wildlife and Countryside Act, and much previous conservation attention of NRA activities has concentrated upon identifying and minimising damage to actual or potential SSSIs (the main pretective designation for sites under this act). The NRA is now, in pursuing its broad responsibilities for conservation, moving beyond site-specific activities into the wider river environment. Here it is constrained by land drainage duties, which take priority in most instances.

Provision made under Section 34 of the Land Drainage Act for the creation of byelaws by the previous Water Authorities have, since 1989, been enforceable by the NRA. Hence the Anglian Region NRA has in force 'Land Drainage and Sea Defence Byelaws'. These confer the legal authority to secure the necessary working of drainage systems in the region. Section 15 (Part 1) relates to the planting of trees on banks. This byelaw prohibits any person from planting trees or shrubs within eight metres measured horizontally from the foot of any bank of a main river without written consent from the NRA. Where there is no bank, the distance is nine metres measured horizontally from the top edge of the batter enclosing the river.

This control over trees on river banks relates to the fear that they might undermine bank protection, directly through their root systems and collapse or indirectly through burrowing animals such as rabbits. Trees may also obstruct access for machinery used in river maintennce operations – dredging or weed-cutting. There is little disagreement that extensive tree and shrub clearence has been carried out along riverbanks since the 1940s, much as a precaution rather than in the certainty that obstruction of land drainage was occurring. The nation is now in the political and economic situation where it is no longer necessary to apply the standards of land drainage so zealously, and opportunity exists for a revision of earlier attitudes to riparian trees. This change in attitudes has been paralleled by a growth of evidence which suggests that trees have many beneficial effects upon river systems, not least of which is the protection they can provide against erosion.

The role of trees in the physical aquatic environment

Protection against bank erosion

The erosion of river banks varies with both the in-stream conditions and the bank composition and structure (Petts and Foster 1985), and as such is variable and complex. The processes that lead to bank erosion can be grouped into four main categories; direct hydraulic action or corrosion, slumping, rotational slipping and frost action (Knighton 1984). Fluvial erosion of banks can result in the loss of soil, levee failure, loss of property, desiccation of meadows and loss of riparian vegetation. The preservation of river banks is therefore of great importance (Patterson *et al.* 1981, Brookes 1988).

Vegetation has a stabilizing effect on the upper layers of an eroding stream bank and as such reduces the rate of bank recession (Wolman 1959, Smith 1976, Hooke 1980, Thorne and Tovey 1981). This effect is mainly due to the presence of roots which bind the soil together. The large scale root structures of riverine trees are especially effective in staving river bank erosion. The root system of a hardwood tree can protect a length of river bank up to five times the diameter of the tree (Keller and Swanson 1979). Eaton (1986) found that stands of bankside softwoods reduced erosion even where scouring is most severe on the outside of meander bends.

The protection afforded by riverine trees is dependent upon the position of the roots relative to the water level. The distribution of roots within a river bank is not homogenous but decreases with depth such that the tensile strength of the soil also changes and is at a minimum at approximately 250mm below the surface (Thorne and Tovey 1981). Therefore if the river bank is high, which may be the case where a river is incising into non-alluvial deposits, then the root structure may well be above the level of scour. In such cases undercutting and bank failure may occur as the roots have no stabilizing effect. It is therefore important to contain river bank erosion before bank height increases to a level at which tree roots become ineffective as means of bank protection. Futhermore, trees planted on high banks may advance cantilever failure through 'top-heaviness'.

Since the 1930s there has been frequent removal of riverine trees on the grounds that they pose a flood hazard and obstruct access for river maintenance. It is now however accepted that trees, such as certain willows and alders, can quite successfully protect banks from erosion (Lewis and Williams 1984). Trees planted on banksides need to be planted far enough from the water's edge to enable a firm root system to develop before the bank erodes back to that position. Approximately fifteen years is required for alders, so the position of planting should be calculated accordingly.

It is often necessary to manage bankside vegetation to achieve the best protection. Coppicing, for example, acts in two ways to increase the level of bank protection. By promoting growth, coppicing increases root structure; and by keeping growth to a low level it prevents the bank from becoming too 'top-heavy'. It is important when coppicing bankside trees to restrict access to livestock as browsing restricts the growth of vertical and bankward shoots whilst leaving outward curving ones free to grow. Uneven development of a coppice causes instability and leads to increased likelihood of bank collapse. Willows are commonly used in forms of bank maintenance work other than simply coppicing. The regenerative property of willow that is made use of in coppicing can also be exploited in the technique of 'faggoting' (Lewis and Williams 1984). Thin branches of willow are fastened together and laid along the bank, held in place by poles. This structure is ideal for trapping silt as the velocity of the river is retarded to a level where sedimentation takes place. The willow faggots can grow shoots and roots which further stabilize the bank structure. Faggoting has to be introduced with caution since dense willow growth can occasionally reduce a channel's flood capacity.

The relative value of riparian trees as bank protection may change as they mature. Whereas young trees are supple enough to withstand storms, older trees of a hundred years or more are more likely to be uprooted during such events. In Bavaria, osiers were planted for bank protection as part of a land drainage policy (Zimmerman *et al.* 1967). Forty years later there was no evidence to suggest that these plantings had had a detrimental effect on bank stability. However forty years is not long in the life of a tree or in land drainage terms and it has been suggested that the shortcomings of using trees for bank protection might only become evident after a considerable period of time. The effect therefore of tree planting on banks will only be seen ninety to hundred years after the planting.

Trees are generally an effective method of preserving the integrity of a river bank where due consideration is given to the conditions of planting and proper maintenance. Other bank protection techniques include the use of rock, concrete or stone as reinforcing walls or revetments at the toe of a bank. Gabions of chicken wire and rock, stone or timber can also be used. Although other artificial methods can be put in place immediately and may be sympathetic to the river environment depending on the materials used, riverine trees provide a more 'natural' solution to the problems of bank erosion.

Influence upon flow

The physical mechanisms controlling flow, erosion and deposition in alluvial channels have received much attention from engineers and geomorphologists in recent years. Historically, the influence of trees upon river flow was probably more significant than at present, because more channels were wooded or ran through forest; but the development of managed channels can still be strongly influenced by the presence of riparian trees.

Keller and Swanson (1979) drew attention to the importance of the impact opf woody debris upon flow in channels, summarising its dynamics and the importance of input/output processes in relation to stream order and distance from headwater. For example, output of organic debris is more important in streams of third order and above for the McKenzie River system. They emphasised the semi-permanent nature of organic matter in streams through accumulation of coarse material by debris dams. The processes that cause the periodic input of coarse woody debris in addition to the channel shape at the point of initial input influence its size distribution and stability.

Allochthonous organic material enters a river channel seasonally. The bulk of tree debris enters during autumn due to leaf abscission. Other factors that will effect organic input include woodland type, stand composition and age structure, nature of adjacent topography together with associated weathering and transport processes.

Debris movement

Transport depends on size of debris relative to stream order. Lienkamper and Swanson (1987) conducted a study of five first to fifth order stream reaches in old-growth Douglas-fir forests of the Cascade Range, Oregon. Their study lasted for nine years and they concluded that most individual pieces of woody debris that migrate downstream are shorter than bankfull width. Conversely pieces of woody debris that greatly exceed channel width tend to remain *in situ* for many decades and possibly centuries. Downstream migration of coarse woody debris occurs sporadically and will only happen when there is enough stream power to transport material. Obviously, coarser, heavier material requires more energy for transportation.

Keller and Swanson's (1979) study of the McKenzie River system, an area of large old growth trees in Oregon, indicated that in steep gradient, mountainous small streams (first and second order), large organic debris locally influenced flow characteristics as the streams were too small to redistribute the debris. The faster flowing waters of intermediate sized channels were capable of redistribution and distinct accumulations formed at channel bends which were able to directly affect the entire channel width. Large rivers (exceeding 5^{th} order) tended to scatter debris and deposit it in the high water zone where it only had influence on the channel flow during bankfull flow conditions. These principles apply generally to any lowland or highland stream.

A further distinction was made between low gradient meandering streams (Indiana and North Carolina) and mountain streams (Oregon). Debris dams in low gradient moderate sized streams were usually accompanied by bank erosion, in-channel deposition, braided reaches, and locally increased channel width. Debris dams in small-moderate, steep gradient streams might locally alter (increase/decrease) erosion and/or deposition of the channel bed and bank. They also provided long term in-channel sediment storage sites combined with a pronounced stepped profile.

Significant Obstruction Types

Debris dams are the most common form of obstruction in such channels. These vary greatly in size (a factor which is controlled by the available woody debris) and usually consists of a variety of material such as trunks, branches of various size, leaf litter, root wads and finer organic/inorganic matter. Small pieces of wood lodge against the initial obstruction and form a lattice onto which leaves and other small material (referred to as Coarse Particulate Organic Matter (CPOM) are retained to form an almost water tight structure. Pools can form behind dams which reduce flow rate and so produce a deposition zone for fine sediments and organic matter. Finer organic/inorganic matter is important in helping to create and maintain a water impermeable or semi-permeable barrier by filling gaps between larger woody components. Several workers have tried to classify different types of debris dams based upon their relationship to the channel. According to Gregory (1990) active dams form a complete cross channel barrier and cause a step in the river's long profile. Complete dams are similar to active ones except they do not induce a step in the long profile, while partial dams are those that incompletely span the channel. Active dams are also termed log steps (Marston 1982) and may consist of a single large log or an accumulation of debris. Alternatively log stepping may be called organic stepping, but the induced effect in long profile is the same.

A study conducted on a second order stream draining an experimental watershed of the Hubbard Brook Experimental Forest, New Hampshire serves to show the important role that debris dams play in organic matter retention. Bilby and Likens (1980) measured export rates of organic matter following debris dam removal from a 175m experimental stretch of river. The DOM output from the system increased by 18% after removal. Fine Particulate Organic Matter (FPOM) export showed the highest increase of 632% after dam removal, as the pool areas were removed stopping any deposition. Also the sediments became open to erosion and were therefore removed with the current. CPOM export increased 138%. Prior to dam removal only 10% of total available CPOM in the stream was removed annually; but this increased to 37% after removal.

These trends were mirrored by the estimated turnover times which dropped from 0.71 year (a low estimate for 1977-78 due to high rainfall) to 0.31 year after dam removal as more organic matter was washed from the system due to decreased retention properties. Measurements of the standing stock CPOM over streambeds of the Hubbard Brook area revealed that the organic debris dams were very important in retaining organic matter within the system until processed into more mobile components. The headwaters were shown to hold the highest concentrations of CPOM, where current flows are less likely to dislodge the dams. This trend is expected as headwaters possess the communities that are capable of processing CPOM.

The study concluded that leaf litter provides a very important energy source which has a processing time of approximately 1 year. The reduction in ability to retain leaves after dam removal leads to energy loss from the system as processing effectiveness is reduced. This reduction of energy base is felt by both CPOM- and FPOM-dependent communities.

Living trees and root systems are locally relevant, effecting immediate stream flow. Depending upon species longevity, an individual may affect flow characteristics for decades and in some instances centuries (Beschta and Platts 1986). The in-stream above ground portion of a tree will add to channel roughness thus reducing flow velocity and hence erosive ability along channel margins. It was noted by Mosley (1981) during field study of a New Zealand stream that living trees rooted to the bank can also obstruct flows and that the channel wound among trees that were frequently hundreds of years old. It was also noted that undercutting of the stream bank occurred beneath trees during low flow periods. However this erosion was limited to floodplain sediment below the level of tree roots and the depth to which the roots penetrated was controlled by water table height. Tree roots did not extend below the water table. It was inferred that where present, tree roots protected banks against erosion. It was concluded that that the full length of this channel was influenced by plant root systems (including trees).

Effects of obstructions

Beschta and Platts (1986) stated that unit stream power can be reduced by stream obstructions. Flow resistance can be increased by large roughness elements such as woody root systems and channel sinuosity. Dissipation of potential energy is one of the major processes which occurs at the base of active debris dams. A significant portion of a streams energy is lost through turbulence. This leaves less potential energy available for conversion to kinetic energy which takes part in sediment transport and erosion and leads to slower flow rates (Marston 1982). However this does depend on the flow stage of a stream. Gregory (1990) reported that low-medium discharges and active dams coincide with longer travel times, but at high discharges the sheer volume of water may effectively 'drown out' any number of these dams resulting in a much shorter travel time. Both length of travel time and potential energy dissipation due solely to active debris dams ultimately depends on numbers of dams present, plus their cumulative height in relation to total stream height.

Increased flow resistance by stream side and in-channel roughness elements such as trees and woody debris has long been noted. Hickin (1984) believed that with other factors constant they can produce great changes in small streams, and also exert lesser but significant influence over flow resistance in larger channels.

Indications are that coarse woody debris can be a dominant control on the style, number, and geometry of pools and riffles. Robison and Beschta (1990) document plunge, dam, deflector, and underflow pools as being influenced by organic debris and Beschta and Platts (1986) have produced a similar classification diagram. Different pool types are a function of the different flow regimes occurring in close proximity to the debris dam and these regimes are due to the nature of individual dams in relation to the channel. A brief summary of pool class by formation method and obstruction type could include backwater pools along channel margins which form behind tree trunks/root wads; dammed pools formed upstream of debris jams or beaver dams; lateral scour pools that arise due to flow deflection by coarse woody debris; and plunge pools formed beneath /active dams. Dammed and backwater pools arise by impoundment of water whereas plunge and lateral scour pools are caused by erosion. Robison and Beschta (1990) also defined four 'influence zones' for debris at any point along a stream. These included a terrestrial zone, a zone directly above active channel, a summer flow-bankfull flow zone, and a summer low flow zone. This was in order to assess the amount of wood impeding and thus altering current pattern during bankfull flow and its relationship to the channel. They concluded that spatial distribution and orientation of individual debris pieces imparted additional variables to channel features in low gradient streams of S.E. Alaska and so were important.

Mosley (1981) assessed from field study that along 40% of a single streams' channel length riffles and pools and gravel bars were related to flow patterns induced by organic debris accumulations. A specific example of this was where water was forced to flow beneath a log jam, resulting in scouring of a pool, and redeposition of eroded material as a large gravel bar downstream. Similarly Harmon *et al.*. (1986) found that coarse woody debris can cause both abrupt changes in channel pattern/position (by blocking main channel flows) and chronic changes (by deflection of currents toward banks thus speeding lateral migration). This has been documented by Keller and Swanson (1979) in Campbell Creek, North Carolina. A single large tree falling into the small channel caused local streambank erosion resulting in the channel's lateral migration over two years. It was perhaps also responsible for chute development across a meander as water collected behind the log until it overspilled.

Large debris dams have been associated with/responsible for a complex series of pools, riffles, and scours. One such dam studied by Keller and Swanson (1979) at Mallard Creek, North Carolina was reported to have caused scours and mid-channel bars which are directly related to it . The dam had also triggered smaller log jam development downstream as it broke up. The result was local bank erosion resulting in a 230% channel width increase.

Channel shallowing and widening along coniferous forested streams has also been described on Narrator Brook, Dartmoor by Murgatroyd and Ternan (1983). Here, the forested channel was three times wider than its unforested counterpart. This was attributed to the river flowing around in-channel woody debris (flow deflection) in conjunction with suppression of the turf layer due to the forest shade. Without the turfs' fine roots the banks were more susceptible to erosion. Note this is the converse of the case stated above by Mosley (1981) where trees were considered responsible for delaying channel widening.

Coarse woody debris, in providing the main structural elements of in-channel obstructions, helps accumulation processes for both inorganic/organic detritus. On the Squamish River, British Colombia, mid-channel bars of the highest relief are the ones with vegetative elements incorporated into the sediment at the head of the bar. Hickin (1984) stated that when such vegetation was present it occurred on the bar tops and so was not responsible for initiating bar formation. However it did enhance development rates by trapping further quantities of debris and sediment.

Vegetative debris may also aid the development of a concave bank bench, a feature which develops when the outer bend of a migrating river is impeded by a valley wall. On migration down valley a depositional 'vacancy' occurs as the style of flow at a river bend prevents bed-load sediment entering the 'void'. However, it may infill if sufficient woody debris carried by the river can enter this dead zone, filling it, and increasing its efficiency as a sediment trap. Carey *et al.* (1982, in Hickin 1984) found that the organic content of concave bank benches was very high which indicates the necessity of coarse particulate organic matter for their formation.

Where riparian trees and their debris inputs reduce flow rate and dissipate stream energy they cause erosion retardation and possible sediment accumulation/storage. Erosion, scouring and sediment removal can however occur where tree debris causes a local relative increase in flow as a result of deflection. These alterations in stream morphology are important in extending and/or maintaining diverse in-stream habitats for aquatic fauna and flora.

As virtually all British rivers are atypical, in that they do not flood annually and are confined to single channels in the lowland part of their basins, any research on them concerning flow characteristics related to trees may be flawed; especially if any future work was applied elsewhere without taking this into account. Many authors state quite clearly that more study is required as there is a need for both more accurate field data and more widely applicable models. Models at present tend to be restricted and only applicable to their specific study areas/river catchment. This is largely due to the fact that such studies are not easily quantifiable and the nature of organic debris obstructions are highly variable.

Channel Shading

Shading directly effects two parameters of the stream environment; light and temperature. The susceptibility to temperature change decreases as the size of the river increases thus the ecosystem of a larger river will be more stable in this respect. Temperature effects also vary with elevation and exposure. Changes in temperature of 6 ^{0}C to 9 ^{0}C have been documented by Shields and Nunally (1984). Mahoney (1984) measured a temperature difference of 12 ^{0}C between shaded and unshaded sections of the same river. The temperature effects are also seasonally regulating causing cooling in summer and maintaining relatively warmer temperatures in winter (Knight 1984).

Riparian shading can effect aquatic plant growth in several ways; by reducing the light available for photosynthesis thereby decreasing productivity, by contributing to the build-up of detritus which in turn may create more shading and by increasing the competition for light (Dawson 1983).

The growth of *Myriophyllum* sp. was studied by Brookes (1987) and was shown to have higher biomass-production in unshaded sections; 2.7 kgm^{-2} compared to 0.09 kgm^{-2} within the shaded areas. The total macrophyte biomass was between 4.4 and 29 times greater in unshaded channelised reaches than in those measured in shaded reaches.

Haslam (1981) described the distribution of river plants in relation to channel shading. Of the common species of river plant, *Ranunculus* spp. are the most light-demanding and *Sparganium emersum* the most shade-tolerant.

Table 1. Shade Tolerance of Common River Plants:

More light-requiring species	*Ranunculus* spp., *Veronica beccabunga* *Rorippa nasturtium-aquaticum* agg., *Zannichellia palustris* *Veronica anagallis-aquatica* agg. *Apium nodiflorium, Berula erecta, Glyceria maxima,* *Nuphar lutea,* *Sagittaria sagittifolia, Potamogeton crispus* *Ceratophyllum demersum, Elodea canadensis,* *Myosotis scorpioides, Alisma plantago-aquatica*
More Shade-tolerant species	*Callitriche* spp., *Phragmites australis, Sparganium erectum* *Sparganium emersum*

The distribution of macrophytes on a shaded and an unshaded section of the Lambourn river was investigated by Ham *et al.* (1981,1982). In the shaded section of the river it was noted that *Berula erecta* had the greater cover followed by *Callitriche* spp. and then *Ranunculus* spp. In the unshaded river section, *Ranunculus* spp. was the dominant species. In terms of biomass, Wright (1982) studied the same sections and also found *Ranunculus* spp. to be dominant in the unshaded section. The biomass of *Berula erecta,* however, was found to be similar in both the unshaded and shaded sites, whilst *Callitriche* spp. had a higher biomass where there was shade. Both studies support the findings of Haslam.

Aquatic plants can often grow to 'weed' status during summer months, clogging water courses and requiring expensive mechanical and/or chemical control for flood defence and navigation. The use of bankside vegetation to reduce aquatic plant growth has received considerable attention (Dawson 1978, Dawson and Hallows 1983, Krause 1977). Dawson and Haslam (1983) consider the issue in some detail and recommend a desired optimum of 50% shading of the water surface by deciduous trees in regular but intermittent stands along two-thirds of the bank. Orientation should also be taken into account: trees on the southern bank of streams running east-west naturally have the largest shade effects.

The effect of shading on primary production can both indirectly and directly influence stream fauna. Triska (1983) noted a change in invertebrate number with time as a result of shading. This was attributed to the differences in periphyton biomass since periphyton, an algae which forms a thin film (or mat) on submerged rocks, plants and stream debris, has reduced productivity where light is limited. Shading by trees, where not too excessive, allows for a greater temperature range which can increase species diversity (Mahoney 1984). Stoneflies, for example, favour cooler temperatures and prefer to browse on thinner films of periphyton whereas chironomids are tolerant of warmer waters and prefer to browse on thicker periphyton mats (Quinn 1990).

Several studies have investigated the influence of aquatic vegetation on fish (Boussu 1954, Smith 1980, Baltz 1984). They can be influenced by temperature variation, since different species have temperature ranges for completing certain stages of their life cycle such as reproduction (Baltz 1984). Changes can occur within a fish community as a result of changes in the invertebrate community (Mahoney 1984), through alteration in primary production due to shading. Excessive shading by riverine trees may also have a detrimental effect on certain fish species such as trout (Smith 1980). Such an interpretation, however, must be made with caution given that bankside trees can affect a river channel in other ways.

Shading by riparian trees can also provide shelter for fish. Baltz (1984) demonstrated that a fish within a shaded area is less visible to other fish in unshaded areas. This can obviously be exploited by both predatory and non-predatory fish.

The value of trees to water quality

Woody riparian vegetation has been evaluated as a possible approach to the problem of reducing pollution from diffuse cxatchment sources through the establishment of buffer zones between the pollutant source areas and the receiving waters. These may provide a biochemical and physical barrier against pollution inputs from upland areas (Muscutt *et al.* 1993a). In the United States a catchment strategy that uses best management practices and techniques is advocated. Such practices incorporate natural physical and biological processes to reduce, convert or store pollutants on the land before they enter the aquatic system. Approaches to mitigate adverse impacts have included use of riparian vegetated buffer strips. Their use has become an accepted management practice, with the US. Department of Agriculture providing some of the funds for their installation, under the 'Conservation Reserve Program'.

Buffer zones and pollution sources

Buffer zones may extend a prescribed distance from the water's edge for the purpose of protecting the quality of water (Nieswand *et al.* 1990). Their vegetation may consist of trees, grasses and wetland plants and they are separately managed from the rest of the field or catchment (Muscutt *et al.* 1993b).

Vegetated buffer strips are regarded as being of value for the removal of sediment and attached and dissolved pollutants in overland flow, by filtration, deposition, infiltration, absorption, adsorption and decomposition. They are also proposed on the grounds that they reduce sheet, bank and stream bed erosion by stabilisation of ground surfaces on banks and by reduction in overland flow velocities. Another factor in favour of their usage is that they can displace activities from the water's edge that present potential sources of non-point source pollution (Myers & Swannson 1992).

Various studies on the merits of riparian buffer zones have been undertaken at many different locations around the world, most notably in the United States and North West Europe. The subsequent literature has provided evidence in support of the concept that:

> "Retention of nutrients in riparian buffer strips has been reported in numerous locations globally and suggests riverine buffer strips critically effect the concentration of agricultural pollutants in river water" (Haycock & Pinay 1993).

A study was undertaken by Jordan *et al.* (1993) to examine the changes in chemistry of groundwater flowing laterally from a cornfield, through a riparian forest, and subsequently to a stream, between July 1990 and August 1991. The forest was located on a hill slope and floodplain on the Delmarva Peninsula, near Centreville, U.S.A. Groundwater moving through the forest towards a tributary of the Chester River was sampled at increasing distances from the field boundary. They found that the chemistry of the groundwater differed greatly with distance. Nitrate concentrations showed the greatest spatial variation. This fell from 8mg/l at the edge of the cornfield to less than 0.4mg/l halfway through the forest. Most of this change was found to be 25-35 metres from the edge of the cornfield.

Another major source of pollution is in the form of sediments. Soil erosion occurs where the soil type, landform, cropping and rainfall factors favouring erosion occur together. The expansion of areas sown to winter cereals and the consequent increase in bare ground during the autumn and winter months combined with the enlargement of fields and uncropped, downslope tractor tramlines all contribute to increased erosion. It is estimated that 37% of the soil in England and Wales is at risk (Chambers *et al.*. 1992).

The Nature of the Buffer zone

Osborne & Kovacic (1993) found that the pollution removal potential of a simple linear buffer strip would be limited if subsurface drains crossed the riparian zone. Subsurface drains decrease the rate of pollutant (especially nitrate) removal in two ways. Firstly, by lowering the water table, thereby limiting the frequency of reducing conditions which are required for denitrification. Secondly, through restriction of the time of contact between soil and water, thereby reducing the opportunities for pollutant removal by plants and bacteria (particularly in the case of nitrate uptake) (Groffman *et al.* 1992).

Muscutt *et al.* (1993a) suggest that the problems of subsurface drains in decreasing pollutant removal potential can be overcome by the creation of 'Horseshoe Wetlands'. These are described as being semi-circular excavations at subsurface drain outlets occupied by grasses and shrubs.

Osborne and Kovacic (1993) carried out a study to compare grass and forest buffer strips. Forested buffer strips were found to reduce nitrogen in the groundwater by 68 to 100% and in the surface run-off by 78 to 98%. Grass buffer strips reduced the nitrogen input by between 10 and 60%, but no clear pattern emerged for the effects on phosphorus, in either the forested or grass vegetated buffer strips. The figures found by Osborne and Kovacic (1993) have large ranges mainly owing to the large number of variables that are inherent to pollutant transport. The efficiency of buffer strips is dependant on sedimentation rates, surface and subsurface drainage, soil characteristics (i.e. the redox potential of the soil), organic matter content and type, temperature and successional status of the vegetation (Haycock & Pinay 1993). Above all, buffer strip effectiveness is dependant upon the pollutant loading rates from upland areas. It is therefore not surprising that comparisons are difficult to make. In general terms, Osborne and Kovacic found that riparian forests are more efficient at removing nitrate from shallow subsurface water than grass buffer strips. They suggest that the reason behind this difference in the nitrogen removal efficiency of forest and grass buffer strips is associated with the form of the carbon available for denitrification. Despite the greater efficiency of nitrate removal associated with forest riparian zones, grass buffers are more often found on agricultural land. The benefits of grass buffers are that they can be installed and maintained more easily and produce an effect on water quality within a much shorter time scale.

The density of the vegetation is an important factor affecting the ability of buffer strips to control inputs from surface run-off, and in particular sediment associated pollutants which are likely to be removed if the density of the vegetation is sufficient to cause deposition. The study undertaken by Muscutt *et al.* (1993a) indicated that grass buffers appeared to offer sufficient resistance to encourage deposition and the removal of nitrogen and phosphorous. The efficiency of forested riparian areas as buffer strips, however, depended largely upon the degree of ground cover and were found to actually increase the surface run-off if the ground cover was too low.

The use of plant species with rapid growth rates (with associated faster accumulation of nutrients) was proposed to overcome the problem of a lack of ground cover. However, the pollutant retention potential of such plants is limited by the absolute nutrient requirements of the plant (although mixed crops might be shown to overcome this problem). Furthermore, pollutant retention by plants will only occur in the growing season. As this tends to be in the summer, the species will have little or no effect in the winter months when inputs of pollutants are at their maximum and frequent run-off events ensure that they are rapid (Muscutt *et al*. 1993).

The density of riparian buffer zones not only effects the pollutant input from agricultural practices, but may also have important shading functions. Osborne and Kovacic (1993) reported that forested buffer strips were found to reduce solar radiation to their study stream. The buffer strip will therefore minimise the temperature fluctuations of the stream. In North America, buffer strips between 10 metres and 30 metres were shown to maintain stream temperatures.

Relevance of buffer strip concepts to riparian tree management and ecotones

The nature of riparian tree management in the Great Ouse is such that consideration of the value of trees as buffer strips in water quality management is likely to only occur in specialised circumstances. There are relevant R&D projects at NRA national level and in English Nature which examine the value of buffer zones for conservation and water quality further. Trees have a number of contributions to make to riparian 'ecotones' – edges between two different ecological communities – and these have importance in the wider conservation responsibilities of the NRA introduced at the beginning of this chapter.

Value of trees to the natural riparian ecosystem and its wildlife

The presence of trees and scrub alongside the river channel greatly enhances the wildlife value of the river coridor. Trees, especially mature and old specimens, can support a diversity of plant and animal groups. They provide food and shelter for invertebrates, birds and mammals. The roots of trees at the water's edge provide spawning sites for fish and secure holts for otters. Many organisms are restricted to the riparian zone but some use them as migration corridors. Over the last century, much of the riparian vegetation including its trees has been lost. Some of the loss has been due to river channel 'improvement' and the reduction of the width of the woodland for agricultural expansion. In the context of widespread and continuing habitat loss throughout the country, riparian woodlands are becoming increasingly important as 'reservoir' habitats for many species (Klebnow and Oakleaf, 1984).

Energy inputs into river systems from riverine trees

Adjacent terrestrial environments have a high impact on the stream ecosystem. Streams running through, or downstream of, wooded catchments receive large quantities of debris (organic allochthonous material) from trees (and other riparian vegetation) in the form of branches, twigs and leaves (Winterbourn and Townsend 1991). In low order streams this usually acts as the major energy input because in-channel primary production is limited by the shading effect of the trees. Animal communities have consequently evolved to utilise this energy resource through specialised feeding strategies. Communities progressively change downstream in response to the organic material (energy) which is swept down from this upstream processing of detritus. Initial input of allochthonous material at the upper reaches therefore acts as a valuable energy source along the length of the river and not just in the headwater region.

The input of allochthonous material from riverine trees is strongly seasonal with the main peak occuring in autumn with leaf fall from deciduous trees. According to Anderson and Sedell (1979) inputs of woody debris however are at their greatest in winter and spring. Where such inputs provide the only significant energy source for stream communities, it is important to them that this material is retained within the system. Subsequent processing and nutrient release can therefore occur throughout the year. Organic debris dams play an important part in retaining organic matter in the upper areas of rivers and thus reducing energy loss from the system in the form of unprocessed detritus (Bilby and Likens 1980).

Nutrient processing in the stream ecosystem

Efficient processing of leaf material is performed by a number of animal species which not only nutritionally benefit but also liberate other forms of this material on which downstream communities depend. Leaf material is therefore utilized by a number of communities along the river channel in a number of different forms. This effect is known as nutrient spiralling (Minshall *et al.* 1983) whereby energy is processed in a cyclical manner. This of course occurs in other systems but not in the unidirectional manner found in river systems where nutrients are displaced downstream. Communities depending on leaf-fall as their main energy source are therefore displaced along the river channel as well and locate themselves in an optimum position with regards to the presence of a suitable form of processed detritus. Species distribution along the length of a stream can be predicted considering the type of energy source available and the method of feeding upon it.

A model of these community changes has been developed by Vannote *et al.* (1980) with emphasis on energy processing, retention and transportation through the system. 'The River Continuum Concept' states that community structure within a stream varies in a predictable way from headwater to mouth with the physical changes that occur, the most important being that of changes in energy availability. The type of food available directly influences the feeding guild distributions since only certain species of invertebrate have the necessary morphological and behavioral adaptions to process particular states of matter. Feeding guilds are groups of invertebrates that possess adaptations to process a certain type of energy (Cummins and Klug 1979).

There is no standard classification or size parameter to describe different classes of allochthonous debris. Coarse particulate organic matter (CPOM: Keller and Swanson 1979) describes material over 1mm in diameter and is the most frequently used to describe leaves, branches and other types of larger woody debris. Other terms include coarse woody debris (CWD: Gregory 1990, Harmon *et al.* 1986) and large woody debris (LWD: Lienkamper and Swanson 1987). The guild involved in directly processing this material is termed the 'shredder' group which includes *Gammarus pulex* , certain cased caddis larvae and members of the dipteran family Tipulidae. The action of the shredders plus associated microbial decomposition produces another potential food source known as fine particulate organic matter (FPOM, 0.45µm to 1mm in diameter: Kaushik 1981). FPOM is utilized by the 'collector filterers' and 'collector gatherers' which reaggregate small particles during digestion thereby increasing the average particle size between ingestion and excretion. Predators and grazers are the other guilds, but these are of little interest as they are not directly associated with leaf litter input in the headwaters. During all detrital processing stages, leaching of dissolved organic matter (DOM) occurs. DOM includes organic material able to pass through a 0.45µm filter (Kaushik 1981). This can be made use of by microbes and may play a small role in the nutrition of invertebrates. It is however very mobile within the system and may be removed before it can be utilized. DOM is estimated to have a turnover time of less than one day within the detritus pool of a river (Fisher and Likens 1973).

Shredders and collectors are co-dominant within the headwater reaches (orders 1-3) where riparian trees have their largest influence on river energetics *via* leaf-fall input and shading. The presence of shredders has been shown to have a significant effect on the availability of food for collectors (Short and Maslin 1977). In this study, radio labelled leaves were introduced into an experimental river channel which contained two collector species, *Hydropsyche californica* (Trichoptera) and *Simulium arcticum* (Diptera). The uptake of labelled phosphorus by the collectors was measured after seven days in the presence and absence (control) of the shredder species *Pteronarcys californica* (Plecoptera). The results showed that the action of shredder processing produced a statistically significant increase in collector uptake. Therefore the shredders were making more food (FPOM) available than simple mechanical breakdown of the leaves.

Headwaters are characteristically heterotrophic ($P/R < 1$, where P = gross primary production and R = rate of ecosystem respiration) compared to the middle order streams (4-6) which are usually autotrophic ($P/R > 1$) due to increased algal primary production. They are still however reliant to a large extent on the import of energy from upstream detrital processing. This is illustrated by the fact that only 25% of CPOM is actually mineralized in this form, the rest is released into the detrital pool as FPOM and DOM (Cummins and Klug 1979). The dominant guilds of middle order streams again represent the dominant food types available. Grazers utilize the photosynthetic algae whereas collectors are again co-dominant relying on FPOM drift from upstream. Shredders are relatively infrequent as there is little CPOM present due to decreased riparian inputs and the upstream storage in organic debris dams. There are fewer debris dams in middle and high order streams as the increased flow volume tends to dislodge them (Bilby and Likens 1980). High order streams are characterised by a return to heterotrophy, and are thus reliant on the products of detrital processing again. The collector guild is dominant in these waters while shredders and grazers are both infrequent.

Energy budget for a stream ecosystem

Fisher and Likens (1973) calculated an energy budget for Bear Brook, an undisturbed second-order stream in northern USA. This study illustrated how allochthonous material is processed, partitioned and transported within a 1,700m stretch. The annual input of energy was estimated at 6,039 $KCal/m^{-2}$ of which over 99% was allochthonous material, 56% from geologic sources mainly in the form of DOM and 44% from forest litter input. Of the 44%, 66% was in the form of leaf litter, 19.5% in the form of branches, 13.9% miscellaneous and 1.2% throughflow. 90% of leaf input occurred during the autumn leaf fall and so these figures not only show the importance of leaf litter as an energy source but also the seasonality of input.

In terms of storage and efficiency, it was estimated that the particulate organic load was reduced by 63% into either dissolved matter or dissipated as heat energy. The system was therefore 63% efficient since this percentage of initial allochthonous input was released for further nutrient cycling.

The particulate detritus standing crop was approximately 4,730 KCal/m^2 which was equally divided between leaves and branches. Most of this matter was stored in debris dams until processed. The turnover time of the branch compartment was found to be 4.2 years and for the leaf approximately 1 year. This indicates that debris dams are necessary in retaining organic matter until fully processed.

The importance of riparian trees in maintaining the functional and structural integrity of the stream ecosystem was shown in a separate study when the W2 watershed of Hubbard Brook was deforested (Fisher and Likens 1973). This action led to an increase in runoff by 48%, a fifteen fold increase in DOM export and a ten fold increase in particulate organic matter export. This indicates that without riparian vegetation the system becomes much less efficient.

Factors effecting processing rates

When a leaf comes into contact with water there is an initial period of 24 hours when physical leaching of DOM occurs and upto 15% of its mass can be lost (Petersen and Cummins 1974, Smith 1986). Following this there is a longer term microbial and invertebrate decomposition. Both of these processes are unaffected by stream temperatures as many microbes and animals are specifically adapted to take advantage of the autumn pulse (Bolling *et al.* 1975). The rate of conversion of CPOM to DOM (FPOM being an intermediary) is dependent on the rate of leaching, colonisation by micro-organisms, consumption by the invertebrate community and mechanical disruption such as physical abrasion resulting from stream turbulence (Reice 1974). The rate of CPOM colonisation by micro-organisms and degradation by macroconsumers are inextricably linked. Macroconsumers usually utilise CPOM only after a certain level of microconsumer conditioning has occurred. Micro-organisms are however able to convert CPOM to FPOM in the absence of an invertebrate community but the rate of conversion is significantly reduced (Cummins 1974). Woody CPOM is conditioned at a much slower rate than leaf CPOM due, at least in part, to the decreased penetrability and smaller surface area.

The conversion rate is also effected by the species of leaf. Different species have different processing rates resulting in nutrient release throughout the year as long as the leaves are in the headwater, shredder dominated communities. Studies on these different rates include Petersen and Cummins (1974) who classified three processing groups and Boling *et al.*

(1975) whose study differentiated between fast species (ash and elm) from slow species (oak and aspen). The result of a mixed species leaf input is therefore a 'processing continuum' that releases nutrients year round even though the majority enter the system in autumn. Fast species tend to be those that are conditioned by microbes quickly. They are also consumed by aquatic invertebrates in preference to slow leaf species as they have a higher protein content, although the calorific values of the two are similar (Willoughby 1974). In addition, conditioned leaves may offer the macroconsumers a gut microbial flora, enabling the assimilation of a greater proportion of the leaf. Fast species are therefore removed from the system quickest and as this occurs the less favourable species become colonised and are later consumed by aquatic invertebrates.

The presence of leaf packs in the stream may also affect the processing rate as they can affect oxygen concentrations and flow characteristics within the stream (Boling *et al.* 1975). The actual position of packs can also be important with those located in riffles having a higher processing rate over pools due to increased microbial colonisation and mechanical breakdown (Smith 1986). It should be noted that most will occur in the pools formed by organic debris dams.

The autumnal leaf litter that enters headwaters is a very important energy source which the communities of these areas are adapted to process efficiently. The processing products are themselves an important food source for downstream communities. The initial allochthonous input therefore serves as a nutrient source along the whole length of the river provided such material is retained in the upper reaches. Loss of such material would constitute a loss of energy from the system and would adversely affect downstream communities dependant on CPOM. The action of debris dams is very important as it allows leaf litter to be processed and not exported from the system still as CPOM.

Values of trees to particular wildlife groups

Mammals

The otter, water vole and water shrew are the only truly aquatic native British mammals. The mink and the coypu are introduced aquatic species. Foxes, badgers, stoats, weasels and rats also use the river banks and bats hunt over the water and use trees for roosts. Water voles can be found in woodland on river banks and water shrews feed on willow leaves.

Since the late 1950's, the numbers of otters found along British rivers has been declining because of the effects of persistent pesticides and the removal of bankside vegetation. They are a protected species under the Wildlife and Countryside Act 1981 (Lewis and Williams 1984). Otters are nocturnal animals and therefore need dense thickets of scrub for concealment during daylight hours. Secure refuges or holts are also required for daytime resting and breeding. These are usually the cavities that have eroded between the root systems of mature, bankside trees. Favoured trees include the ash, oak and sycamore. Otters range over many miles of river so that it is important that mature trees should be conserved over a large stretch of river bank and that replanting is encouraged to make holts available for future generations.

There are fifteen species of bat resident in Great Britain, all of which are subject to legal protection. Natterer's (*Myotis nattereri*) and Daubenton's (*Myosotis daubentoni*) bats are most commonly associated with rivers. Natterer's bats need mature trees with cracks and hollow trunks in which to roost in the summer (Lewis and Williams 1984). Daubenton's bats prefer hollow branches, especially those overhanging water. Noctules roost in holes and cracks in wych elm, willows and beeches. Pipistrelle bats (*Pipistrellus pipistrellus*) most frequently colonise human habitations. They are however sometimes known to roost behind the bark of decaying trees and under ivy (Anon 1983). Old willow pollards are especially good bat roosts as disease and old age form holes and cracks in and just below the crown. Bats may also utilize abandoned woodpecker holes. Natterer's and Daubenton's bats forage for insects over water and riparian vegetation. Insect availability is obviously dependent on the variety and abundance of trees and plants.

Cross (1985) found that riparian habitats in south west Oregon (USA) contained all the small mammal species found in the surrounding habitats but that the converse was not true. The species richness, abundance and diversity was highest in the riparian zone than the other habitats studied. The reason being that these are very diverse habitats and hence provide a variety of food niches for small mammals. Small mammals in turn providing a source of food for larger predators. The size of the riparian woodland both in terms of length and width was suggested to affect the number of species present. The degree of connectivity with similar habitats also being important. Riparian zones may be used as migration corridors between larger habitat islands.

Simons (1985) found that there was only a weak association between the habitat type on the bank and the frequency of the small mammal fauna found. This was discovered by studying areas that had and had not been logged in the US. The difference in small mammal fauna was not significant even though there were large differences in the overstorey. The understorey, which did not differ between plots, must therefore have had the greater influence on distribution . The presence of the red backed vole (*Clethrionomys occidentalis*) in logged areas aids the regeneration of conifers by eating and spreading mycorrhizal fungi spores to sapling roots. These fungi have a symbiotic relationship with the conifer and aid nitrogen fixation.

Birds

Birds use the trees in the riparian zone as a source of food, shelter and nest sites. Some that use the riparian zone will also forage on neighbouring agricultural land (Anderson and Ohmart 1984b). These areas are especially important for woodland birds where there is little woodland nearby and for wetland birds as a link between other wetland habitats. Food is usually abundant during the summer months so that birds select their habitat primarily on suitability for nesting and in winter on food availability.

Willows provide a rich source of food for insectivorous birds and are the favoured nest sites of owls, woodpeckers, tits and ducks including mallards. Moorhens and coots construct their nests amongst trailing branches that rest on the water's surface (Anon 1983). Dippers nest amongst the overhanging roots of large trees. Kingfishers nest in vertical banks and prefer sites with overhanging tree roots or branches close by to use as fishing perches (Burnett *et al.* 1978). Dead trees attract species that nest in the hollow limbs and cavities. Where an area is revegetated and there are no dead trees present, nest boxes can be used to encourage the species that prefer such nesting sites.

Decamps (1987) found that riparian woodlands were more richly and densely populated than the other types of woodland he had studied. He also found that the surface area was less influential on the structure of the bird community than in other areas. The conservation of a continuous corridor of riparian woodland was shown to be an important condition for maintaining a rich community of nesting birds. In addition, Knopf (1985) found that riparian bird communities were more stable and had a lower species turnover than in other woodlands. Furthermore, an open type of woodland was found to contain a greater variety of bird fauna than one with a closed canopy. Helliwell (1976) showed that the degree of isolation of a woodland area is not a major factor in determining the conservation value of its bird fauna, as they are highly mobile.

Amphibians and reptiles

Reptiles and amphibians may be found in the damp bankside habitats associated with rivers. They require a combination of dense vegetation for shelter, foraging and hibernation and open areas for basking. Where the tree canopy is too dense, there will be too little light penetration and therefore few basking sites. If there are too few trees however and no scrub layer, there will not be sufficient cover (Lewis and Williams 1984). The presence or absence of these cold-blooded animals is therefore dependent on a precise habitat structure.

Fish

The value of trees to fish is not limited to their underwater components; overhanging trees provide shade, which to the fish is cover against both aquatic and aerial predators. In summer an important source of food at the water surface is provided by the fall of terrestrial invertebrates from tree canopies (Mason & Macdonald 1983) and the roots of trees provide both sheltering zones and spawning sites (Balon 1975). Smith (1989) in studies of the Wensum and several other East Anglian rivers, showed that Chub had a strong distribution associated with overhanging trees and with areas of higher velocity. He suggested that tree cover (in sluggish areas) provided shelter from predators whilst high velocity areas provided drifting food; chub move between the two. A similar pattern of habitat use has been shown for salmonids.

Invertebrates

Each species of tree supports a different number of invertebrate. The willow and the oak are particularly significant in terms of the numbers of insect fauna suppported. Willows provide a food source for flies, beetles, butterflies, moths and their caterpillars including the puss moth, herald moth and the eyed hawk moth (Anon, 1983). A rich invertebrate fauna in turn attracts insectivorous birds such as flycatchers and warblers and provide shelter and hunting grounds for dragonflies such as the rare club-tailed darter (*Gamphus vulgatissimus*). During warmer months, the underside of leaves provides shade for dragonflies of the genus *Aeshna* spp. Dead wood is utilized by woodlice, flies and beetles and earthworms, springtails and other decomposers feed on decaying leaves in the soil.

The submerged roots of trees provide shelter for aquatic invertebrates, many aquatic insects spending part of their life cycle in the riparian zone. Megaloptera and aquatic Neuoptera burrow into banks or decaying shoreline trees in order to pupate. Beetles can be found pupating under logs. In the U.S., the caddis fly *Desmona bethula* emerges from the water to mate on the lodgepole pine (*Pinus contorta*).

Where eggs are laid out of water the larvae on emergence must have easy access to water. Megaloptera and aquatic Neuroptera lay their eggs on overhanging leaves and branches. After hatching, the larvae crawl along until they fall into the water. *Lenarchus rillus*, a Trichopteran found in Sierra Nevada, lay their eggs under damp logs near to the water's edge. As the bank dries up they remain here in a gelatinous mass until the water level rises again.

Trees in the Mosaic of riparian wildlife habitats

As part of R&D project 291, Riparian & Instream Habitats for Aquatic Communities (Parkyn, Harper and Smith, 1993), we reviewed the range of functional habitats to be found in the riparian and floodplain zone. Many, but not all, of these, are based upon trees. The list of habitats is reproduced below; the scientific basis for it, more extensive than contained above, may be found in that report.

Table 1.1 List of riparian habitats

Habitat	Notes
Mature trees (each species)	Value for invertebrate diversity and biomass, epiphytes, nesting sites
Mature shrubs (each species)	Nectar and fruit feeding stations for insects and birds
Tree features - holes, pollards	Additional nesting site value
Patches of continuous low scrub	Value for passerine bird feeding and nesting
Leaf litter and dead wood	Important for decomposer invertebrate community
Field layer vegetation zones	Invertebrate architectural diversity - ground, turf, short and tall grass/herbs
Field layer - flowering plant spp.	Additional nectar value for lepidoptera and hymenoptera
Emergent plants	Invertebrate community, nesting birds
Marginal (rosette) plants	Terrestrial invertebrates and oviposition for aquatic
Bare ground zones	Beetles & spiders. Classify by substrate, water, vegetation, shading, debris
River banks (soft)	Bees. Classify by soil type and elevation
Rock cliffs and riverbanks	Epiphytic bryophyte and fern community with associated fauna

The importance of these tables is that they show a range of functional habitats which may be created or encouraged in the riparian zone by appropriate management, which give additioanl options for ecological management where the establishment or maintenance of trees may not be compatible with the primary function of land drainage.

Table 1.2 List of floodplain habitats

Habitat	Notes
Woodland	Over 2 ha for 'woodland' characteristics and community
Trees	As riparian
Shrubs	As riparian
Tree features - holes, pollards	As riparian
Patches of continuous low scrub	As riparian
Leaf litter and dead wood	As riparian
Hedgerows	Cross-section and function affects wildlife value
Field layer vegetation zones	As riparian
Field layer features - tussocks	Additional value for birds
Field layer features - grazing	Intensity of grazing affects value for birds
Field layer - flowering plant spp.	As riparian
Bare ground zones	As riparian
Lentic water	Thirteen point classification - see text

Many riparian zones have additional importance as foci for human recreation,both formal and informal, which may affect their value and management for wildlife conservation. Angling is the largest example of a formal recreational activity, but increasing numbers of people also value the riverine environment as a place to walk and enjoy nature close to thier homes. Tress play an important role in people's enjoyment of nature and in their perception of what is natural.

Trees and humans

Conceptual values of trees

There is little written policy guiding how riverine trees should be managed by the NRA, outside the flood defence operational requirements, which would help to maintain their ecological, landscape and public recreational importance, although national R&D is developing guidelines for landscape policy. This section briefly reviews the value of trees to the public, their philosophy of space, and their perception of trees in the context of informal recreation within the countryside and in riparian areas in particular.

Trees at the landscape scale

The linked disciplines of landscape planning, landscape architecture and most recently, landscape ecology, have developed detailed concepts relating trees, landscapes and people. Colvin (1965) found that people perceive trees in an aesthetic light; under the artificial surroundings of modern life they help to keep us in touch with our own origins in nature. She suggested that the further we drift from our natural conditions, the greater our need for natural contacts in some form. Suitable planting in a waterside environment, besides benefitting us practically also provides us with the classic, characteristic valley landscapes, that are synonymous with the English countryside.

Eldin (1966) came to much the same conclusion in his analysis of man's relationship with trees. He stated that however much we are interested in the scientific aspects of tree growing and tree use, it is primarily as objects of beauty that trees make their most telling impact on us. He also believed that without these trees there is something missing from national life and well being, and that the landscape beauty of Britain depends not so much on any single feature but on it's blending of field, tree and waterway. Eldin emphasised the importance of trees to our cultural heritage of art and literature.

Barber and Lucas-Phillips (1975) held a similar view of trees within the British landscape, highlighting their roles in history, in literature, and the prosaism of our everyday lives. They also stated that trees are important to the mental, physical, and emotional health of our population, and consider the genetic bond we all have with the natural world and our innate yearning for the green and the growing. The authors emphasised the simple pleasure of the contemplation of trees themselves, as an aesthetic wealth of different shapes, sizes and species.

Wilkinson (1981) studied the history of the contribution of trees to the British landscape and believed that part of our perception of trees must have come from our cultural history. We have always used trees such as the oak, ash, hazel, aspen, bramble and sallow in herbalism, all having medicinal qualities that were perceived as a quality inherent in the tree. Wilkinson believes that we as a population have inherited this regard for trees within our psyche, and that this in an extreme form is shown in our rememberance of how important they once were to us in the spiritual context of the 'Green Man'.

Graham *et al.* (1983) described the perception of trees in a different way. They showed how we perceive the shape of trees in our mind's eye, through reflection on water surfaces, and the altering colour, texture and tone of the foliage within the seasons of the year. They noted how the shape and patterns of trees can contribute to perspective in a piece of landscape, and how trees can be used in marking the route of a road or a river. They conclude that it is important to remember how the observer will perceive the tree within a given identified terrain, for instance in a river environment, where a willow may arouse sadness, and an oak may symbolise vigour.

Although this latter book, and the previous references are writen from the perspective of landscape planners, they are a useful insight into how much in Britain we perceive wooded environments, and show what symbolic value we give trees within our culture.

Man's environmental perception

Saarinen (1974) provided the best work linking the way men perceive and value the environment and how this becomes the basis for their decision making. Man's behaviour and tastes are a function of his image of the real world, and results from a complex information processing system and a number of cognitive processes. Saarinen used a model to illustrate these processes, linking "information" with our "perceptual receptors" resulting in a "value system" of a given environment based on our "image of the real world": these values are then expressed as "behavioural feeling" which in turn results in change. The different values that people place on an environment are a result of sets of filters; physiological, linguistic, personal, cultural, class, need. There are two aspects of this value, actuality and subjectivity, the latter being those values reflected in the feelings of mankind. This cognitive structuring of the physical environment could therefore be as applicable to river corridors as any other environment, even though the above values are difficult to quantify. Schnenfeld (1972) carried out similar but more complex psychological work on this subject involving 'Environmental Personality', using personality variables such as awareness, operation, action, reaction and motivation to try and quantify our environmental values through developmental psychology and the philosophy of space.

Burns (1984) argued that evaluating riparian systems was difficult, because they are provided from nature without costs, so it is therefore difficult to calculate their economic worth compared to agricultural land, so the nearest analogy is that of the value of the land for development. He found that the functions of value to the public are; fish and wildlife production, bank erosion protection, flood control, water quality maintenance, recreation, timber production, fuel production, sound absorption, air quality maintenance and scenic barriers.

Burns believes that if real estate value is not relevant then environmentalists' values can be used as subjective data for decision makers. There is therefore an important role for 'valuation' in riparian systems, because the question remains of how much of the systems should be preserved, under the vast political pressure exerted by developers in the US. This causes increased pressure to plant in riparian floodplains due to subsidies for water supply and flood and erosion control to agriculture, which is detrimental to the native riparian vegetation and public resources it supports. In the U.S a public land manager is unable to control private use of a public resource like riparian areas, and in this regard, political influence is paramount, and is always a threat despite governmental decisions. He concludes that the decision making process of aquisition, law, subsidy, and government action will all have a strong effect on the survival of US riparian systems.

Buckhouse (1984) came to similar conclusions. He believed that the social, political, and economic elements are sometimes missing from riparian management, and that there is something of value for everyone in each system. As regards management, Buckhouse stated that the only common denominators are Water and People, and that riparian systems require comprehensive planning based upon ecological principles and mankind's needs.

Meyer (1984) asked the question of whether man should be treated as an integral part of the riparian equation, or whether he should be treated as an intruder. He believes that man is a riparian creature, and that systematic treatment of riparian zones should include people within that zone, and that all plants, animals and human activity should be considered in their management and preservation. He sees the riparian system as dynamic, and the question is not whether the system exists, but where and for whom, so there is an economic, social and political choice whether to safeguard the area, or to consumptively exploit it. Meyer concluded that riparian systems should be valued for their own sake, through public sentiment for preservation, community interest, co-operative planning and joint use.

Hoover *et al.* (1984) tried to quantify the value and the satisfaction people derive from visiting a riparian environment. They see these areas as attracting and accommodating important recreational activities, and as combinations of land, water, vegetation, and wildlife that are aesthetically valuable. They also foresaw the importance of the areas due to increasing scarcity, and believe that they should be carefully managed to incur maximum social benefits, there is therefore a need for information on the values of riparian sytems to society, and the public's satisfaction from recreation, their perceptions of desirability and the commonness of environmental attributes. They used Mount Baldy Wilderness Area as a test, interviewing 301 visitors, asking for the visitors overall satisfaction, and their ratings of satisfaction on a scale of 1-7 for features such as scenery, streams, forests , meadows, wildlife, flowers, other visitors, fishing, trail signs and cattle. The test also required the visitors views on amenities, facilities and pollution. In all there were 34 factors. The results concluded that visitors were on the whole satisfied with their visit, the scenery, streams, forests and meadows, but were dissatisfied with meeting other people, the fishing, trail signs and cattle. A number of environmental attributes were also tested on the visitors, with the five best being virgin forests, views, open meadows, dense forests and stream side trails, and the five worst being water pollution, carvings on trees, litter on camps, trails and in the streams. The study concludes that environmental dissatisfaction was related to previous education and experience of nature, and that any steps to maintain the ecological health of the system would contribute to the value it would hold for a visitor.

Public perception of riparian values in the U.K.

House and Gardiner (1990) studied the use of river corridors related to recreational and amenity values. They found that the recreation and amenity use of these areas had increased dramatically with 3.5 million people angling, one million canoeing and millions more walking and picknicking. It is therefore important that catchment management policies throughout the U.K. reflect the opinions of the users of the corridor itself. The possible applications of such a study would be to the commercial development of rivers for recreation and amenity or office and residential development, in the rehabilitation of river corridors, in the planning of future flood schemes and dredging for improved navigation. They conclude that there is a need for environmentally sensitive management of river corridors and water quality.

Fordham and Tunstall (1990) investigated the values of residents within river corridors in the south-east of England. They found that significant numbers of floodplain residents were not prepared to accept any development to reduce the risk of flooding because they perceived that the beneficial aspects of residence would be damaged. It is overlooked by engineers and planners that although the residents acknowledge the risk of flooding, the amenity benefits of the location may outweigh this. Like Gardiner (1988) they see public perception of rivers and flood plain defence as an integral part of the development of flood alleviation schemes. Their study (1989) used 494 residents and asked them about flood hazard perception, their perception of local and environmental issues, their preferences for river management and consultation procedures and their attitude towards the NRA. The results of the study showed that most of the residents would live in an area if the flood risk was one in five and that they would support some flood alleviation schemes but were prepared to make a trade off in the direction of tolerance of flood risk. Twenty five percent would rather put up with flooding than spoil open space with flood relief channels and almost twice as many respondents with previous experience of flooding would be prepared to live in the 1 in 5 flood risk area. It was found that if no risk was perceived then the focus of the public's decision rested on the risk presented by the proposed scheme such as the threat to amenity, ecology and the change in a valued environment. They also found that there is a certain degree of irrationality in the public's trade off resulting in the choice of personal risk over environmental damage. Ultimately both engineers and residents consider that they are both dealing in irrelevancies. Fordham and Tunstall conclude that there should therefore be a multidimensional approach to decision making with public involvement, and that the risk trade off should be used as a tool rather than an obstacle, with the engineers giving the public what they want rather than what they perceive they need.

House and Sangster (1990) showed that recreational activities are increasing as rapidly as commercial and residential development in river corridors. Therefore, they believe that it is important that catchment management policies throughout the U.K. should reflect the opinions of users and residents. This is desirable on several counts. Firstly, the water industry is accountable because of invested public money in the works. Secondly, it is the public who work beside, use, or benefit from the end product of proposed river works. Thirdly, direct public involvement should provide a forum to reduce conflict and obstructions to proposals. Finally, public co-operation is essential for proposed plans.

House and Sangster (1990) proposed that public preference for certain environmental features may differ from those of the decision-makers (councillors). They therefore recommend that there should be some sort of appraisal system to investigate the particular river corridor features favoured by the public. Furthermore, the public should have a say in the final chosen river works. House and Sangster conducted 2000 interviews from 1986 onwards concerning the public perception of water and river corridor features and their preference for a range of these features. Recreation, flood defence and river rehabilitation schemes were covered, and the respondents were categorised as "contact" (canoeists) "non-contact" (anglers and rowers) and "remote contact" (walkers and picnickers). Eight sites were used in towns and the urban fringe which had natural channel banks and were largely unaltered by past management. The result was an agreement between perceived and actual water quality (indicators were used such as 'many fish', 'can see river bottom', 'foam/oil/dead fish in the river') with the bad indicators having greatest effect on perceived water quality. A similar study was carried out to analyse public perception of river corridor quality. Respondents were asked whether a feature made the corridor an unattractive or attractive place to visit, based upon a scale from 1 to 10. The results of this were reinforced with photographs. The study concluded that the ideal riverine setting is one with an open deciduous forest of mixed plants and grasses where trees overhang the banks of a naturally meandering mature river, without an overabundance of vegetation within the channel. Most significantly, there was a substantial preference in favour of the presence of trees. They concluded that the public has a very definite idea of what they perceive to be their ideal river setting in terms of river and floral characteristics. There is also a close relationship between perceived water and river corridor quality.

Green and Tunstall (1990) carried out a number of surveys around the country considering the amenity and environmental value of river corridors, and the recreational and intrinsic benefits they provide. They also considered the economic value of river corridors and the associated problems with evaluation, and dealt with the question of what visitors want from the area. In addition to this they looked at perceived water quality and the important indicators of it. They found that water is both a final 'good' and an intermediary 'good', and that the public want an unpolluted river because it is a bad thing and ought not to occur, and because they want to live by a river which supports a rich habitat. The public want quiet river corridors, that are rich in wildlife, plants and landscape, but with facilities like toilets and paths. Anything that will attract a large number of visitors is not desired, and concerns about the safety of children and public health come before any environmental concerns. The public also have a clear idea of what they mean by a polluted river, but judge a good river by attractiveness rather by its pollution content, and they are prepared to pay increased water rates to achieve water quality improvements (not for enjoyment but for moral reasons). Other findings are that river corridors can substantially increase the attractiveness of an area as a place to live, even though they attract more frequent visits with a wider catchment than other open spaces.

Economic Evaluation of riparian values

People's willingness to pay to preserve an environmental asset provides one way of valuing such assets, previously considered intangible. Pearce (1990), a major proponent of this, considers that in order to promote sustainable development within an economy the natural environment must be valued in monetary terms. The economy and the environment are interdependent on each other and as such the latter should be given economic value within the market place to avoid excessive demand and possible exploitation. The theory of supply and demand predicts that where a good or service is valued at zero price, more of it would be demanded than if there was a positive price. Pearce acknowledges that the idea of putting a price on the preservation of a species or landscape, for example, rests uneasily with some people: he considers however that this monetary strategy is supportive of environmental values and policy in the long term.

Pearce sets out a number of techniques for valuing the environment mainly for use in the context of Cost Benefit Analysis (CBA), a technique employed by decision makers for weighing up the advantages and disadvantages of proposed public investment projects. It entails the identification of all impacts of a project on social welfare, including impact upon the environment, pitched against the ensuing benefits. In an attempt to compare like with like, the different components of the analysis are expressed in monetary terms wherever possible. CBA is an example of an instance where the estimated monetary value of a natural resource should it be entirely destroyed or else the cost to the community of partial loss or pollution can be included in the CBA equation.

One method of evaluating resources is called the Contingent Valuation Method (CVM), which relies on respondents to questionnaires stating what they would be willing to pay to prevent the destruction of an environmental asset in a hypothetical situation. They are briefed thoroughly on the specific threat and on the actions needed to prevent destruction since the quality of the answer is reliant on the extent of the respondents' knowledge. The value of a site or habitat can also be estimated by calculating the cost of providing an alternative of equal worth. The application of this technique may be limited given that there maybe no perceived connection between the cost of providing an alternative site and the intrinsic value of the present site. Furthermore, the alternative chosen may be somewhat spurious (Bowers, 1990). A further valuing technique is the travel-cost approach. In brief, an individual's willingness to pay the costs of travelling and entrance to a recreational site in addition to total time spent visiting and potential earnings forgone.

The theory of costing environmental resources within the marketplace is not without its critics. Bowers (1990) in 'The Conservationists' response to the Pearce Report' dismisses this idea referring to the 'intractable issues of uncertainty over the value of natural eco-systems'. He further states that protection for the natural environment should be sought through more stringent rules and legislation. As regards CBA, Bowers considers that its failure lies in the fact that the proposers of projects have 'monopoly of information ' and can potentially manipulate CBA toward their own objectives.

THE DISTRIBUTION AND ABUNDANCE OF TREES IN THE FLOODPLAIN OF THE RIVER GREAT OUSE

Introduction

Areas of lowland woods have undergone progressive tree clearance since historical times. Initial deforestation occurred as a result of medieval settlement and the need for livestock pasture which continued steadily up until the 1950's. Since the Second World War, more rapid encroachment upon remaining lowland woods has taken place as a result of agricultural intensification. This has largely been due to UK government and latterly EC agricultural policy which has made tree clearance in favour of agricultural expansion economically attractive. Riverine tree communities have not been exempt from human impingement. Use of lowland rivers for agricultural flood control purposes has meant that extensive engineering work has been undertaken in the UK. As a consequence of this, few if any lowland river stretches can be regarded as 'natural' and undisturbed. At best, they could be referred to as being 'semi-natural' (Peterken 1981). This description however does not detract from their conservation value. In fact, it may be argued that due to their scarcity riparian tree communities represent a valuable asset in an environment that is already ecologically degraded.

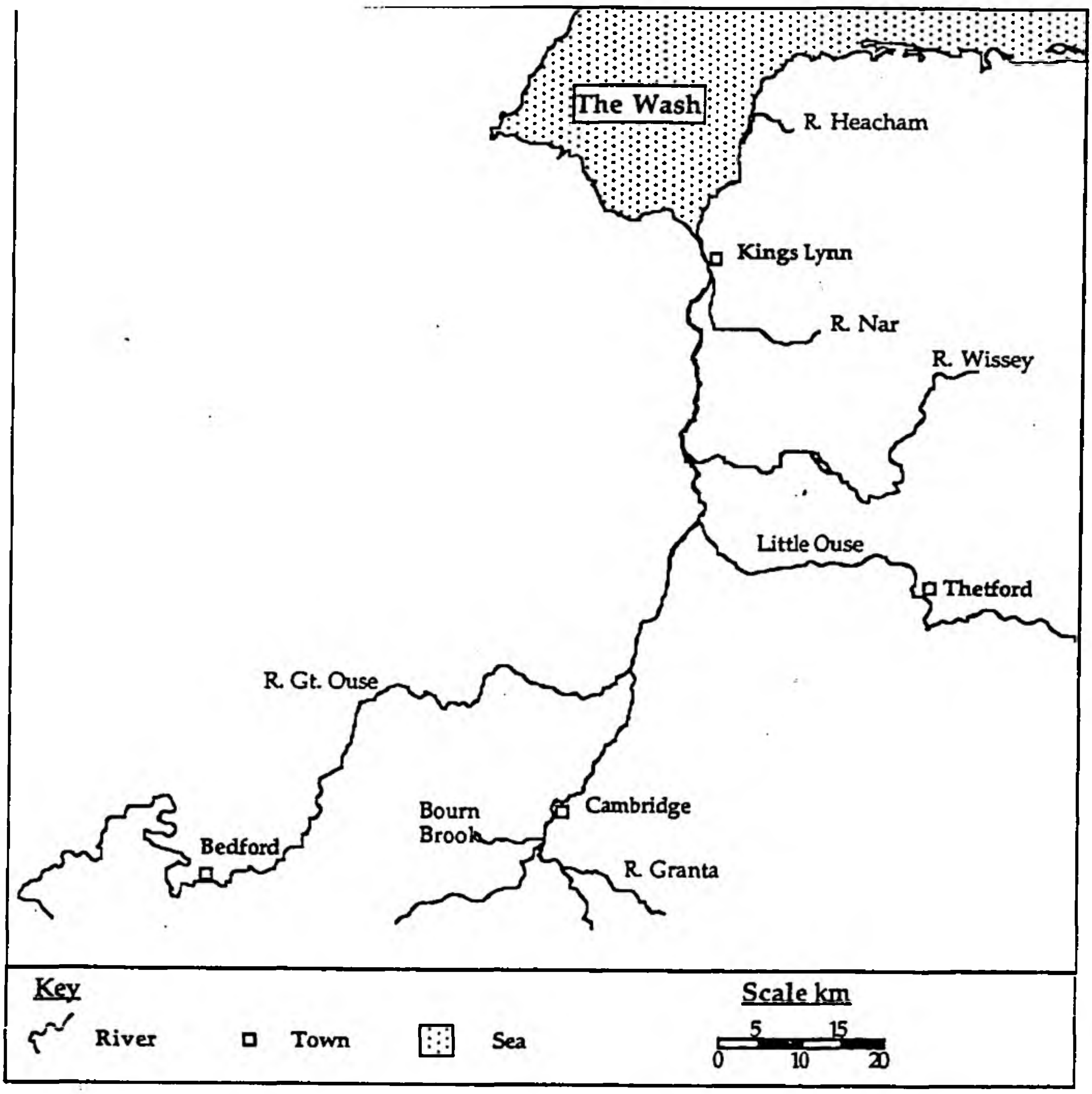
Survey work is necessary to identify those areas of scientific interest as points for conservation in the face of a drainage scheme or other major alteration. As Holmes (1986) pointed out, "without surveys features of scientific interest will only be discovered when they have been effectively destroyed". The study of river corridors as distinct biological units has only recently become widespread. This is due in part to practical problems associated with studying major linear habitat complexes which span a wide range of vegetation types, altitude and geological formation in this country (Slater, Curry and Chadwell 1987).

Accurate descriptions of vegetation are therefore necessary as a basis for making deductions about the environment. Most studies to assess complex land-use problems are dependent upon a vegetation inventory (Burks 1939). Field surveying is the most frequently employed method for gathering such data; however this is naturally time-consuming and costly. A useful initial step is the use of aerial survey. Although not a complete substitute, aerial survey is a rapid, albeit less detailed, means of collecting information. In particular, examination of aerial photographs can eliminate substantial ground survey associated with the determination of land classification and cover densities.

Methods

A study was undertaken to survey the tree cover and land use along several river floodplains of the Great Ouse drainage basin in the counties of Norfolk, Cambridgeshire and Bedfordshire. This study area covers an area of approximately 6,400 km^2, in floodplains of the rivers Heacham, Nar, Wissey, Little Ouse, Great Ouse, Granta and Bourn Brook (Figure 1).

Figure 1. Location map of the rivers studied in the Great Ouse catchment



The study involved the use of stereo aerial photography which allows the observer to view objects in three dimensions. Stereoscopic examination is essential for accurate land-use classification (Krieg 1970) because stereo viewing enables easier interpretation as textures are enhanced and the effects of relief are more striking (Fuller 1988).

Aerial photographs at 1:10,000 scale were used from the collections of County Planning Departments; these being the common vertical aerial photographs held by the councils within whose areas rivers were studied. All of the photographs were colour, except for those of Bedfordshire which were monochrome as their 1991 colour aerial survey was not completed in time for the purposes of this project (Table 1). Acetate overlays were made using either a pocket stereoscope or mirror stereoscope on stereo photographs with a standard 60% overlap. The scheme for marking landform features involved defining rivers in blue and river floodplains in brown (after Young 1991). Land-use classification and tree crown counting was carried out within this defined area. Five categories of land-use were identified; arable, pasture, wood, scrub and built-up. These were chosen due to their relative ease of identification and as a means of comparing the different/competing land uses within the floodplains. Recognition of land-use was achieved through examination of the tone, colour, texture, shape and pattern of areas of land on the aerial photographs.

Quantifying ground cover on aerial photographs entails the measurement of micro areas, in this instance, the pockets of land designated a land-use classification on each floodplain. The method used for this was a 'dot grid'. This consists of systematically arranged dots spaced at regular intervals on a circular acetate overlay. Ground cover was measured by overlaying the acetate and counting how many dots fell into a defined area of land. These dots were on a scale equivalent to 50m apart (when using 1:10,000 scale photographs). Thus every four dots represented 50m x 50m or a quarter of a hectare. The area of classified pockets of land were calculated by dividing the number of dots by 16 to obtain the area in hectares. Addition of similarly classified land units yielded the total area covered by a certain land-use classification for any particular river floodplain. Each floodplain value for a particular classification was converted to a percentage of the total floodplain area and then plotted as individual pie diagrams for each river and as a single stacked bar chart for ease of comparison between different sized basins.

In order to analyse the distribution of trees within the floodplains each tree was assigned to one of three location classes. These were 1) riverside, 2) field boundary and 3) 'other'. These categories were partly chosen on the basis of ease of distinction on the aerial photographs. For example, field boundary trees were relatively easy to distinguish as they tended to occur as linear groupings that were usually never more than two abreast and which were often, although not always, perpendicular to the river. The two classes of

RIVER	COUNTY COUNCIL	FLOWN BY	YEAR	COLOUR	RUN LINES	O.S. SHEET	GRID REF.
River Great Ouse	Bedfordshire	Hunting Surveys Boreham Wood Elstree Herts	1986	B & W	2166-2168, 2097-2099, 2006, 2007, 1949-1953, 4879-4881.	153	west end G.R. 027479 east end G.R. 099509
River Granta	Cambridgeshire	Cambs. Univ. Committee for Aerial Photography	1988	Colour	BE 120-124 & BE 58-62.	154	west end G.R. 464515 east end G.R. 545486
Bourn Brook	Cambridgeshire	Cambs. Univ. Committee for Aerial Photography	1988	Colour	BF 54-56, 58, 60, 62.	154	west end G.R. 357557 east end G.R. 435546
River Nar	Norfolk	B.K.S. Surveys Ltd Coleraine, N. Ireland.	1988	Colour	3311-3316 & 3396	132	west end G.R.782151 8 east end G.R. 832164
River Little Ouse	Norfolk	B.K.S. Surveys Ltd Coleraine, N. Ireland.	1988	Colour	2951-2953 & 3000-3004.	144	west end G.R. 799874 east end G.R. 836872
River Wissey	Norfolk	B.K.S. Surveys Ltd Coleraine, N. Ireland.	1988	Colour	2282-2287, 2073, 2074, 2077-2084	143	west end G.R. 589991 east end G.R. 701979
River Heacham	Norfolk	B.K.S. Surveys Ltd Coleraine, N. Ireland.	1988	Colour	4623-4627 & 4505-4508	132	west end G.R. 663307 east end G.R. 726356

Table 1. The sources of aerial photographs used.

riverside and field boundary were chosen because these were believed to be where the majority of trees existed. The third category (other) was a 'catch all' class which included all trees that could not be classified as being either field boundary or riverside trees. It included isolated trees within fields/urban areas as well as groups of trees in woods and plantations. Care was taken to avoid recording a tree more than once. For example, where a woodland area extended upto the riverside only trees whose crowns were judged to be right next to the river were allocated to the riverside class, while the remainder of the woodland trees were assigned to category 3, 'other'. Actual tree numbers were recorded by means of a click counter, to give the raw number of trees in each of the three classes. The total of these was the minimum total observable for each floodplain. Tree numbers were also re-calculated to yield percentage figures by dividing the number of trees in any single category by the total number of trees for that particular floodplain. These percentage values for trees in each floodplain were then plotted as pie diagrams to show tree distribution within floodplain. The figures were also re-calculated to yield the number of trees per hectare by dividing separate class numbers by their associated floodplain area. This removed study area size variation from the data. The number of trees per hectare and woodland percentage were then tested against certain land-use percentage categories and those that were significant were then plotted as scatter diagrams. Linear correlation coefficient lines were then plotted for each scattergram.

It was necessary to assess the accuracy of photo interpretation by undertaking fieldwork or 'groundtruthing'. Fieldwork conducted by the other two tree surveyors was used for comparison. A total of 146 sample sites were studied and each ground classification was compared to the corresponding site on the aerial photo classification. Both corresponding classifications and incorrect aerial interpretations were recorded and compiled into a simple table or 'confusion matrix'. The sum of the mis-classifications in each class (row of the matrix) was divided by the class total (row total). This yielded the omission error for that class which represents a measure of the accuracy for each land-use category/class.

The mean accuracy of the aerial survey method employed was 0.81. In percentage terms, 81% of land-use classifications made using standard aerial photo interpretation procedures and equipment were correct. It is also possible to deduce that similar land-uses or more specifically those that appear similar on aerial photographs were generally mistaken for each other and mis-classified. For example, the arable class was mistaken for pasture in approximately 24% of instances and wood was mis-classified as scrub in approximately 14% of cases. A possible cause of arable land-use being recorded as pasture may be due to the fact that after harvesting/mowing both of these classes appear remarkably similar on aerial photographs.

Due to the nature of the data, normal distribution of population could not be assumed so that only non-parametric tests could be applied. The data were therefore analysed using the Kruskal-Wallis (H) test and the Mann-Whitney U test. Initial analysis looked at inter-floodplain relationships. The Kruskal-Wallis test was used to determine whether percentage land-use and/or tree frequency (tree/ha) recorded on separate river floodplains was significantly different. This was to establish whether land-use and/or tree variation was due to inter-plain variation or not. The test was then repeated with row and column values (category and floodplain study area) transposed. This was to test whether variation between land-use class and tree location site were significant. The within floodplain distribution of trees was further analysed using the Mann-Whitney U test which shows whether a difference in the means of two samples is statistically different. For this analysis, the sum of riverside and field boundary classes were taken in order to compare them with category 3, 'other'. These two classes were combined as they were considered to represent a greater proportion of remaining floodplain trees.

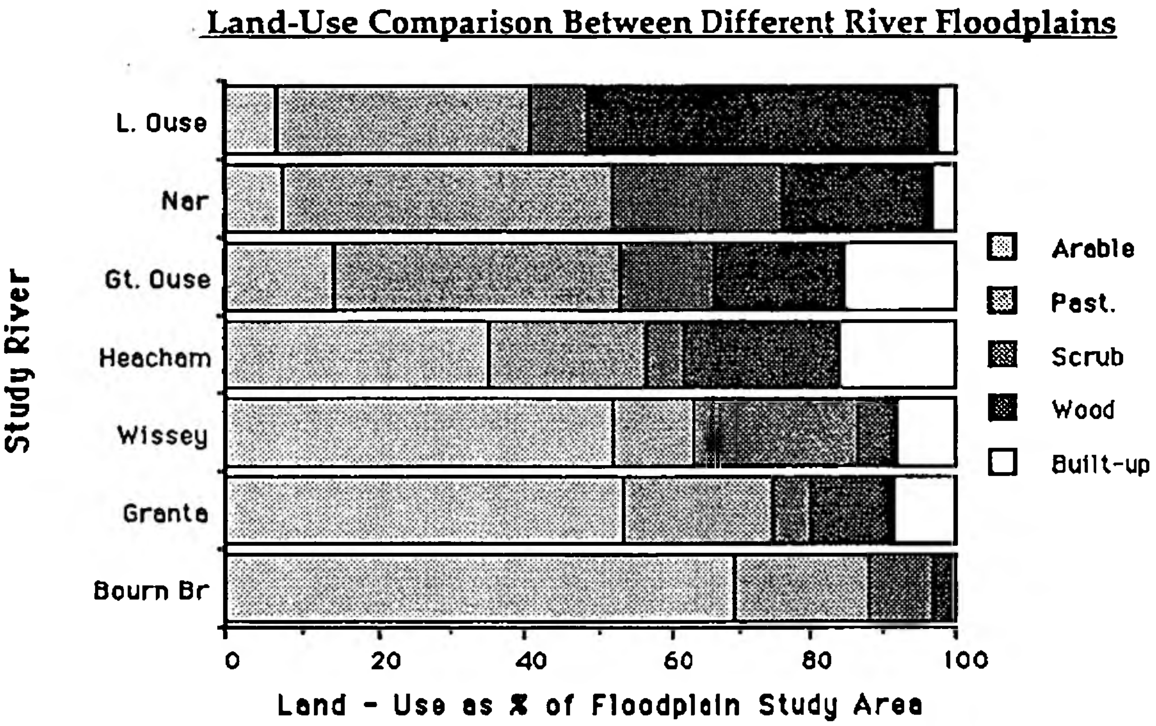
Results

The inter-floodplain comparison of land-uses showed that agricultural land-use dominates these particular study areas as, with the exception of the Little Ouse, over 50% of each is taken up by arable and pasture (Figure 2). The Little Ouse is an exception because a high proportion (48.86%) of wooded land-use within the study area encompasses Santon Downham, a community forest composed of mostly plantation woodland.

The Kruskal-Wallace analysis of inter-floodplain variation indicated that there was no significant variation in land-use between river floodplains. In effect these floodplains exhibit similar land-use trends. The same test was performed to analyse within-floodplain variation, i.e. variation between percentage land-use in each floodplain. There was found to be no significant variation between the percentage areas occupied by the different land-use classes of each floodplain.

In all the floodplains, over half of all recorded trees were at field boundary and riverside locations. Three out of seven river floodplains held over 70% of all their recorded trees within field boundaries or along the riverside. To establish whether variation in tree distribution within the floodplain or between the floodplains was significant comparisons were made of numbers of trees per hectare using Kruskall-Wallace (H) test. On this occasion, the null hypothesis (H_0), that insufficient variation between floodplain tree/ha distribution existed, was rejected. Thus sufficient difference existed between individual floodplains for it to be significant. Tree density therefore varied noticeably among the floodplains.

Figure 2. Land use and tree distribution in the seven floodplains



The H test was also used to establish whether within-floodplain tree distribution varied according to their floodplain site location. The null hypothesis (H_0), that density on the floodplains was unconnected to the site location category (field boundary, riverside or other), could not be rejected.

These tree distribution analyses using the Kruskal-Wallace test were repeated with the exclusion of Little Ouse data. This particular study area included an area of forestry plantation and was therefore not considered to be representative of agricultural lowland England. These data were removed to see whether the outcome of the tests would be altered. Repeat testing however confirmed that between floodplain tree variation was significant whilst tree/ha variation within floodplains was not.

The Mann-Whitney (U) test was used to establish whether the combined riverside and field boundary sites represented the larger proportion of surviving floodplain trees. The null hypothesis was rejected in favour of the alternative hypothesis, the latter stating that the 'other' category contained significantly fewer trees/ha than the combined riverside and field boundary class. Tree distribution was therefore related to location within a floodplain. Little Ouse data were also omitted from this analysis.

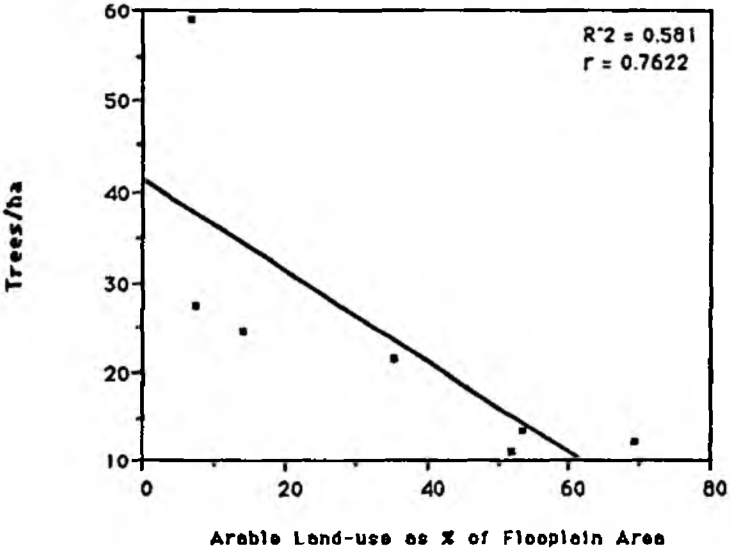
Scatter diagrams of tree density and percentage woodland against certain land-use percentage categories were plotted where a significant statistical relationship was proven. This was the case for arable land-use. These statistically significant graphs show a negative correlation between data sets. As the percentage of floodplain study area occupied by arable cultivation increased the number of trees/ha decreased. Likewise, as the percentage area of arable cultivation increased the percentage of floodplain occupied by woodland diminished. These findings indicate that where arable cultivation is widespread tree cover is likely to be low (Figure 3).

Discussion

The photo interpretation of the floodplains of the Great Ouse basin demonstrate that this region is predominantly rural landscape with only minor tracts that are built up. No single land-use was statistically dominant within any individual study area. Results of the land-use survey also indicated that no significant differences existed between floodplain study areas.

No single class of tree location site was found to be dominant when analysed individually. There was however a significant result when the combined field boundary and riversides

Floodplain Tree Density v Arable Land-use



Woodland v Arable Land-use

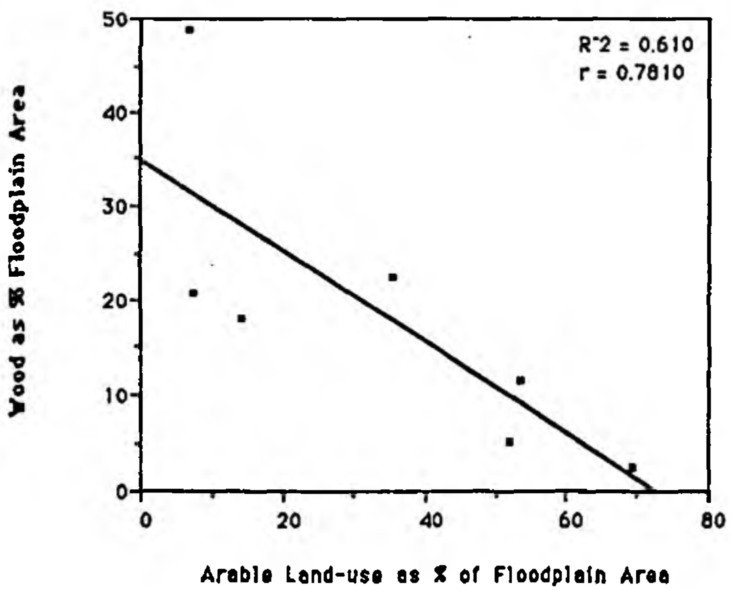
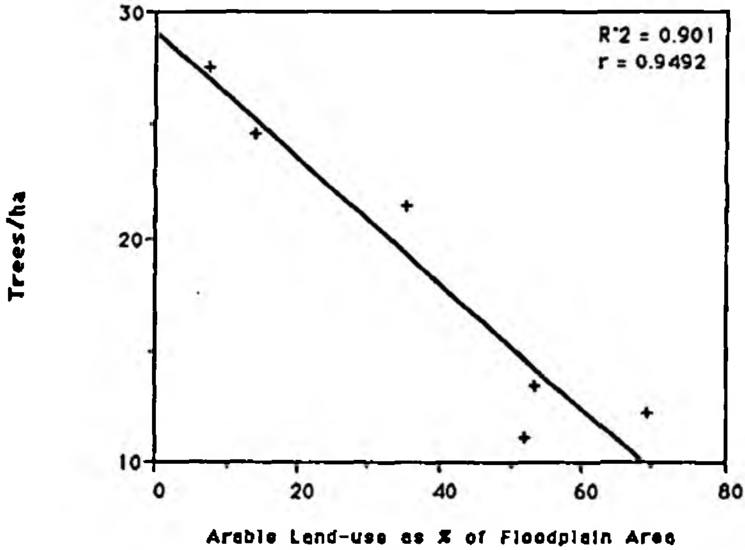
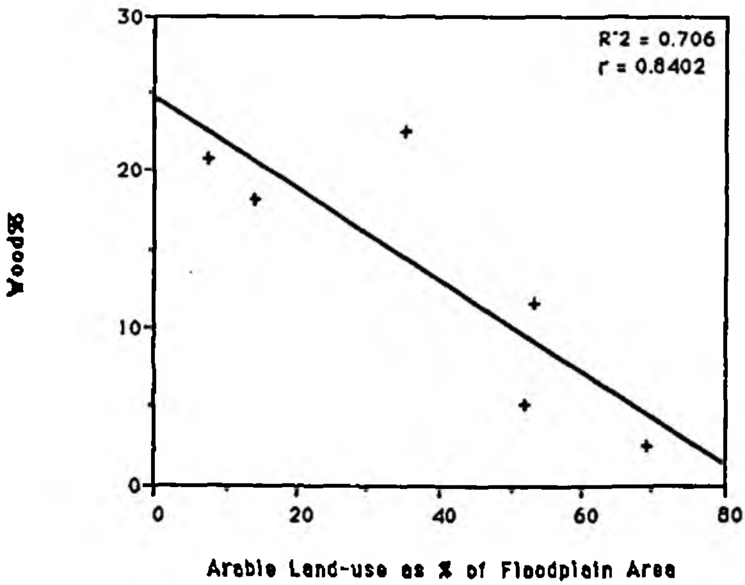


Figure 3. The relationship between tree density and floodplain arable land

Floodplain Tree Density v Arable Land-use (minus Little Ouse)



Woodland v Arable Land-use (minus Little Ouse)



class was compared to other floodplain tree locations. Within all floodplains, trees tend to be concentrated along field boundaries and riversides rather than as woodland or isolated trees.

The 1:10,000 aerial photography was considered to be of insufficient scale to be able to identify trees at genus level. Use of larger scale photographs (1:3,000) may have permitted this and also increased crown count accuracy (Spurr 1960, Stellingwerf 1967). Time series of aerial photographs could be used to identify which categories of land-use were responsible for decline in floodplain tree cover. In this way, photographs from successive years could perhaps enable observation to determine which land-use replaced which.

This study showed tree cover to be low in this region of the British Isles with a significant proportion of woodlands present being recent plantation. It is likely that those native trees remaining along the floodplains are small and disturbed fragments of once larger alluvial forests. Two types of relict alluvial forest exist in the British Isles, valley elm woods and valley alder woods. The former are almost entirely confined to eastern England, while the latter are more widespread but with their best examples in Norfolk (Anon. 1981). The Great Ouse basin has some of the most important remnants of alluvial forest woodland. This aerial survey showed that the remaining areas of semi-natural tree cover within the study floodplains was largely restricted to field boundaries and riverside sites. The NRA has the ability to influence the future of riparian trees, shown to be one of the most important features oif these floodplains.

THE ECOLOGY OF TREES IN THE RIPARIAN ZONE OF THE RIVER GREAT OUSE

Introduction

There is a reasonable amount of information available about the role and value of trees in riparian zones, but almost no information about the species, populations and individuals within this environment. In Britain the only two published works which could be found are those of Mason *et al.* (1984) and Mason & Macdonald (1990), who studied trees in the English-Welsh borders and the Essex area respectively.

Two field surveys of the riparian tree community of the Great Ouse were carried out. The more extensive of the two covered eighteen rural sites each of 500-1000 m stretches of river channel, chosen to cover the full range of channel sizes, geologies and managements within the catchment. The second was a more intensive study of the rural-urban fringe.

The objectives were primarily to find out what trees existed, their density, frequency and distribution. Secondary objectives were to ascertain whether there were any links between aspects of tree ecology and aspects of river or bankside management. Additional objectives were to find out whether there was any link, positive or negative, between riparian tree cover and the assemblages of flowering plants.

Methods

Sections were chosen at random after selection of tributaries or stretches of the main Great Ouse to cover the full range of river type (Figure 1, Tables 1 & 2). Maps were prepared and the river banks then surveyed using standard River Corridor Survey techniques. Tree species and location was recorded in both tabular and map form; height, girth, distance from river bank of individuals together with flowering plant species were further recorded in tables.

Results

Twenty nine species of tree and shrub were found in the rural catchment survey, of which four or five species are obviously non-native (eg. laburnum) and several others not typically riparian (eg. Scot's pine and horse chestnut). In the rural-urban fringe study a further eight species were recorded, again including aliens (eg. buddleia) and non-riparian (eg. lime).

Figure 1. Location maps of the study sites

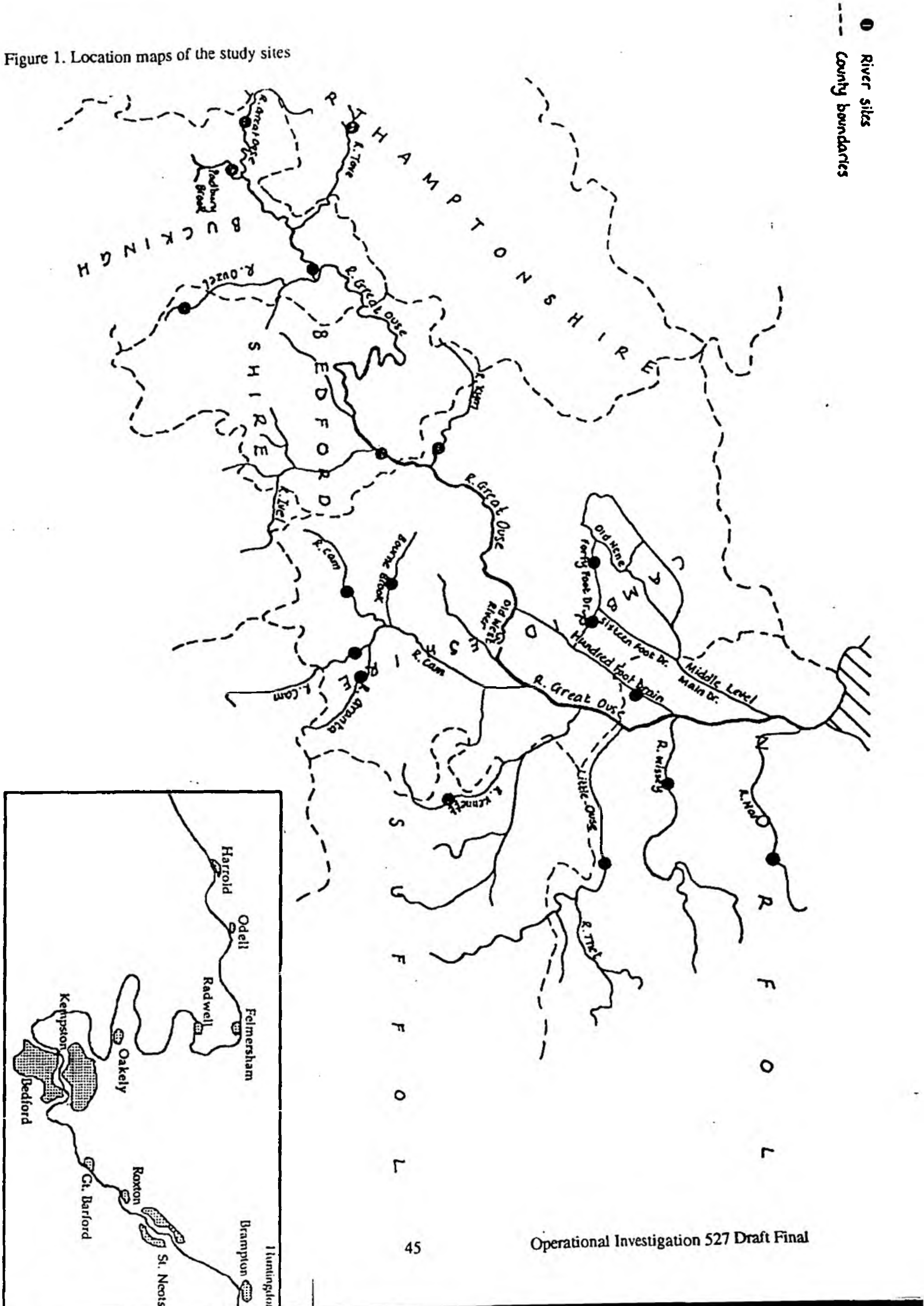


Table 1. Rural survey sites on the Great Ouse.

Name of River	Solid Geology (dominant)	O.S. Map no. 1:50 000	O.S. Map no.(s) 1:2 500	Date(s) Surveyed	Sub-sections
Hundred Foot Dr.	Clay	143	TL 54/95	Jun 5, 1991	S1:Eastbank no trees
Forty Foot Drain		142	TL 42/87	Oct 8, 1991	S2:Northbank elm/Ht S3:Northbank no trees
Bourne Brook	Greensand	154	TL 36/55	Sep 10, 1991	S4:RB arable/pasture S5:RB old meanders
Cam/Rhee	Greensand	154	TL 36/48	Aug 27, 1991	S6:RB
Granta	Chalk	154	TL 50/49; TL 50/50	Aug 20/Nov 27,1991	S7:RB woodland S8:LB fieldside S9:LB ht copse
Granta/Cam	Chalk	154	TL 48/47	Aug 28/Nov 27, 1991	S10:LB fruit trees/scrub S11:LB fieldside
Heacham	Greensand	132	TF 70/36	Aug 5/28 Nov./Dec 17, 1991	S19:LB S20:RB
i-ii: Great Ouse	Oolite Series	152	SP 64/34	Oct 10, 1991	S12:RB pasture S13:RB thornscrub S14:RB d/str
ii-iii: Great Ouse		152	SP 86/45	Oct 9, 1991	S15:LB willow plantation S16:LB pasture
iii-iv: Great Ouse		153	TL 14/53	Oct 8, 1991	S17:LB fieldside S18:LB thorns/elder (footpath)
Kennett	Chalk	154	TL 70/63	Aug 19, 1991	S21:LB S22:RB
Kym	Clay	153	TL 14/63	Sep 9, 1991	S23:LB no trees S24:LB bushes S25:LB juv.elms
Little Ouse	Chalk	144	TL 82/87	Jul 31/Aug 1/Nov 26, 1991	S26:LB S27:RB
Nar	Mixed	132	TF 80/14; TF 80/15	Jun 8/Jul 25, 1991	S28:LB upstream sec. & meanders S29:LB open
Ouzel	Clay	165	SP 90/23	Oct 9, 1991	S30:RB
Padbury Brook	Mixed	165	SP 72/32	Oct 10, 1991	S31:RB
Tove	Clay	152	SP 66/48; SP 66/49	Oct 11, 1991	S32:RB
Wissey	Greensand	143	TL 68/97	Jun 7/Jun 12, 1991	S33:RB planted willows S34:RB open bank

Table 2. Urban fringe study sites on the Great Ouse.

Site No.	Site name	OS grid ref	Map sheet
1	Priory Country Park	0672 4919	TL0649
2	Bedford central channel	0641 4925	TL0649
3	Bedford flood relief channel	0638 4942	TL0649
4	Near Queen's Park (Beds)	0387 4890	TL0248
5	Kempston area (Beds)	0270 4824	TL0248
6	Felmersham	8904 5791	SP9857-9957 & SP9858-9958
7	Odell	5961 5773	SP9657-9757
8	Oakely bridge	528 009*	
9	Radwell	0049 5726	TL0057-0157
10	North of Oakely	0104 5441	TL0155
11	South of Great Barford	1243 5103	TL1251-1351
12	Kingfisher cottage	1409 5261	TL1452-1552
13	Great Barford	1361 1578	TL1252-1352
14	Roxton lock	1599 5347	TL1453-1553
15	Brampton	706 225*	
16	St. Neots (Eynesbury)	595 178*	
17	Harrold	8553 5650	SP9456-9556

* denotes grid reference taken from 1:50,000 Landranger map.

The density of mature trees varied from none to 120 km^{-1}, a range so great that an average would be meaningless (Table 3). Lowest tree cover, as would be expected, occurred in the fenland reaches whilst highest cover occurred in headwater streams. There was also considerable range in landcape aspect, from Great Ouse reaches where mature trees occurred with little shrub cover to the Kym which was almost entirely scrub-dominated.

The most abundant species larger than 5 m in height were crack willow, hawthorn, ash and elder. The most abundant shrubs or trees under 5 m in height were elm, hawthorn, elder and blackthorn. Comparison of the over 5m and under 5 m category for trees suggests that only elm is regenerating succesfully; all the other species have a high proportion of old to juveniles in their population (Table 4).

Table 3. Summary of total tree abundance in the Great Ouse by study sites

Site name	Length of survey banks	No. of species	No of indivs	Nos. per km	Nos. > 5 m height	Nos. < 5m height	Nos. >5m per km
New Bedford River	500	0	0	0	0	0	0
Forty Foot Drain	500	4	19	38	14	5	28
Bourne Brook	500	9	87	174	60	27	120
Cam (Shepreth)	1000	3	38	38	19	19	19
Granta	1000	12	60	60	36	24	36
Cam (Duxford)	500	11	42	84	20	22	40
Great Ouse (Water Stratford)	500	7	68	132	57	11	114
Great Ouse (Lathbury)	500	3	16	32	13	3	26
Great Ouse (Roxton)	500	7	42	84	24	18	48
Heacham	1000	10	96	96	82	14	82
Kennett	1000	10	125	131	88	43	88
Kym	500	5	118	236	3	115	6
Little Ouse	1000	10	87	87	31	56	31
Nar	500	6	19	38	14	5	14
Ouzel	500	3	20	40	18	2	36
Padbury Brook	500	7	49	98	18	31	36
Wissey	500	3	*	5		10	
Tove	500	11	97	194	31	66	62

* many planted saplings too closely spaced to count

Table 4. Tree abundance in the Great Ouse by species

Species	No. of individuals > 5m high	No. of individuals < 5m high	No. of sites with >5m specimens	No. of sites with <5m specimens
Crack Willow	85	23	12	7
Hawthorn	59	91	13	12
Ash	57	7	8	3
Elder	55	77	9	10
Alder	54	15	4	3
Elm	45	138	4	5
White willow	44	14	6	4
Field Maple	29	18	4	3
Blackthorn	12	39	3	6
Goat willow	10	9	2	1
Grey poplar	10	1	1	1
Sycamore	7	2	3	2
Pedunculate oak	6	2	3	1
English oak	5	1	1	1
Hazel	3	4	1	2
Buckthorn	3	10	3	4
Scots pine	2		2	
Italian alder	2			1
Dogrose	1	23	1	5
Horse chestnut	1		1	
Weeping willow	1		1	
Crab apple	1	3	1	3
Laburnum	1			1
Osier		5		1
Almond-leaved willow		1		1
Greengage		1		1
Plum		2		1
Holly		1		1
Cherry		1		1

There was an a slight but non-significant tendency for smaller streams to have a higher tree density, measured both as stream orderand as distance from the stream source (Figure 2). It is readily understandable that these two factors are linked, though not linearly (Figure 3).

Figure 2. Tree abundance against distance from source

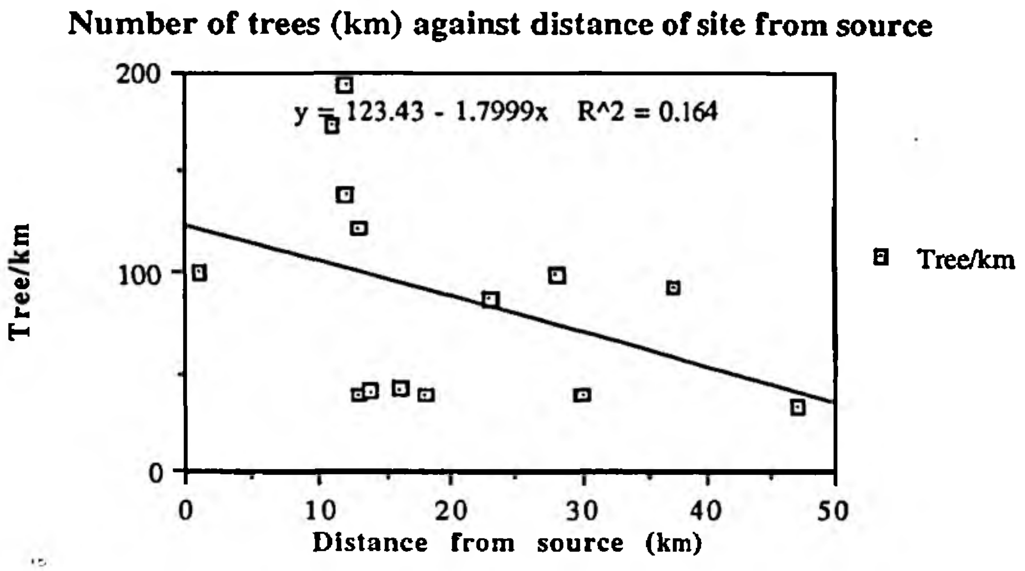
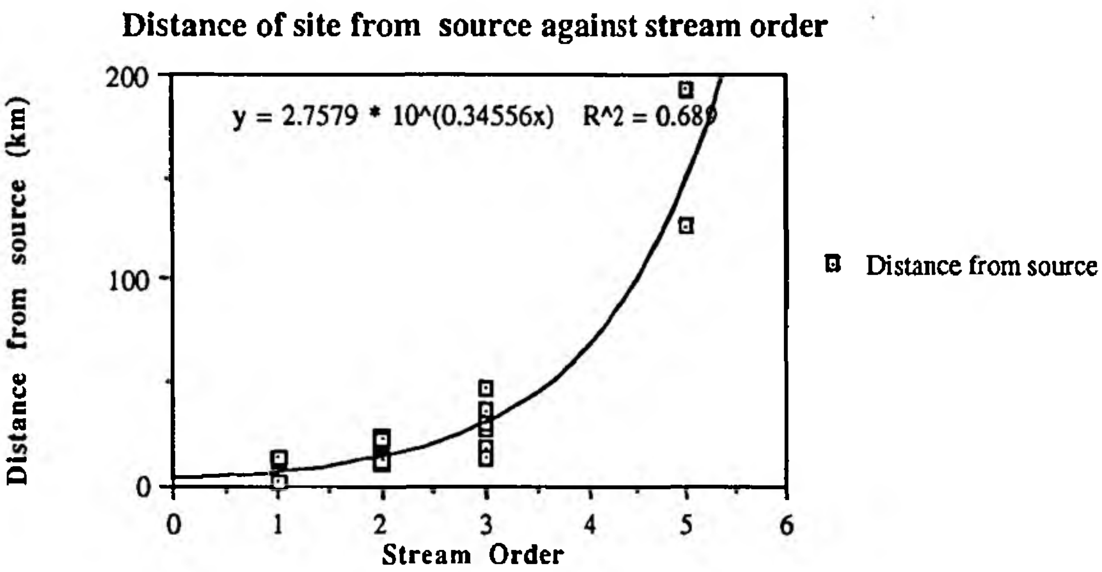
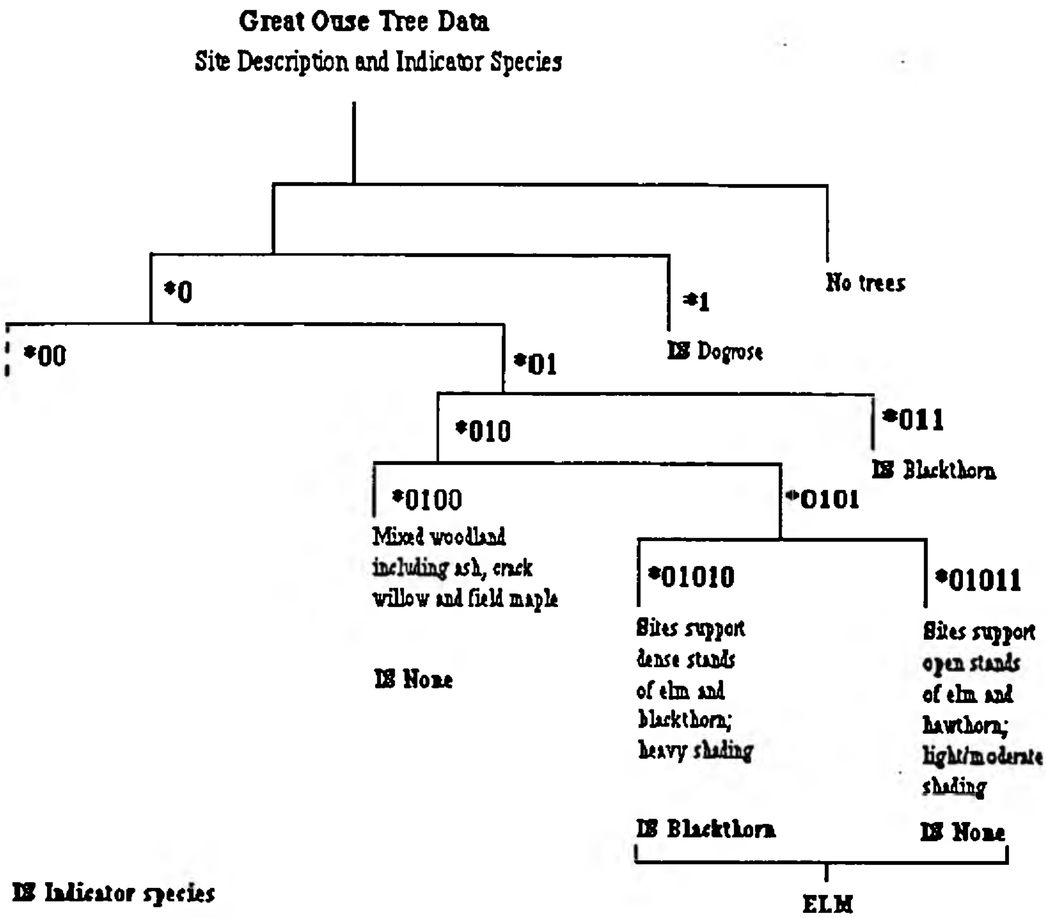


Figure 3. Relationship between stream order of site and distance from source



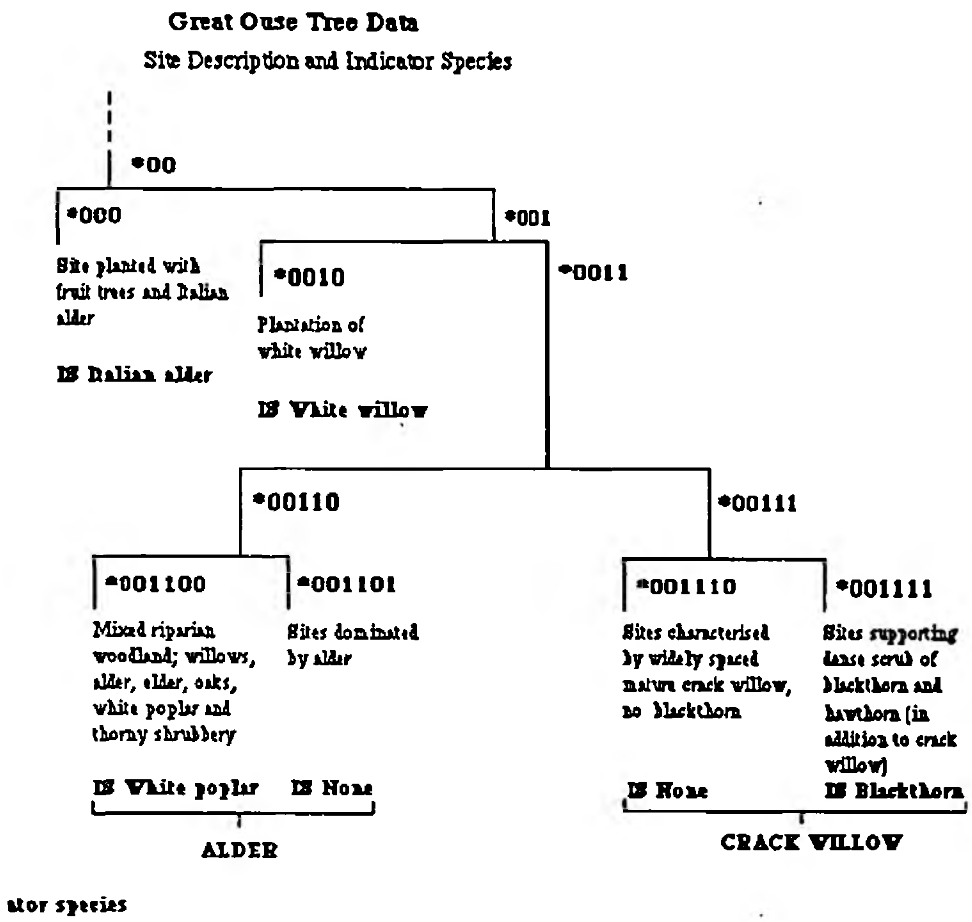
Analysis of community structure using Twinspan and cluster analysis gave an indication of distinct communities. It is likely that the samples represent a series of fragmented remnants of the same willow- and alder-dominated plant community, heavily influenced by plantings and woodland escapes. The lower level Twinspan divisions were identified as belonging to either alder, crackwillow or elm dominated groups (Figure 4). A phytosociological account can be made of these groups.

Figure 4 (i) Twinspan analysis of Great Ouse trees by site and indicator species



The class Querco-Fagetea describes mixed deciduous British woodlands found on nutrient rich soils. Alno-padion is an alliance belonging to this class and refers to alderwoods found in areas which have damp, occasionally waterlogged mineral soils. The tree layer, in addition to *Alnus glutinosa* (alder), may include willow , ash and birch. The commoner shrubs are *Crataegus monogyna* (hawthorn), *Sambucus nigra* (blackthorn) and *Corylus avellana* (hazel). This alliance could be used to describe groups 001100 and 001101. River bank willow is classified as Salicetea purpurea using phytosociological terminology. This class contains riverside plants associated with relatively nutrient-rich

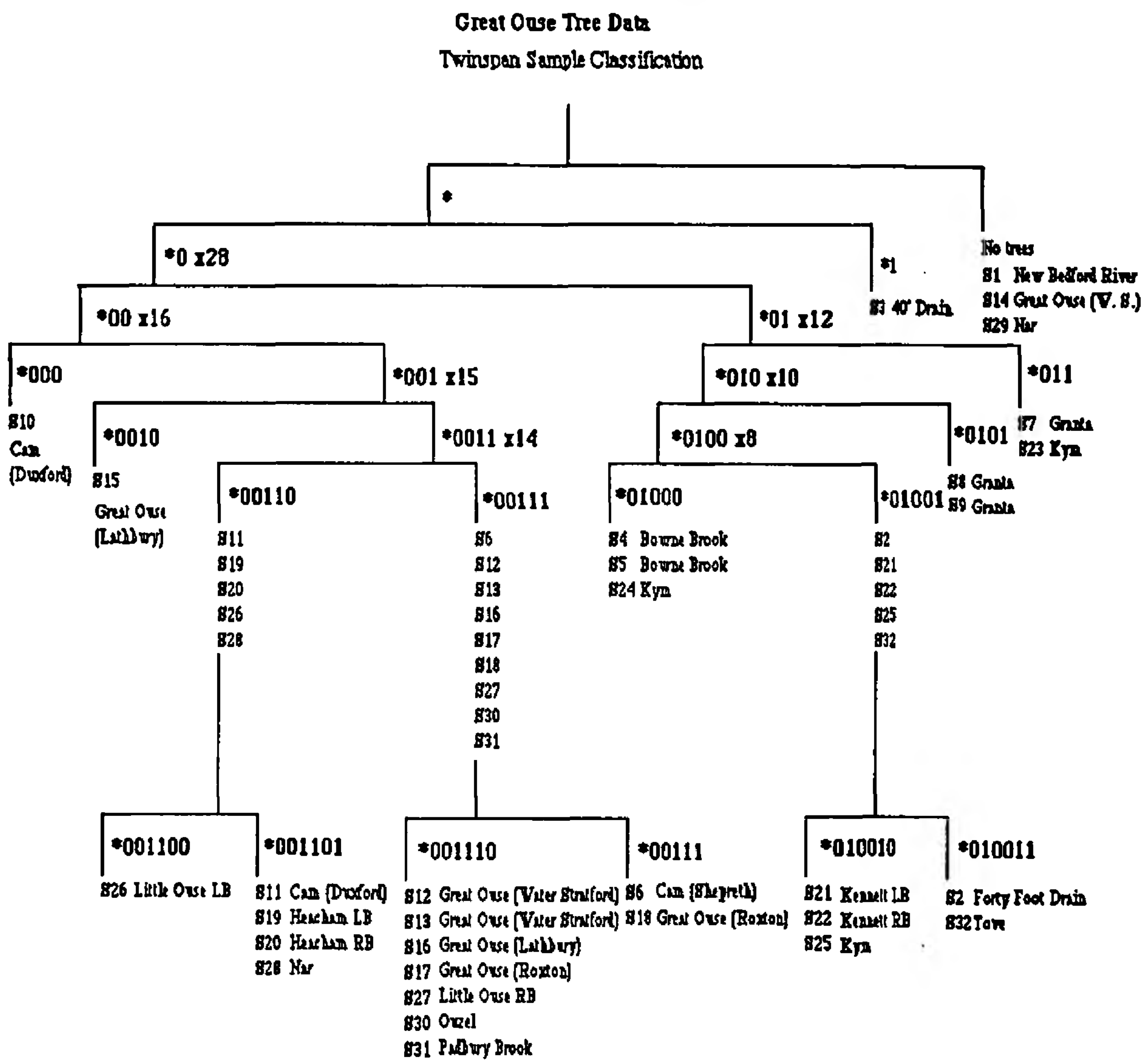
Figure 4 (b) Twinspan analysis of Great Ouse trees by site and indicator species



IS Indicator species

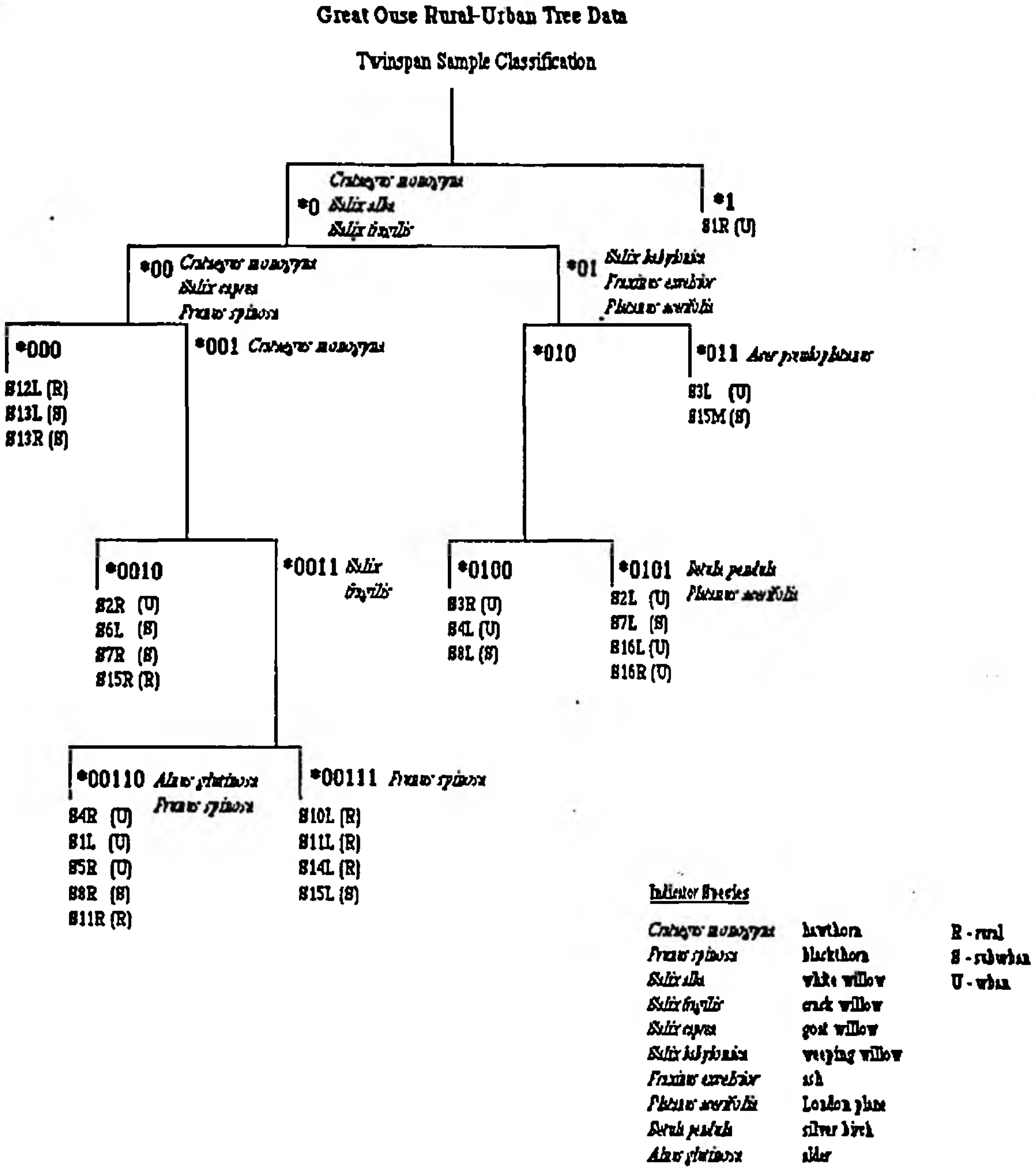
water and substrate. Characteristic species include *Salix triandra* (almond willow), *S.viminalis* (common osier), *S. alba* (white willow) and *S. fragilis* (crack willow). The latter two species in particular are found on nitrogen-rich river alluvium. The sites supporting predominantly elm and hawthorn or blackthorn may be classed within Querco-Fagetea (lowland woods on nutrient -rich soils). Ulmion carpinifoliae, an alliance within this class, refers to mixed oak-elm valley woods on fertile soils. Group *000 represents sites supporting anomalous trees, such as those that are ornamental or orchard species. Figure 5 shows the site assemblages of the same data.

Figure 5. Twinspan analysis of the Great Ouse tree data by site



Twinspan analysis of the tree species data collected at urban, suburban and rural sites along the Great Ouse are illustrated in Figure 6. The letter in parenthesis (R, S and U) after the site number denotes the nature of the site: rural, urban, suburban. The distribution of sites and indicator species between the two branching arms at division *0 show a distinct grouping. The species of the left arm of the dendogram are characteristic riparian trees and shrub whereas those of the right are not naturally found at the riverside. The distribution of sites corresponds to some degree with this grouping; all of the rural sites falling within the left branch and a predominance of urban sites within the right, but there are no more distinct site groups.

Figure 6. Tree communities from the rural /urban sites on the Great Ouse



Herb Community

An extensive group of flowering plants was recorded from the riparian zone (Tables 5 & 6). These showed some slight relationship, not convincingly significant, between species richness and degree of riparian tree shading (Figure 7).

Figure 7. Relationship between shading and herb species richness

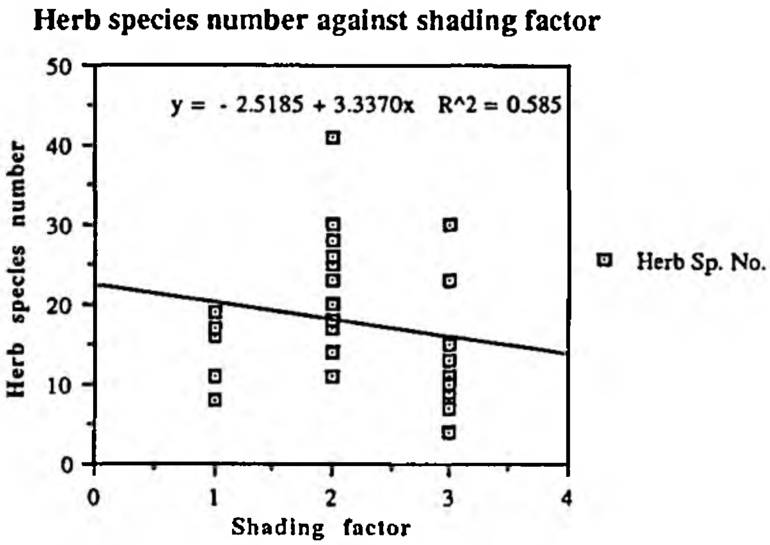


Table 5. Flowering plant species recorded from the rural Great Ouse sites

Plant Species list for the Great Ouse study sites

FAMILY:	Generic Name:	Common Name:	100' Drain S1 5 June '91	Wissey S33 12 June '91	S34	Nar S28 25 July '91	S29	Little Ouse S26 1 Aug '91	S27	Hencham S19 5 Aug '91	S20	Kennett S21 19 Aug '91	S22	Granta S7 20 Aug '91	S8	S9	Cam/Rhee 27 Aug '91	Granta/Cam S10 28 Aug '91	S11
ARALIACEAE	Hedera helix L.	Ivy										F	O						
BALSAMINACEAE	Impatiens glandulifera Royle.	Indian balsam																	O
BORAGINACEAE	Myosotis scorpioides L.	Water forget-me-not				R	R	O	R										
	Symphytum officinale L.	Common comfrey			F	R	R												O
CANNABIACEAE	Humulus lupulus L.	Hop							R	R	R								R
CAPRIFOLIACEAE	Viburnum opulus L.	Guelder-rose							R						R				
CARYOPHYLLACEAE	Cerastium fontanum Baumg.	Common mouse-ear	R					O											
	Myosoton aquaticum (L.) Moench	Water chickweed								O	O								O
	Silene dioica (L.) Clairv.	Red campion																	
	Silene pratense (Rafn) Godr. & Gren.	White campion						R	R										
	Stellaria media (L.) Vill.	Common chickweed	O									R	R				R		
CHENOPODIACEAE	Chenopodium album L.	Fat-hen																	R
COMPOSITAE	Achillea millefolium L.	Yarrow							F						R			R	
	Arctium pubens Bab.	Burdock													R		R		
	Artemesia vulgaris L.	Mugwort													R				R
	Bellis perennis L.	Daisy	R																
	Carduus crispus L.	Welted thistle					R		R										
	Chamomilla suaveolens (Pursh) Rydb.	Pineappleweed	O																
	Cirsium arvense (L.) Scop.	Creeping thistle	F		F	O	F	F	R							F	O		F
	Cirsium palustre (L.) Scop.	Marsh thistle																	R
	Cirsium vulgare (Savi) Ten.	Spear thistle	O		R											R	R		O
	Eupatorium cannabinum L.	Hemp agrimony			R			O		O	O								
	Lactuca serriola L.	Prickly lettuce																	R
	Lapsana communis L.	Nipplewort										R			R				
	Matricaria perforata Mérat	Scentless mayweed													R		R		R
	Petasites hybridus (L.)**	Butterbur			R			O		A	A				R		R		
	Senecio vulgaris L.	Groundsel			R														
	Senecio jacobaea L.	Common ragwort							O								R		
	Sonchus arvensis L.	Perennial sow-thistle							R										
	Sonchus asper (L.) Hill.	Prickly sow-thistle																	
	Sonchus oleraceus L.	Smooth sow-thistle																	
	Taraxacum officinale Weber.	Dandelion							O										
	Tragopodon pratensis L.	Goat's-beard							R										
CONVOLVULACEAE	Convolvulus arvensis L.	Field bindweed			R			R							R		F		
CRUCIFERAE	Alliaria petiolata (Bieb.) Cavara & Grande.	Garlic mustard				R						F	F		O		O		
	Brassica napus L.	Rape			R														
	Capsella bursa-pastoris (L.) Medic.	Shepherd's-purse	O						R										
	Hesperis matronis L.	Dame's violet																	
	Nasturtium officinale R. Br.	Water cress				R				R	R			R	O		F		F
	Sisymbrium officinale (L.) Scop.	Hedge mustard			R			R	R						R				
CUCURBITACEAE	Bryonia dioica Jacq.	White bryony													O				F
CYPERACEAE	Carex sp.	Sedge			O	O			O										
	Scirpus lacustris L.	Common club-rush																	
DIPSACACEAE	Dipsacus fullonum L.	Teasel			R								R				R		R
EQUISETACEAE	Equisetum fluviatile *	Water horsetail				R	R												
GERANIACEAE	Geranium pusillum L.	Small-flowered cranes-bill							R										
	Geranium dissectum L.	Cut leaved cranes-bill																	
	Geranium pyrenaicum Burm. f.	Hedgerow cranes-bill							O										
	Geranium robertianum L.	Herb robert						R		O	O		O						
GRAMINEAE	Agrostis stolonifera	Creeping bent																	
	Alopecurus pratensis	Foxtail																	
	Arrhenatherum elatius	False oat grass			•														
	Bromus sterilis L.	Barren brome	•																
	Dactylis glomerata L.	Cocksfoot	•			•		•	•										
	Elymus repens	Common couch																	
	Glyceria maxima (Hartm.) Holmberg	Reed sweet-grass			•	•	•		•								•		
	Hordeum murinum L.	Wall barley	•																
	Hordeum secalinum Schreb.	Meadow barley																	
	Lolium perenne	Perennial rye-grass				•			•										
	Phalaris arundinacea L.	Reed canary-grass			•		•	•	•						•		•		•
	Phragmites australis (Cav.) Trin. ex Steud.	Common Reed			•		•	•	•										
	Phleum pratense	Timothy-grass		•	•														
	Poa sp.	Meadow-grass	•	•	•	•		•	•										
		Grass (general)	A	O	F	R	F	O	A				R		F		A		F
HALORAGACEAE	Hippuris vulgaris L.	Marestail																	
IRIDACEAE	Iris pseudacorus L.	Yellow iris			R		R												
JUNCACEAE	Juncus sp.	Rush																	

FAMILY:	Generic Name:	Common Name:	100'Drain S1	Wissey S33	S34	Nar S28	S29	Little Ouse S26	S27	Heacham S19	S20	Kennett S21	S22	Granta S7	S8	S9	Cam/Rhee	Granta/Cam S14	S11
			5 June '91	12 June '91		25 July '91		1 Aug '91		5 Aug '91		19 Aug '91		20 Aug '91			27 Aug '91	28 Aug '91	
LABIATAE	Glechoma hederacea L.	Ground ivy			O			O	O	F	F	F	F	O	F	O		F	O
	Lamium album L.	White deadnettle	R						R				O			R	O	O	
	Lamium purpureum L.	Red dead-nettle						R	O	R	R	O			R				R
	Mentha aquatica L.	Water mint				R				F	F								
LEGUMINOSAE	Lotus corniculatus L.	Bird's-foot trefoil										R							
	Medicago lupulina L.	Black medick							R										
	Trifolium sp.	Clover							R										
	Vicia sp.	Vetch						R											
LEMNACEAE	Lemna sp.	Duck weed												R	R	A	A		
LYTHRACEAE	Lythrum salicaria L.	Purple-loosestrife																	
MALVACEAE	Malva sylvestris L.	Common mallow	R						R						R		R		O
NYMPHAEACEAE	Nuphar lutea (L.) Sm.	Yellow water-lily																	
ONAGRACEAE	Epilobium hirsutum L.	Great willowherb			R	F	O		F	O	O		O		O		O		F
PLANTAGINACEAE	Plantago lanceolata L.	Ribwort plantain							O										
	Plantago major L.	Greater plantain							R										
POLYGONACEAE	Polygonum persicaria L.	Redshank													R		R		O
	Rumex obtusifolius L.	Broad-leaved dock	O						R			R	R		F		R	O	F
	Rumex sanguineus L. var. viridis Sibth.	Wood dock														O			
RANUNCULACEAE	Clematis vitalba L.	Traveller's-joy											R					F	O
	Ranunculus penicillatus (Dumort.) Bab.	Stream water-crowfoot						A	A									F	
	Ranunculus sceleratus L.	Celery-leaved buttercup				R													
	Ranunculus repens L.	Creeping buttercup	O					R	F										
ROSACEAE	Filipendula ulmaria (L.) Maxim.	Meadowsweet				R	O	F		O	O								
	Geum urbanum L.	Wood avens								R	R		R						
	Rubus fruticosus agg.*	Bramble			O				O				R	O	F	F		R	
RUBIACEAE	Galium mollugo L.	Hedge bedstraw													R				
	Galium saxatile L.	Heath bedstraw																	
	Galium aparine L.	Common cleaver			F	F	F	F	A					A	F	A	R	O	F
	Galium palustre L.	Marsh-bedstraw	R																
SCROPHULARIACEAE	Scrophularia auriculata L.	Water figwort				R			O	R	R						O		
	Veronica beccabunga L.	Brooklime			R	R				O	O								R
SOLANACEAE	Solanum dulcamara L.	Bittersweet				O	O										R		O
SPARGANIACEAE	Sparganium erectum L.	Branched bur-reed												O	F		O		O
UMBELLIFERAE	Aegopodium podagraria L.	Ground elder				R		O	O										
	Angelica archangelica L.	Garden angelica											O		R			R	
	Anthriscus caucalis Bieb.	Bur chervil							R										
	Anthriscus sylvestris (L.) Hoffm.	Cow parsley	O		R	R	O					F	F						
	Apium nodiflorum (L.) Lag.	Fool's watercress	R									O	O						O
	Chaerophyllum temulum L.	Rough chervil			F	R													
	Conium maculatum L.	Hemlock		R	F			A	F						F		O		F
	Heracleum sphondylium L.	Hogweed			O		R						R		R		R		R
	Oenanthe aquatica (L.) Poir.	Fine-leaved water-dropwort					R												
URTICACEAE	Urtica dioica L.	Common nettle	F	D	F	A	F	A	F	A	A	O	A	F	A	F	F	O	F

* from Fitter, Fitter & Blamey ('78)
**Gaertn., Mey. & Scherb.

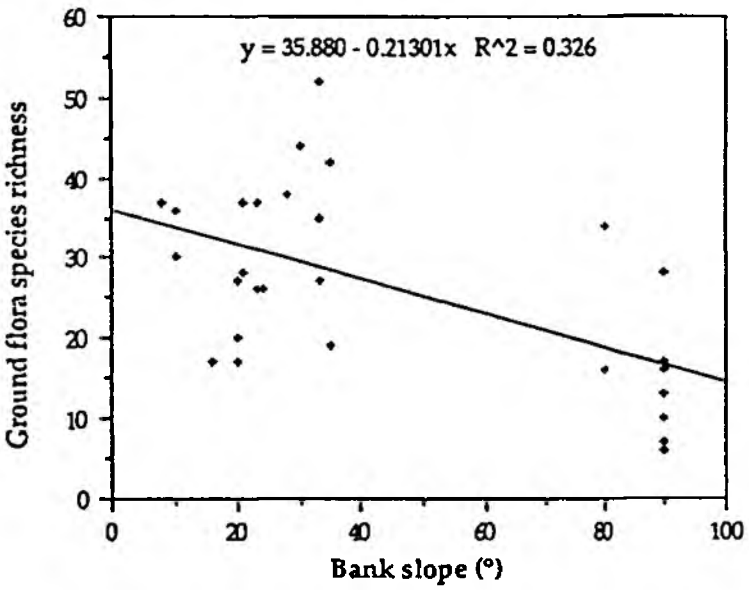
Tree species	1L	1R	2L	2R	3L	3R	4L	4R	5R	6L	7L	7R	8L	8R	9R	10L	11L	11R	12L	13L	13R	14L	15L	15M	15R	16L	16M
Acer pseudoplatanus L.	2				5				13								6					1	5	8			
Aesculus hippocastanum L.						3					1													2			
Alnus glutinosa (L.) Gaertn.	1						3	4	1					3					3		2						
Betula lenta L.													3				1										
Betula pendula Roth			1								1																1
Buddleja davidii											1																
Buxus sempervirens L.						1					1																
Crataegus monogyna Jacq.	16			15		2	6	25	12	1	3	12	1	7		15	7	6	4			18	25	2	6		1
Fraxinus excelsior L.				6		5	5		11		9	1	5	9		1	4	1	2	1	1		4	5	2	1	7
Ilex aquifolium L.																											
Malus spp.																		1									2
Platanus acerifolia (Ait.) Willd.			3		26																					1	2
Populus canescens (Ait.) Sm.								7						6								1	30				
Populus nigra cv. "Italica"				1																				2	2		
Populus nigra L. var. betulifolia (Pursh) Torr.							6	4	3				5										2			1	4
Prunus spinosa L.								1				1				15	2					1	5				
Prunus spp.																	1										
Quercus spp.									2										1	1							
Salix alba L.	5		1		5	2	2	10	12		26	81	1	17		13	65	2				2	49	5	3	1	14
Salix babylonica L.		3			1	2	25				1		2							1							1
Salix caprea L.								7				3					2	2	31	2		1					
Salix fragilis L.	19		1		21	6	15	5	1		6		2	43		2	54	7	2	10	1	7	5	9			4
Salix spp. (Hybrid) L.												12	30	2		10	11	4			1	6	2		48		30
Sambucus nigra L.			1	1					1		2	3		1		18	1	1				6	5	1			9
Sorbus aucuparia L.																	2										
Tilia cordata Mill.					14																						
Ulmus procera Salisb.									15				3			4	1	43						5			

Table 6. Flowering plant species recorded from the rural/urban fringe sites

GENERIC NAME	COMMON NAME
Achillea millefolium L.	Yarrow
Agrostis stolonifera L.	Creeping bent
Alisma plantago-aquatica L.	Water plantain
Alliaria petiolata Bieb.	Garlic mustard
Allium vineale L.	Wild onion
Alopecurus pratensis L.	Foxtail
Anthriscus sylvestris L. (Hoffm.)	Cow parsley
Arctium pubens Bab	Arctium nemorosum
Arrhenatherum elatius L.	False oat grass
Artemisia vulgaris L.	Mugwort
Bellis perennis L.	Daisy
Brassica napus L.	Rape
Bromus sterilis L.	Barren brome
Calamagrostis canescens (Weber) Roth.	Purple small-reed
Calemagrostis arundinacea	Rough small-reed
Calystegia silvatica (Kit.) Griseb.	Large bindweed
Capsella bursa-pastoris agg (L.) Medic.	Shepherd's-purse
Carduus crispus L.	Welted thistle
Carex acutiformis Ehrh.	Lesser pond sedge
Carex pendula Huds.	Pendulous sedge
Centaurea nigra L.	Common knapweed
Chamomilla suaveolens (Pursh) Rydb	Pineapple-weed
Cirsium arvense (L.) Scop	Creeping thistle
Cirsium vulgare (Savi) Ten	Spear thistle
Clematis vitalba L.	Traveller's-joy
Conium maculatum L.	Hemlock
Convolvulus arvensis L.	Field bindweed
Conyza canadensis (L.) Cronq	Canadian fleabane
Crepis capillaris (L.) Wallr.	Smooth hawks-beard
Dactylis glomerata L.	Cocksfoot
Dipsacus fullonum L.	Teasel
Elymus repens (L.) Gould.	Common couch
Epilobium hirsutum L.	Great willowherb
Equesitum spp.	Horsetail
Eupatorium cannabinum L.	Hemp-agrimony
Euphorbia helioscopia L.	Sun spurge
Filipendula ulmaria (L.) Maxim	Meadowsweet
Galium aparine L.	Cleavers
Galium palustre L.	Common marsh-bedstraw
Geranium dissectum L.	Cut-leaved cranes-bill
Geranium robertianum L.	Herb-robert
Glechoma hederacea L.	Ground-ivy
Glyceria maxima (Hartm) Holmberg	Reed sweet-grass
Greater dodder L.	Cuscuta europaea
Hedra helix L.	Ivy
Heracleum mantegazzianum Somm & Lev.	Giant hogweed
Heracleum sphondylium L.	Hogweed
Holcus lanatus L.	Yorkshire fog
Hordeum murinum L.	Wall barley
Hordeum secalinum Schreb.	Meadow barley
Humulus lupulus L.	Hop
Impatiens capensis Meerb.	Orange balsam
Iris pseudacorus L.	Yellow iris
Juncus inflexus L.	Hard rush
Lamium album L.	White dead-nettle
Lapsona communis L.	Nipplewort
Large bittercress L.	Cardamine amara
Lathyrus pratensis L.	Meadow vetchling
Lolium perenne L.	Perenial rye-grass
Lotus corniculatus L.	Bird's-foot trefoil
Lychnis flos-cuculi L.	Ragged robin
Lycopus europaeus L.	Gipsywort
Lythrum salicaria L.	Purple loosestrife
Malva sylvestris L.	Common mallow
Matricaria perforata (Merat)	Scentless mayweed
Medicago lupulina L.	Black medick
Mentha aquatica L.	Water mint
Myosotis arvensis (L.) Hill	Field forget-me-not
Myosotis scorpioides L.	Water forget-me-not
Nasturtium officinale R.Br.	Water cress
Nuphar lutea (L.) Sm.	Yellow water-lilly
Nymphaea alba L.	White water-lilly
Onopordum acanthium L.	Cotton thistle
Papaver rhoeas L.	Poppy
Phleum pratense L.	Timothy-grass
Phragmites australis (Cav.) Trin ex Steud.	Common reed
Picris echioides L.	Bristly ox-tongue
Plantago lanceolata L.	Ribwort plantain
Plantago major L.	Greater plantain
Plantago media L.	Hoary plantain
Poa nemoralis L.	Wood meadow-grass
Polygonium amphibium L.	Amphibious bisort
Polygonium bistorta L.	Bistort
Polygonium persicaria L.	Redshank
Ranunculus fluitans Lam.	River water-crowfoot
Ranunculus repens L.	Creeping buttercup
Reseda luteola L.	Weld
Reynoutria japonica Houtt.	Japanese knotweed
Rosa canina L.	Dog rose
*Rubus fruticosus	Bramble
Rumex conglomeratus Murr	Clustered dock
Rumex crispus L.	Curled dock
Rumex hydrolapathum Huds.	Great water dock
Rumex obtusifolius L.	Broad-leaved dock
Rumex sanguineus L.	Wood dock
Sagittaria sagittifolia L.	Arrowhead
Scirpus lacustris L.	Common club-rush
Scrophularia nodosa L.	Common figwort
Scutellaria galericulata L.	Skullcap
Senecio jacobaea L.	Ragwort
Senecio vulgaris L.	Groundsel
Silene pratense (Rafn.)	White Campion
Solanum dulcamara L.	Bittersweet
Sonchus arvensis L.	Perennial sow-thistle
Sonchus asper (L.) Hill	Prickly sow-thistle
Sonchus oleraceus L.	Smooth sow-thistle
Sparganium erectum L.	Branched bur-reed
Stachys spp.	Woundwort spp.
Stellaria media (L.) Hill	Common chickweed
Symphytum officinale L.	Common comfrey
Taraxacum officinale Weber	Dandelion
Taraxacum spectabile Dahlst.	Red veined dandelion
Thlaspi arvense L.	Field penny-cress
Trifolium pratense L.	Red clover
Trifolium repens L.	White clover
Typha latifolia L.	Common reedmace
Urtica dioica L.	Common nettle
Veronica catenata Pennell	Pink water speedwell
Veronica persica Poir	Field-speedwell
Vicia cracca L.	Tufted vetch
Viola Tricolor L.	Wild pansy
	Crucifer spp

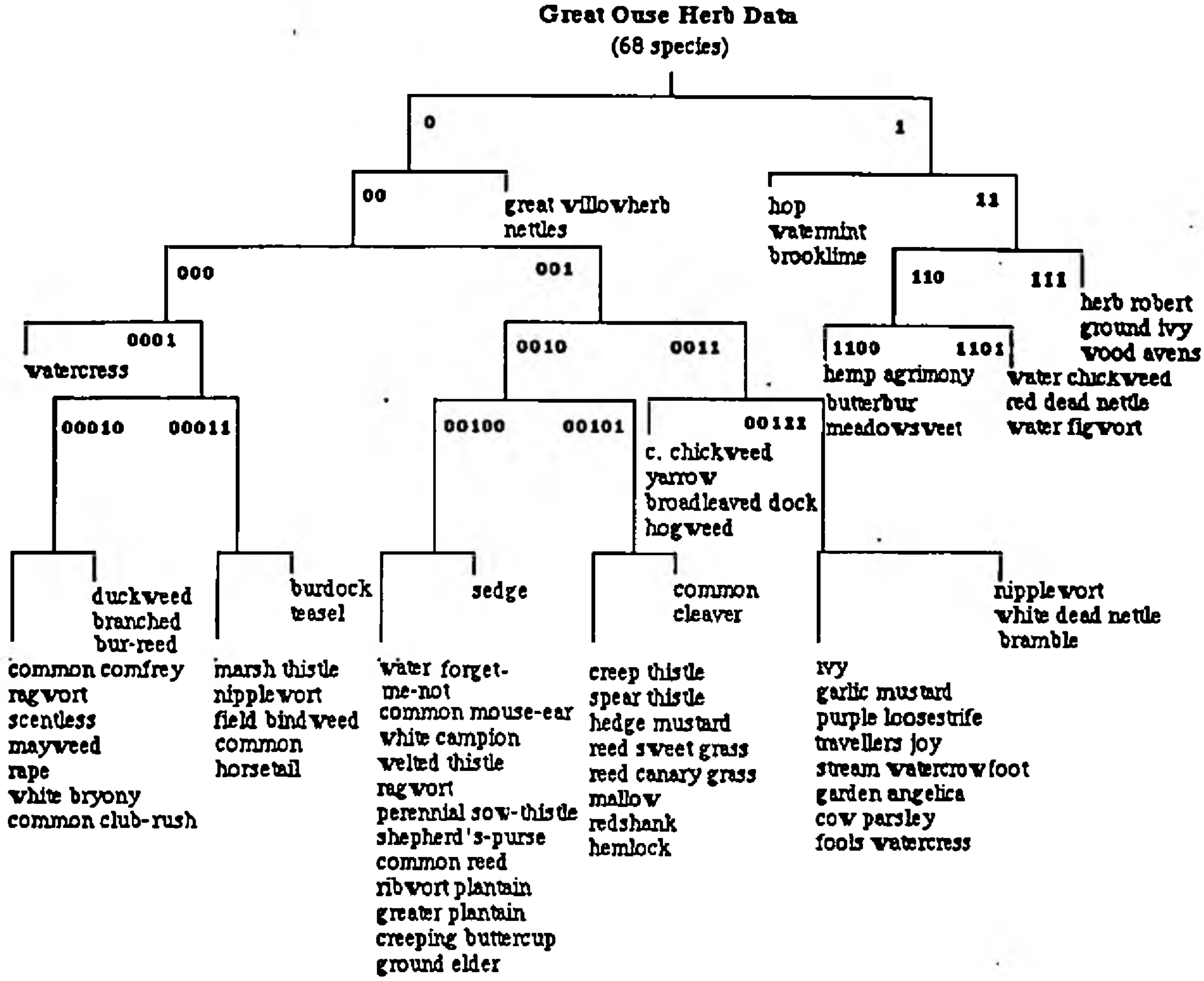
There was also a slight correlation, again not significant, between bank slope and species richness of ground flora (Figure 8). Bank slope is a very variable parameter and field results gave conflicting results; more extensive work would be necessary before asny conclusion could be drawn.

Figure 8. Relationship betwen bank slope and herb species richness



The groups of herb species were identified by Twinspan and compared with phytosociological associations from Rieley and Page (1990). Figure 9 illustrates the groupings of these 68 species at each Twinspan division. They do not correspond with any distinct phytosociological classes; however there are some general comments that can be made on the groups.

Figure 9. Twinspan analuysis of the herb community of the Great Ouse sites



The order Plantaginetea majoris contains plant communities of low growing, successional plants which grow in response to specific environmental stresses, for example, trampling or impoverished habitat conditions. The characteristic species inlude *Plantago major* (greater plantain), *Capsella bursa-pastoris* (shepherd's purse), *Taraxacum officinale* (dandelion), *Ranunculus repens* (creeping buttercup) and *Rumex crispus* (curled dock). The order Artemisietea vulgaris typically contains vegetation of stabilised soils in areas which in the past were severely disturbed. Some of the soils may be rich in humus and nitrogen. Species of this order include *Urtica dioica* (nettle), *Rumex obtusifolius* (broad leaved dock), *Caduus acanthoides* (welted thistle) and *Dipsacus sylvestris* (teasel). Within this single order are the alliances Arction, Gallio-Alliarion and Aegopodion podagrariae. The Arction is characterised by the presence of either or both *Arctium lappa* (greater burdock) and *Arctium minus* (lesser burdock). Gallio-Alliarion comprises plants such as

Alliaria petiolata (garlic mustard) and *Anthriscus sylvestris* (cow parsley) which are typical of hedges and waysides. The latter alliance contains communities reminiscent of shadedwoodland, dominated by nettles and grasses. The typical species include *Aegopodium podagraria* (ground elder), *Urtica dioica* (nettle), *Lamium alba* (white dead-nettle) and *Elymus repens* (common couch).

The above orders relate to vegetation characteristic of disturbed marginal ground to which some of the herb species belong. Species such as *Lythrum salicaria* (purple loosestrife), *Epilobium hirsutum* (great willowherb), *Phalaris arundinacea* (reed canary-grass) and *Filipendula ulmaria* (meadowsweet) correspond with Filipendula, one of the three alliances of the order Molinietalia. The order itself refers to vegetation of periodically wet meadows and the alliance to communities that grow on humus-rich, damp soils high in nitrogen and subject to periodic flooding; conditions often found along streams, rivers and drainage channels.

These herb species comprise a mixture of the above classes and would mostly be identified as weeds. Within the higher divisions, there are some minor associations of plants. *Eupatorium cannabinum* (hemp agrimony), *Petasites hybridus* (butterbur) and *Filipendula ulmaria* (meadowsweet) are all riparian tall herb species (group 1100) and *Geranium robertianum* (herb robert), *Glechoma hederacea* (ground ivy) and *Geum urbanum* (wood avens) damp woodland species (group 111).

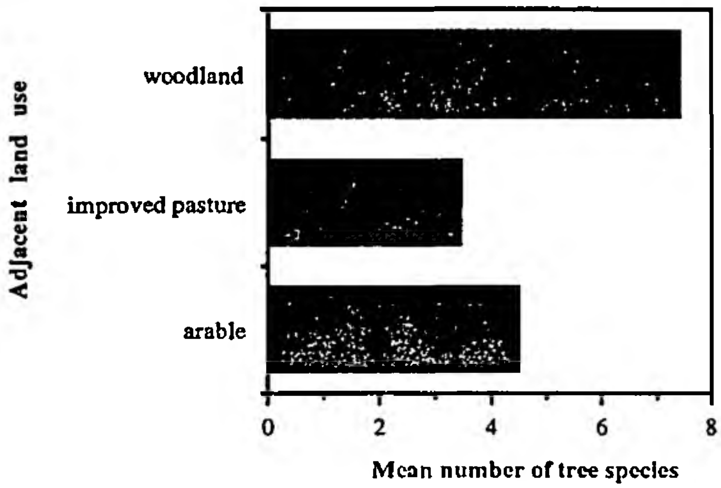
Parkyn, Harper & Smith (1993), in a study reviewing the River Corridor survey practices of the NRA, recommended that plant alliances should be used as the basis of a unified plant recording methodology. Whether or not this is adopted, the alliances identified could also be used as a guide to maximise the variety of plant communities in the riparian zone through appropriate management. Table 7, replicated from Parkyn, Harper & Smith (1993), contains aquatic as well as riparian alliances within the United Kingdom.

Table 7. Main native riparian and aquatic vegetation communities (after Rieley & Page 1990)

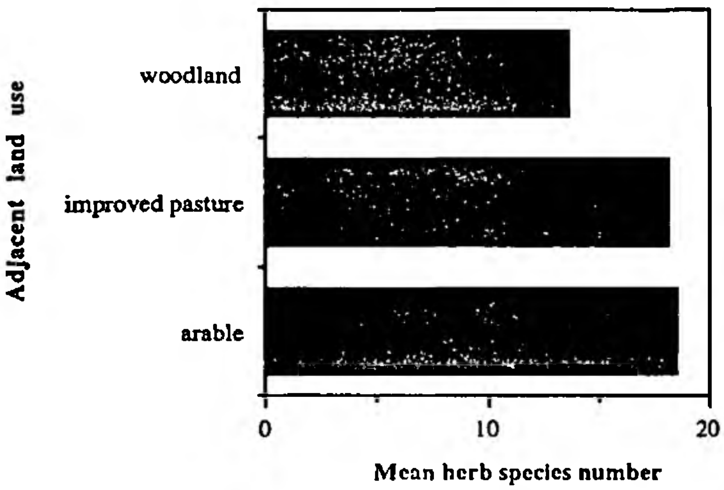
Alliance name	Description and species dominants
Lemnion minoris	Free-floating duckweeds: *Lemna spp.*
Magnopotamion	Submerged large pondweeds: *Potamogeton perfoliatus*
Nymphaeion	Floating-leaved lilies: *Nuphar lutea*
Parvopotamion	Submerged small pondweeds such as *P. crispus* and *Elodea canadensis*
Hydrocharition	Rare calcareous community dominated by *Hydrocharis morsus-ranae* (frogbit)
Callitricho-Batrachion	Shallow or fluctuating waters:*Callitriche* and *Ranunculus spp.*
Potamogetion graminei	Acid waters: *P. gramineus, Myriophyllum alterniflorum*
Littorellion uniflorae	Shallow littoral of oligotrophic water (usually lakes): *Littorella, Isoetes*
Glycerio-Sparganion	Mineral substrates dry in summer: *Glyceria, Veronica*
Apion nodiflori	Mineral, permanently shallow: *Apium, Nasturtium, Scrophularia*
Phragmition	Silty reedswamp often single sp. stand: *Phragmites, Typha, Schoenoplectrus*
Oenanthion aquaticae	Calcareous of clayey, smaller stands: *Oenanthe aquatica, Butomus, Eleocharis*
Magnocaricion	Tall sedges and grasses: *Carex spp., Phalaris, Cladium, Lythrum*
Caricion curto-nigrae	Acidic, peaty, often floating mat: *Carex nigra, Hydrocotyle, Potentilla palustris*
Eriophorion latifolii	Acidic, low growing mat: *Eriophorum, Schoenus nigricans*, bryophytes
Alnion glutinosae	Waterlogged, organic peaty woodland: *Alnus, Fraxinus, Salix cinerea,*
Salicion cinereae	Dryer peaty shrubs: *Frangulua alnus, Viburnum opulus, Salix*
Salicion albae	Pioneer nutrient-rich riverbanks: *Salix fragilis, S. alba, Iris, Phalaris*
Vaccinio-Piceion	Northern, acid soils: *Pinus* and *Vaccinium*
Betulion pubescentis	Acid soils: *Betula* dominated woodland
Quercion robori-petraeae	Acid soils: oakwoodland
Alno-padion	Alderwoods on fertile soils, occasional waterlogging: *Alnus, Prunus padus,*
Carpinion betuli	Mixed woodlands on fertile soils: *Quercus, Fraxinus, Tilia cordata, Corylus*
Fagion sylvaticae	Chalk and limestone soils: *Fagus* dominant with *Acer campestre, Sorbus araria*
Ulmion carpinifoliae	Limestone ashwoods: *Fraxinus, Acer pseudoplantanus*
Eu-Nardion	Acidic alluvial grassland: *Agrostis spp., Festuca ovina, Galium saxatile*
Nardo-Galion saxatilis	Acidic grassland: *Nardus stricta, Agrostis canina, Anthoxanthum odoratum*
Nardeto-Caricion bigelowii	Acidic flushes: *Nardus, Carex spp., Ranunculus acris*
Calluno-Genistion	Dry, acidic heaths: *Calluna vulgaris, Genista anglica, Erica cinerea, Ulex*
Empetrion nigrae	Northern, more peaty heaths: *Calluna, Vaccinium, Empetrum*
Calthion palustris	Organic wet soils: *Caltha, Lotus uliginosus, Lychnis flos-cuculi*
Filipendulion	Nitrogen-rich flooded soils: *Filipendula, Lythrum salicaria, Epilobium hirsutum*
Junco-Molion	Wet acid soils: *Molinia caerulea, Succisa pratensis, Parnassia palustris, Juncus*
Arrhenatherion elatioris	Damp rarely flooded meadows: *Dactylis glomerata, Ranunculus acris, Trifolium*
Cynosurion cristati	Damp grazed meadows: *Lolium perenne, Bellis, Ranunculus bulbosus*
Xerobromion	Rare, thin calcareous soils: *Scilla autumnalis, Helianthemum apenninum*
Mesobromion	Dry calcareous soils: *Brachypodium pinnatum, Avenula pratensis, Briza media*
Lolio-Plantaginion	Trampled, low-growing plants: *Plantago major, Lolium perenne, Poa annua*
Agropyro-Rumicion crispi	Disturbed ground: *Potentilla anserina, Ranunculus repens, Rumex crispus*
Arction	Nutrient rich disturbed: *Artemisia vulgaris, Arctium spp., Solidago*
Gallio-Alliarion	Shaded hedgerow and edges: *Allaria petiolata, Anthriscus sylvestris*
Aegopodion podagrariae	Shaded nutrient-rich woodland edge: *Urtica, Aegopodium, Lamium album*
Epilobion angustifolii	Nitrogenous disturbed soils: *Chamaenerion angustifolium, Rubus fruticosa,*
Polygono-Chenopodion	Sandy, nutrient-poor disturbed: *Polygonum persicaria, Lamium purpurea*

Species richness of both trees and herbs show some relation with adjacent arable land; riparian tree species are greatest with woodland adjacent, whilst herbs where arable is adjacent. The latter may be due to either the relative lack of shading, or the relative lack of grazing. The former is probably associated with woodland 'escapes' to the riparian zone. Neither association is strong and would require further study to confirm.

Tree species number against adjacent land use



Herb species number against adjacent land use



Discussion

Mason and Macdonald (1990) conducted a similar study on the riparian woody plant community of regulated rivers in East Anglia. Fifty 1km stretches of river were surveyed and the site information classified, based on the frequency of occurrence of species, into four groups using Twinspan. The indicator species for each group were as follows:

- Group A, *Acer campestre* (field maple), *Ulmus carpinifolia* (smooth elm) and *Prunus spinosa* (blackthorn)
- Group B, *Salix cinerea* (common sallow), *Salix fragilis* (crack willow) and *Salix alba* (white willow)
- Group C, *Salix fragilis* (crack willow), *Alnus glutinosa* (alder), *Populus nigra* (black poplar) and *Sambucus nigra* (elder)
- Group D, *Salix alba* (white willow)

There are similarities between the groups arising from the analysis of the Great Ouse tree community and those investigated by Mason and Macdonald (1990). Their Group C, for example, is possibly equivalent to group 001100 (mixed riparian woodland) of figure 3. The association between elm and blackthorn is similarly represented in both studies as group 01010 and group A.

Great Ouse Site Descriptions

New Bedford River (Hundred Foot Drain)

The surveyed stretch was straight with a uniform width and bank height. The channel was flanked on either side by a floodbank., 3m high and 15m back from the bank top. Within the strip of land between channel and floodbank all trees and shrubbery had been removed and the area grazed by cattle. Plant species diversity was low with *Circium vulgare* (spear thistle), *Circium arvense* (creeping thistle) and *Urtica dioica* (nettle) being most abundant.

Forty Foot Drain

The length of channel surveyed along this drain was split into two discrete sections according to vegetation cover. Section 2 supported several species of tree including *Fraxinus excelsior* (ash), *Ulmus procera* (elm) and *Crataegus monogyna* (hawthorn) within the riparian zone between channel and roadside. Besides *Conium maculatum* (hemlock) and *Dipsacus fullonum* (teasel) found amongst the trees, more typical bankside reeds and sedges were also present. This section also had artificial banks of wooden slats. Section 3 however had more steeply inclined banks with a dominant covering of *Phalaris arundinacea* (reed canary-grass) on one of the banks. This section was without tree cover excepting a single bush of *Rosa canina* (dogrose). The opposite bank was open to sheep grazing and frequent patches of exposed soil were seen.

Bourne Brook

Two sections were identified; section 4 which had only few trees and section 5 which had substantial stands of mature trees. The channel generally had very low flow both in terms of depth and velocity. As a consequence of this, aquatic vegetation covered much of the channel. Bourne Brook was modified in the early 1970's to reduce sinuosity although the channel is by no means straight. The absence of tree shading in section 4 most likely caused the increased abundance and diversity of marginal herbs. The dry meanders, remnants of the river workings 20 years earlier, have been left unmanaged in section 5. It was here that most mature trees were found. A row of *Salix alba* (white willow), pollarded 50-60 years ago, provided a bankside canopy at the downstream end of section 5.

River Cam (Shepreth)

This section of the River Cam was broadly meandering and had a constant width of approximately 6m. Besides two crack willow, the banks were dominated by hawthorn (*Crataegus monogyna*) and blackthorn (*Prunus spinosa*). Water quality was reported(by the local farmer) to be eutrophic due to sewage effluent input further upstream. The channel was therefore densely covered by macrophytes.

River Granta

Channel width of this 500m stretch of the Granta ranged between 5-6m. The level of the water in the channel was low to the extent that actual stream width decreased below 2m in places. This stretch was partitioned into three distinct sections. Section 7 and 8 had similar numbers of trees. The area designated as section 7 had bankside woodland with few ground flora species. The trees within section 8 were spaced at intervals along the bank and floral diversity was greater with *Urtica dioica* (nettle) being most abundant. Due to the low flow, water had become impounded behind two weirs providing ideal conditions for *Lemna* sp. (duckweed). The stretch referred to as section 9 had a greater diversity and abundance of trees than either of the other sections along this river. Ground cover was similar to section 7 in having few herb species.

River Cam (Duxford)

This site was divided into two sections. Section 10 had a dense bank-top cover of trees and shrubs. This section of the channel itself was of uniform width with occasional shallow berms impeding water flow. There was also a run of riffles and pools. Section 11 was characterised by a single row of trees and an 8m buffer strip of bankside herbs and grasses between bank-top and the adjacent arable field. The river at this section was channelized. The tree species growing along section 10 were evidence to suggest that an orchard had once been there. The water level of the river was as low as 10-20cm in places and the berms, where they were not shaded, were colonised by marginal species. *Ranunculus penicillatus* (stream water-crowfoot) was the established aquatic plant beneath the dense shade of the fruit trees. The trees in section 11 were mostly white willow planted at regular intervals.

River Great Ouse (Water Stratford)

This was the furthest upstream stretch of the Great Ouse to be surveyed. The site had uniformily steep banks and an obvious riffle/pool sequence within the channel. The stretch was divided into three distinct areas covering a bankside length of 500m. Few trees were located in section 12, all of which were *Salix fragilis* (crack willow). The margins were dominated by beds of *Nasturtium officinale* (watercress). Section 13 was identified separately for its dense trees and shrubs. Mature trees (mainly *S. fragilis*) grew at bank-top and well established bushes of *Sambucus nigra* (elder) and *Crataegus monogyna* (hawthorn) grew in between. The area was heavily shaded and damp with the most abundant herb being *Urtica dioica* (nettle). Section 14 was treeless and consisted of an abandoned marshy field mostly colonized by *U. dioica.*

River Great Ouse (Lathbury)

This site was divided into two sections. Both sections had similar bank characteristics with marshy sloping areas due to bank subsidence occurring along stretches of intact bank (0.5m above water level). Within the area between the artificial floodbank and bank-top of section 15 was a plantation of *Salix alba* (white willow) planted in a uniform grid. *Scirpus lacustris* (common club-rush) and *Glyceria maxima* (reed sweet-grass) had colonised the marshy subsided margins. Section 16 supported intermittent *Salix fragilis* (crack willow) and a reduced number of herb species due to grazing.

River Great Ouse (Roxton)

This was one of the largest river sites surveyed; channel width varying from between 25m (section 17) to 40m (section 18). The riparian zone of section 17 was mostly colonised by *Salix fragilis* of various ages and positions. The site area consisting of thorny scrub (hawthorn, buckthorn and blackthorn) was identified as section 18. There were markedly fewer herb species in section 18 than 17.

Heacham River

The left and right banks of this site were studied and, although supporting similar vegetation, were treated as separate sections to investigate the possible role of aspect. Channel width ranged from 3m-6m. Depth of water varied with the riffle/pool sequence along this stretch of the Heacham (3cm-50cm). On either side of this narrow channel there was a 50-125m wide riparian woodland separating the river from surrounding arable land. The tree community was dominated by *Alnus glutinosa* (alder) and *Fraxinus* *excelsior* (ash) and there were noticeably few *Salix* spp. at the site. Long stretches of the channel were lined with *Petasites hybridus* (butterbur). Shallow, sandy shoals which extended into the channel were colonised by *Mentha aquatica* (water mint), *Myosotis scorpioides* (water forgetmenot), *Veronica beccabunga* (brooklime) and *Nasturtium officinale* (watercress).

River Kennett

This site was again subdivided into two sections: section 21 referring to the left bank and section 22 to the right bank. The channel was a uniform width of 3m and depth varied with the sequence of riffles and pools. The left bank was steeper than the right and appeared undercut with exposed tree roots. Both banks were almost continuously covered with trees and woody scrub. *Acer campestre* (field maple) were most evident along the left bank. Where erosion was most severe several trees had been cut-down leaving the stumps in place from which regrowth had since occurred. *Ulmus procera* (common elm) and *Sambucus nigra* (elder) were most abundant on the right bank. *Urtica dioica* was found colonising the unshaded open areas between the trees and shrubs of this bank.

River Kym

The banks of this site were uniformly steep and frequent bank subsidence was evident along stretches without tree and shrub cover. The site was divided into three sections. Section 23 referring to a length of bank directly adjacent to a field of *Helianthus annuus* (sunflower). Section 24 was a stretch of relatively open bank next to an arable field and section 25 refers to a short length of bank bordered by an extensive juvenile stand of *Ulmus procera* (common elm) and *Prunus spinosa* (blackthorn). Section 24 had the greater diversity of flora and the channel at this point was mostly choked by varying densities of emergent and submergent aquatics.

River Little Ouse

Of the larger rivers surveyed, this site had most bankside tree cover. The channel was uniform and straight to the extent that there were no obvious variations in width or bank height over the 500m stretch. Both banks were surveyed from bank-top, the left bank as section 26 and the right bank as section 27. The vegetation of the left bank mostly comprised *C. maculatum* (hemlock) and *Urtica dioica* (nettle). This unmanaged strip was backed by a border of mixed deciduous trees and woody scrub. Section 27 was adjacent to a coniferous plantation upstream and a picnic area/parkland downstream. This section had the greatest number of herb species of the Great Ouse sites. The banktop bordering the parkland contained numorous tall grasses; species present included *Capsella bursa-pastoris* (shepherd's purse) and *Achillea millefolium* (yarrow). At the riverside, *Carex* spp. (sedge) and *Glyceria maxima* (reed sweet-grass) were present. This relative abundance of herb species may be as a direct result of management of the neighbouring land. *Ranunculus penicillatus* (stream water-crowfoot) was abundant within the channel for the entire 500m length of the site.

River Nar

The site on the Nar was divided into two sections; section 28 referring to two discrete stretches colonised by *Alnus glutinosa* and *Salix* spp. whilst section 29 included two stretches of straightened river, devoid of trees. The banks of section 28 had not been modified unlike those of section 29 which had been channelised. The water level in section 28 was low enough to expose several silty shoals which allowed for instream colonization by several aquatic and marginal species.

River Ouzel

This 500m site was identified as section 30 and was adjacent to an area of rough pasture. The bank-top supported a single row of *Salix fragilis* (crack willow) at varying intervals along with characteristic thorny scrub. The neighbouring land was fenced-off by barbed wire and bankside vegetation grew within the narrow 1m strip between the field boundary and channel. The herbs of this field-side strip were dominated by *Urtica dioica*. *Nasturtium officinale* (watercress) was present on the right bank of the meander bend where the water shallowed to expose silty substrate.

Padbury Brook

The width of the site chosen along Padbury Brook (section 31) was 8-10m across and the height of bank above water level approximately 2m. Section 31 was located next to several fields of pasture and, towards the upstream end, a private garden. The tree and shrub community included a row of *Populus canescens* (grey poplar) planted in a single row plus bushes of *Rosa canina* (dogrose) and *Crataegus monogyna* (hawthorn) toward the downstream end.

River Tove

Arable fields were adjacent to the site along the Tove. The left bank of section 32 was uniformly steep whereas the right had areas of relatively low angle that extended into the channel. These were stabilized by a thick growth of marginal macrophytes. The banks were generally about 3m above the water level and the width relatively uniform at approximately 9m. The tree community was dominated by juvenile *Ulmus procera* (elm) with only a few mature *Fraxinus excelsior* (ash) and *Quercus* sp. (oak).

River Wissey

The site chosen along the Wissey was a section of river that had been channelized. This 500m stretch was divided into two sections. The upper section (33) was planted with two dense stands of juvenile *Salix caprea* (goat willow). The density of the trees ranged between $6/m^2$ to $15/m^2$. Section 34 was a relatively open stretch with only few widely spaced trees. Channel width was uniform except for experimental pools which had been dug into the bank of section 34 with the intention of increasing habitat potential. The land adjacent to both sections had been left as a buffer strip and was colonised by a dense cover of herbs and grasses. An artificial floodbank separated this floodplain from neighbouring arable land. Vegetation cover was sparse along section 34 since channel alterations had only recently been completed.

THE VALUE OF RIPARIAN TREES TO BIRDS

Introduction

There is minimal information which clearly show the value of riparian trees to bird in the UK. In order to provide such evidence, analysis was made of a river corridor survey initailly conducted to assess the numbers of breeding birds along stretches of the River Ise, Slade Brook and a tributary of Slade Brook.

This census was conducted to establish exactly how many species of riparian and non-riparian bird bred in the corridor, how many pairs of each their were and where they chose to nest. The results were detailed within a summary map giving the the names of all the bird species holding territory in each river section along with habitat information such as adjacent land-use and the presence and location of trees, bushes and hedges. The latter information was used to explore the direct relationship between tree and bush cover and species and territory numbers.

Methods

The technique used for assessing the populations of birds along these river corridors was that developed by the British Trust for Ornithology (BTO) for use in their own Common Bird Census and other national surveys. The surveyed watercourses were divided into 78 sections, each 500m in length. Individual sections had their own set of maps and a code indicating the river/brook and the 500m section to which it belonged. For example, the first section of the River Ise was numbered RISE 001 at Clipston and the last, RISE 059, at Broughton Park near Geddington. The surveyed stretches of Slade Brook and its tributary comprised of 13 and 6 sections and were coded accordingly.

The river corridor was defined as the strip of land 25m either side of the channel since this is the minimum width of bank necessary to accommodate heavy machinery during maintenance work. All birds within this area were recorded for the survey together with those holding territories which overlapped into any part of the corridor. Ponds or marshes occurring within the river corridor were included within the survey as a whole even where these partly lay outside the designated boundary. The edges of buildings were considered to be the corridor boundaries in built-up areas.

The river sections were grouped into stretches which could be surveyed in one day. Surveys were started at dawn and were completed before 11am since bird song and activity tends to die off towards the middle of the day. Each stretch was visited five times and the completed survey involved a total of twenty days of fieldwork. New section maps were annotated for each visit to a stretch of river (the section maps were photocopies of ordnance survey maps).

The aim of the field surveys was to mark the precise location and activity of every bird present but to record each individual only once. The maps were marked using the official BTO species and activity symbols. Dotted lines between individuals known to be different and activities of a territorial nature such as song were particularly useful when it came to defining territories.

The five visit maps from each section were then used to produce a single map for each bird which illustrated all records for that particular species. The species code was substituted for the appropriate visit letter on this map. For example, if ' WR', the code for wren, was recorded on the third visit day to a particular section, this would be replaced by 'C' on the species map. All corresponding activity codes from the visit maps were also transferred to the species map but where the same nest was seen on more than one visit, it was only shown once on the species map to avoid confusion.

The species maps were then analysed to establish the number of territories for each species of a river section. The basic procedure here was to draw a circle around clusters of species codes that appeared to represent the activities of a single pair of birds. This circle was therefore considered to indicate a distinct territory, but not its exact boundaries, and a territory was considered to indicate a distinct pair of breeding birds. A species had to be recorded at least twice on separate visit maps for it to be considered resident and holding a territory within a river section. Records of nests, songposts, territorial disputes between males and dotted lines between species codes were all helpful in separating territories. The species maps showing circled clusters for each river section were then compiled into a single summary map. These detailed the names of all the birds holding territory in that section written at the nest site, if recorded, or else at the estimated centre of territory. Habitat information was also added to these maps, as has already been mentioned. The nature of adjacent land-use and location of corridor vegetation was recorded as accurately as possible onto the section maps. Alterations to the rivers course which had occurred since the publication of the survey maps were additionally noted as were the removal of hedges and woodland which were marked on the maps. Finally, a summary paragraph was written to accompany each section summary map describing the species and their habitats in greater detail.

Table 1. Common Bird Census Codes as used by the British Trust for Ornithology

B	Blackbird	MA	Mallard
BC	Blackcap	MT	Marsh Tit
BT	Blue TIt	MP	Meadow Pipit
BF	Bullfinch	M	Mistle Thrush
CG	Canada Goose	MH	Moorhen
C	Carrion Crow	MS	Mute Swan
CH	Chaffinch	N	Nightingale
CT	Coal Tit	PH	Pheasant
CC	Chiffchaff	PW	Pied Wagtail
CD	Collard Dove	RL	Red - Legged Partridge
CO	Coot	LR	Redpoll
CK	Cuckoo	RB	Reed Bunting
D	Dunnock	RW	Reed Warbler
GW	Garden Warbler	R	Robin
GC	Goldcrest	RO	Rook
GO	Goldfinch	SW	Sedge Warbler
GH	Grasshopper Warbler	SK	Siskin
GS	Great Spotted Woodpecker	S	Skylark
GT	Great Tit	SN	Snipe
G	Green Woodpecker	ST	Song Thrush
GR	Greenfinch	SH	Sparrowhawk
H	Grey Heron	SF	Spotted Flycatcher
P	Grey Partridge	SG	Starling
GL	Grey Wagtail	SD	Stock Dove
HS	House Sparrow	SL	Swallow
JD	Jackdaw	TO	Tawny Owl
J	Jay	TS	Tree Sparrow
K	Kestrel	TC	Tree Creeper
KF	Kingfisher	TU	Tufted Duck
L	Lapwing	TD	Turtle Dove
LS	Lesser Spotted Woodpecker	WH	Whitethroat
LW	Lesser Whitethroat	WT	Willow Tit
LI	Linnet	WW	Willow Warbler
LG	Little Grebe	WP	Wood Pigeon
LO	Little Owl	WR	Wren
LT	Long - Tailed Tit	YW	Yellow Wagtail
MG	Magpie	Y	Yellowhammer

Activity Codes

B	a singing male Blackbird
Bo__________	a male Blackbird giving an alarm call
Bo food	female Blackbird carrying food
Bo mat.	a male Blackbird carrying nesting material
B*	a Blackbird nest
Bo	a male Blackbird - sight record only
B---------B	different blackbirds singing at the same time
B B	a singing Blackbird takes up a new position
B*---------B*	two Blackbird nests in use at the same time

For the purposes of this report, the survey information was used to investigate the relationship between trees and other vegetation types and species richness and territory numbers (per section bird population and not for individual species). The data and summary map information for the 59 sections of the River Ise were used for this comparison. Trees and bushes were separately added to the maps using symbols, likewise lengths of hedgerow that lay within the defined corridor were also indicated. This additional vegetation was used along with areas of woodland already marked. In order to quantify vegetation cover, an estimate of the influence of the vegetation upon a river section was made and recorded as a percentage. Therefore a 100% influence value would represent a river corridor section that is entirely covered by trees, bushes or hedgerow. The percentage influence of trees alone was also recorded for each section.

The species and territory data taken from the survey and the percentage values obtained from the summary maps are represented as scattergrams.

Results

The results of the river corridor survey yielded several important points. Fifty-five species of bird were recorded in the river sections, but only ten could be regarded as being water birds. Moreover the ten most abundant species were all non-riparian species; wren, chaffinch, blackbird, robin, blue tit, willow warbler, yellowhammer, great tit, treesparrow and dunnock. The river corridor thus provides an important breeding habitat for many more birds besides those associated with the water itself. The riparian zone functions as a 'super-hedgerow', providing a breeding ground and corridor for woodland and hedgerow birds. The river is of obvious importance to water birds and rarer species such as the kingfisher and grey wagtail were recorded along several sections.

The species and territory data were also analysed to establish which of the River Ise sections were the best. A simple Z test was used to identify the river sections that held significantly more species and territories than the mean number. Three sections were identified as being significantly important for both the numbers of breeding species and for the number of occupied territories. All three of these river sections are bisected by other linear features such as a road or railway. This had led to small areas of neglected or less intensively used land and field corners remaining adjacent to the river. These areas, although relatively small, provided varied habitats. Section 9, for example, which had the greatest number of bird species, occurred where a road and disused railway-line crossed the river. At the crossing point, small corners of a variety of habitats had been left. Here, patches of woodland, scrub, wetland with marsh and pond and areas of rough herbage were all represented together with a few large, standing dead trees. It was undoubtedly this diversity of habitat that was responsible for the species richness.

The values for percentage vegetation influence against species showed a strong relationship (Figures 1 and 2). The correlation coefficients (r) for each graph are all significant; the relationship between tree, bush and hedge influence and territory number being the most significant.

Figure 1. Percentage vegetation influence against bird species richness per section

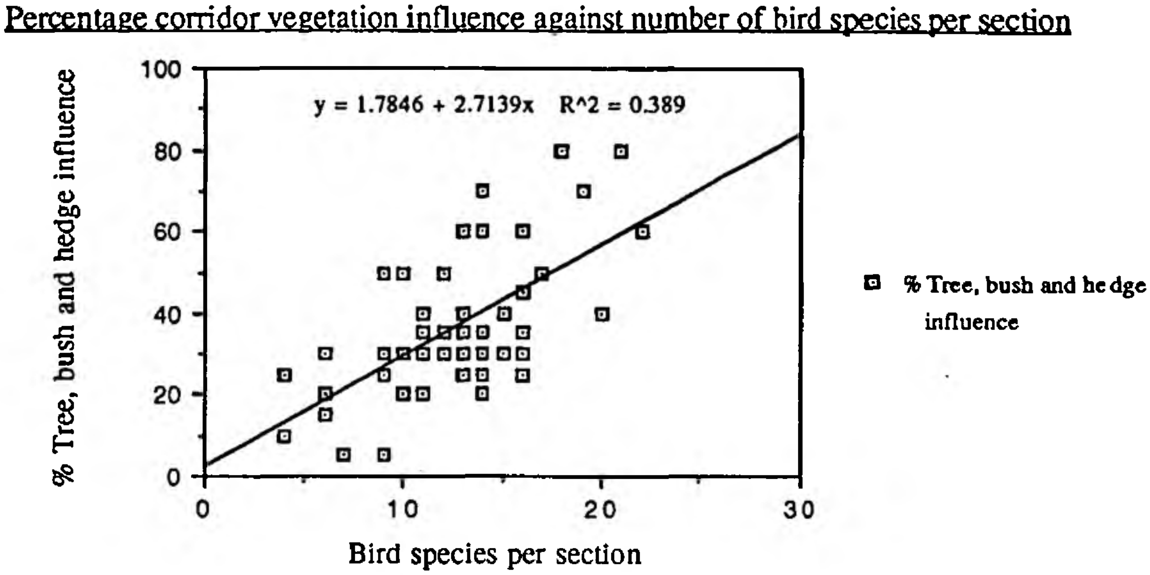


Figure 2. Percentage tree influence against bird species per section

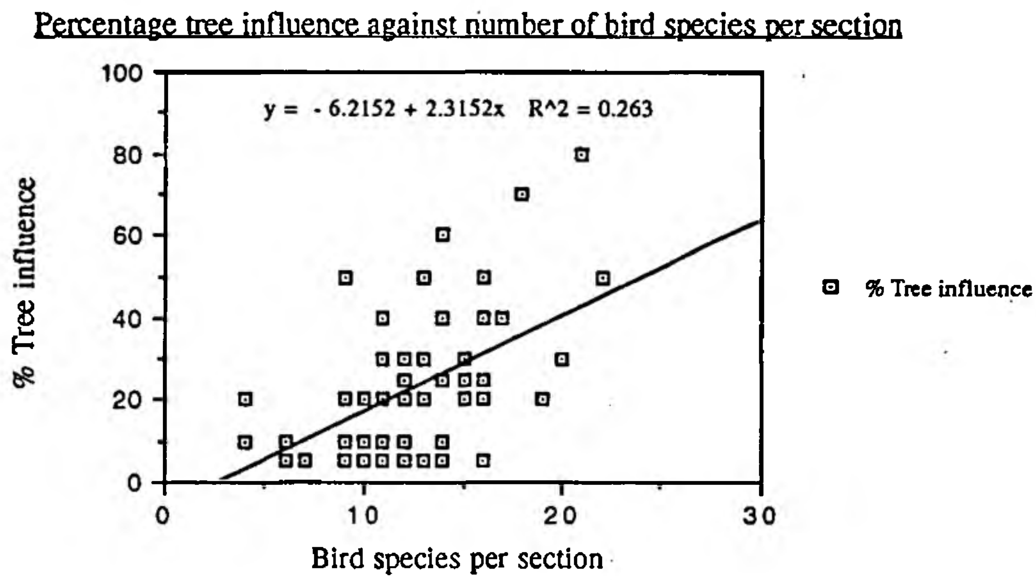


Figure 3. Percentage vegetation influence against total number of territories (all species) per section

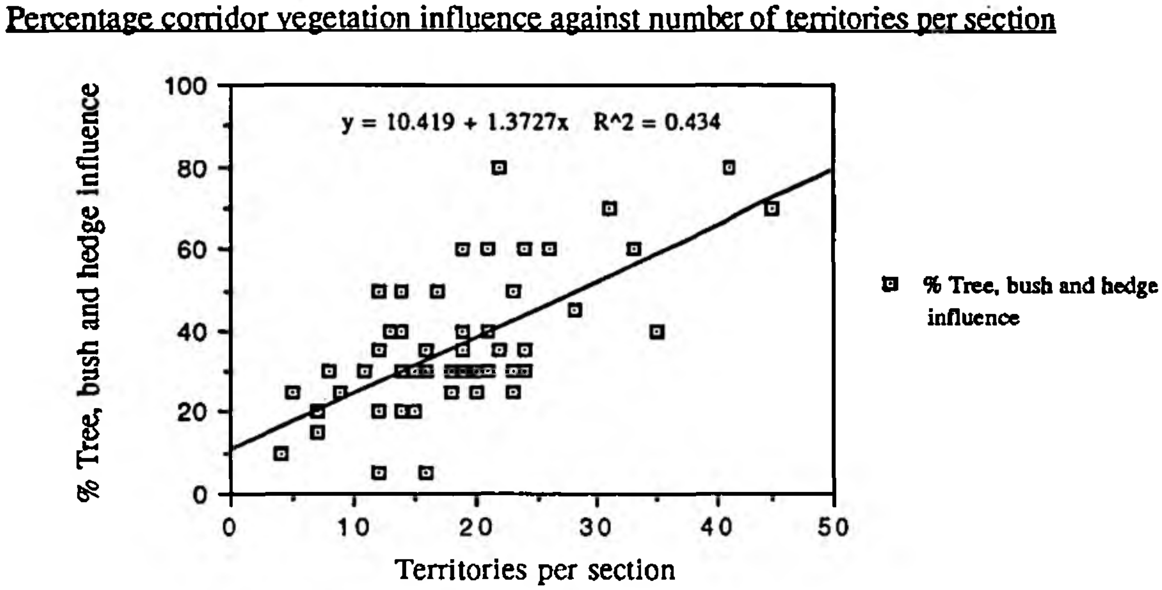
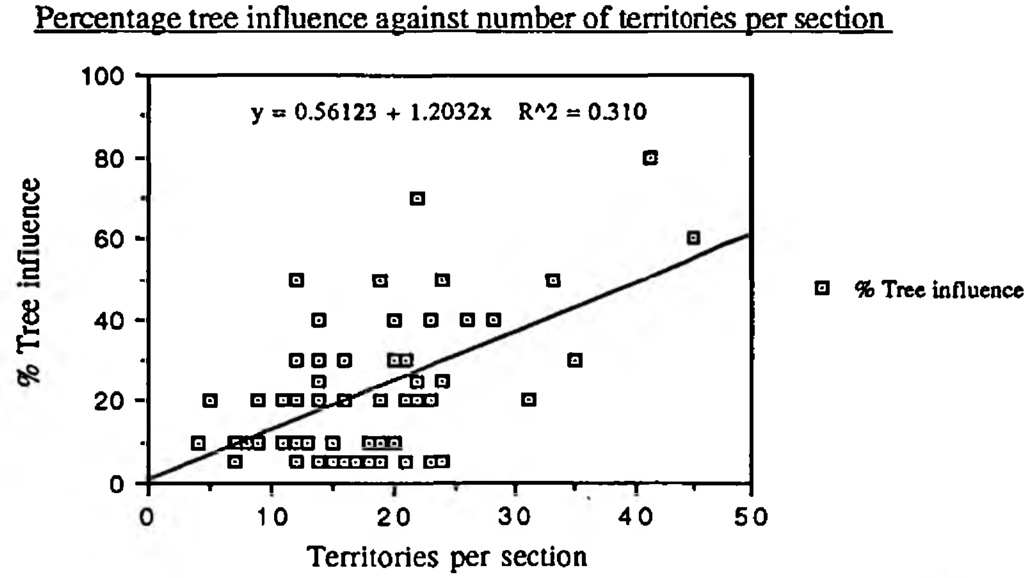


Figure 4. Percentage tree influence against territories (all species) per section



The relationship between percentage tree influence and bird species and territory number is less positive than for the comparison with the combined influence of trees, bushes and hedges. This might indicate that the presence and variety provided by the latter is more important in determining the numbers of breeding birds than the extent of tree cover alone. Whereas it might be assumed that territory is related to the physical abundance of suitable habitat type, the number of actual species attracted to a site is perhaps dependent upon habitat variety. This is perhaps reflected in by the stronger correlation between corridor vegetation cover and territory number. This analysis may therefore have yielded more useful results had the habitat information been more detailed and included species composition. Although all four correlation coefficients (r) were significant, it must be remembered that percentages were used instead of numerical values which lends these results less weight.

Riparian trees are therefore important for water birds and also non-riparian species where few other suitable wooded habitats are present in the surrounding areas. The results of the survey indicate that habitat diversity, however patchy, is necessary to attract the rarer species and not just the commoner birds.

Discussion

There are few direct studies of a similar nature with which these data can be compared in the U.K., although there are probably numerous survey data such as RCS and BTO records which probably contain such information awaiting analysis. Studies outside the U.K., such as Wegner & Meriam (1979) and Dmowski & Kozakiewicz (1990) have focused on the role of riparian or hedge as movement corridors and demonstrated importance for both birds and mammals. Several mammal species show clear association with riparian woodland corridors; *Clethrionomus glareolus* was found to be more closely associated with riparian woodled strips than either woodland or fields whilst *Apodemus sylvaticus* was found to move actively along the riparian zone (Bonner 1993)

Other data which make a useful comparison are those for species-area relationshiops for small woodlands. Such data can be related to the analyses of this survey which highlighted the small patches of scrub in three sections as species richness 'hot spots'. Warrilow (1989) in a study of a number of different-sized woodlands in Leicestershire, showed that there was an exponential rise in species richness with woodland area which quickly levelled off between 0.5 and 1 hectare. This he interpreted this in terms of the 'edge', or ecotone-effect which is known from several other studies to enhance species richness compared with the middle of two adjacent communities. The NRA is not usually involved in the management of larger woodland blocks, but smaller riparian areas may well fall within this 1 ha scale. It could thus be a valauble and practical guideline that riparian woodland, scrub or compensatory planting units should aim to be 1 ha in size wherever possible.

THE VALUE OF RIPARIAN TREES TO THE AQUATIC INVERTEBRATE COMMUNITY

Introduction

The literature review discussed concepts of stream ecology, most particularly that of the the driving force of external energy supplies in the form of woody debris, which were developed in US forested stream systems with relatively minor human impact. There have been no studies in the UK which test these theories in the context of lowland stream systems in agricultural catchments. A number of small lowland streams was therefore studied to see whether they conformed to the 'River Continuum Concept' and the extent to which trees influenced their biology.

Several linked investigations were undertaken:

- The first study investigated the downstream distribution of invertebrate feeding guilds in several streams. The hypothesis pursued was that the importance of the guild associated with leaf processing dominant in wooded headwaters – shredders – would be low in lowland headwaters without trees compared to those with trees.
- The second investigated the geomorphological effect of riparian trees by comparison between a stream with continuous tree cover and one with sparse tree cover. The null hypothesis was that the geomorphological impact of trees would be unimportant, and features such as debris dams infrequent.
- The third study considered the effect of trees upon habitat and biological diversity. The null hypotheses tested was that aquatic 'functional' habitats associated with riparian trees – leaf packs, tree roots, woody debris – would be no different from other habitats within the stream, or would be functionally replaced by other kinds of habitats - such as debris from emergent macrophytes.

Methods

Standard net sampling for invertbrates was used in first- and second-order streams in the Welland catchment in Leicestershire. Invertebrates were collected and recorded intially to families from each potential habitat, defined as a substrate type, a vegetation type or a debris type.

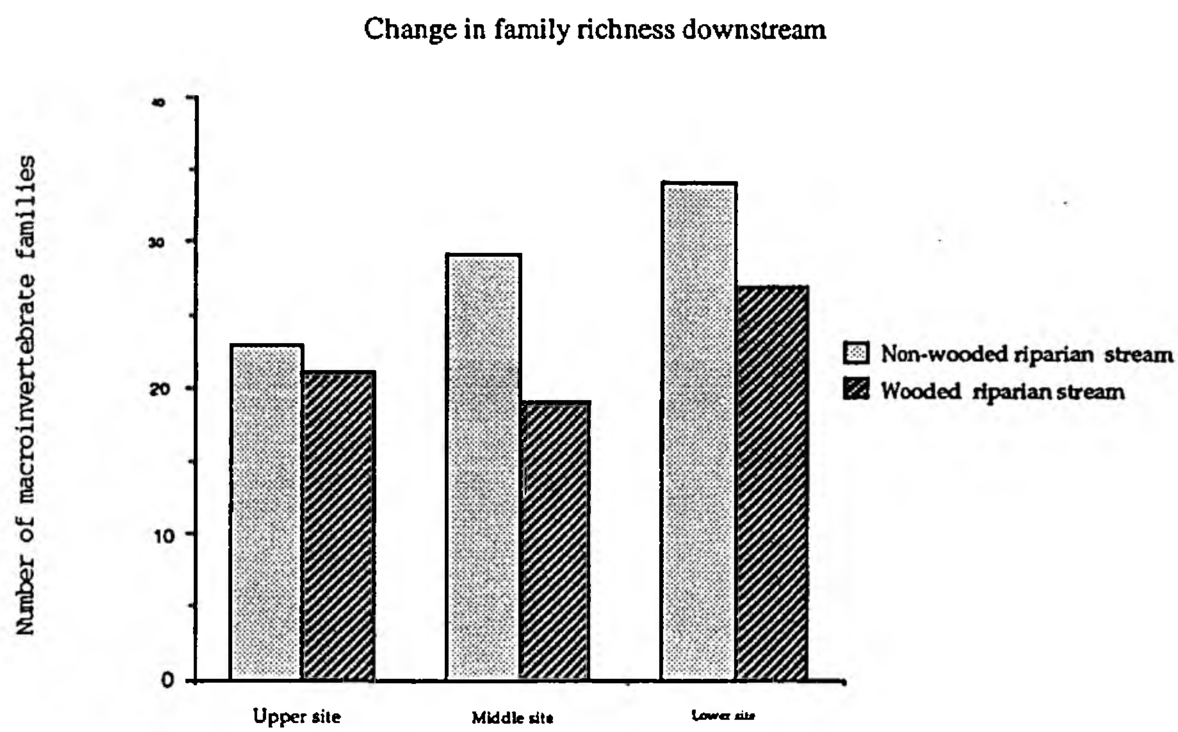
Recods and diagrams were made of potential habitats and all kinds of organic debris, both woody and non-woody, in stretches of stream 50 m in length. The following were recorded:

- pools, riffles, runs
- scoured, undercut or collapsed banks
- sand and silt banks, bars or islands
- sediments as: boulder, cobble, stones, gravel, sand, silt, clay
- vegetation types as: tree roots, trailing branches, trailing bankside plants, emergents in-channel, broad-leaved submerged, fine-leaved submerged, algae, floating, floating-leaved.
- debris types as leaf packs, small woody (twigs), large woody (branches), debris dams, log dams.

Results

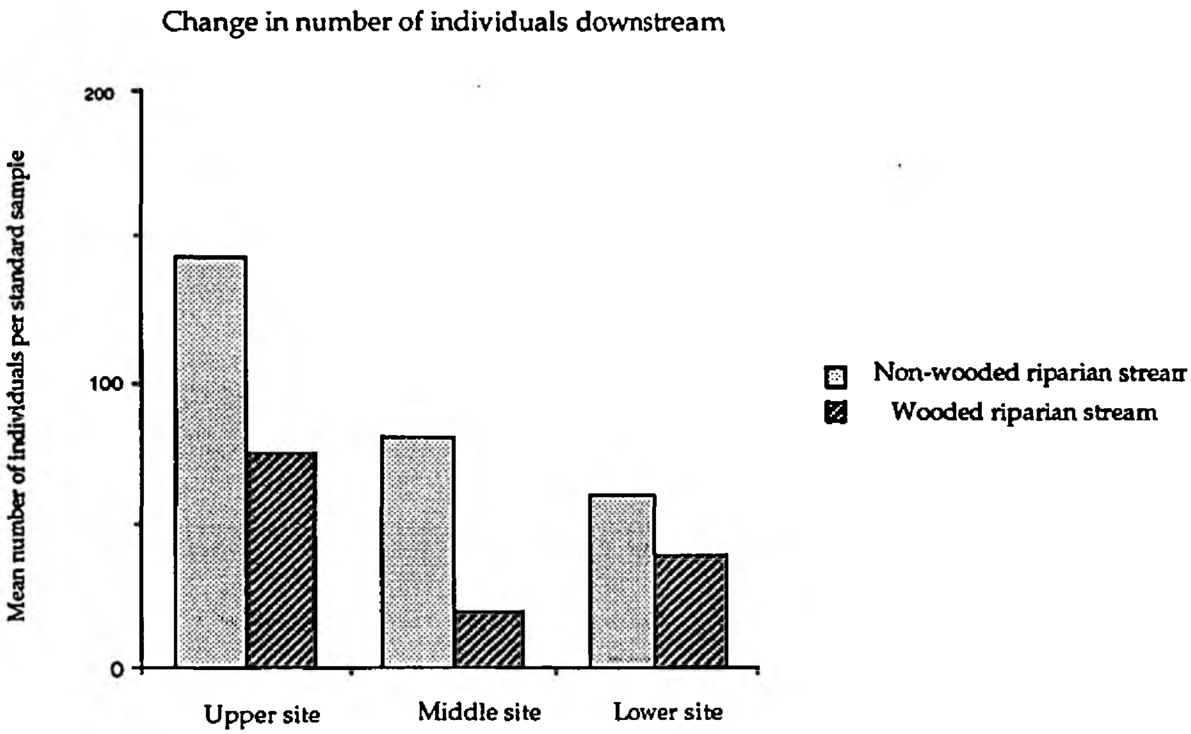
In both headwater streams, lower taxonomic diversity was found compared with downstream locations (Figure 1).

Figure 1. Increase in family richness with passage downstream in both wooded and non-wooded headwater streams



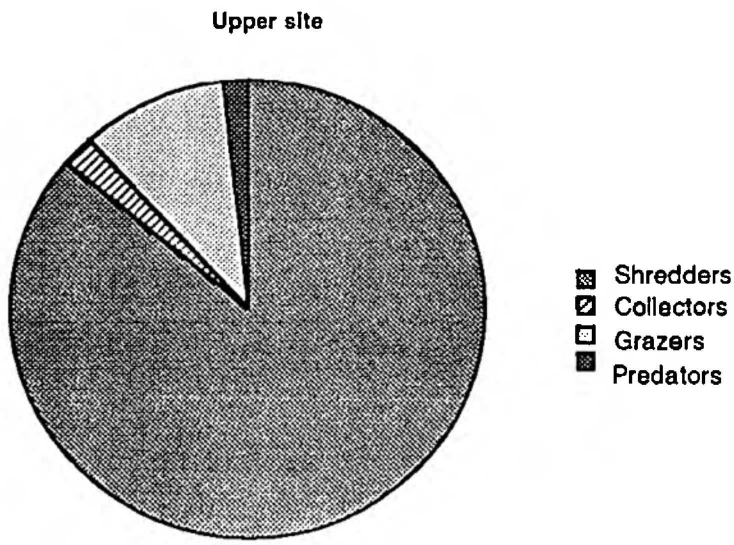
This was combined with a greater abundance of invertebrates (Figure 2), usually dominated by species such as *Gammarus pulex* or limnephilid caddis larvae.

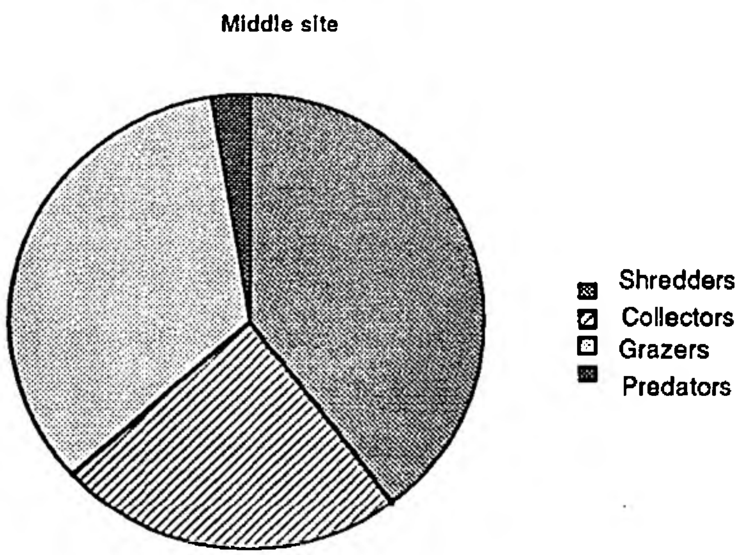
Figure 2. Reduction in abundance of individuals with passage downstream in both wooded and non-wooded headwater streams



In both types of headwater stream, these abundant species at the uppermost sites are shredders – invertebrates adapted to the processing of decaying plant material. There was a progressive decline in the importance of shredders overall with passage downstream, and again this was similar in both streams (Figure 3). The dominance of shredders in both tree-dominated and open streams (Figure 4) is due to the source of organic material in the latter being riparian grasses and agricultural sources (eg. straw).

Figure 3. Change in proprtion of feeding guilds with distance from source in the wooded stream





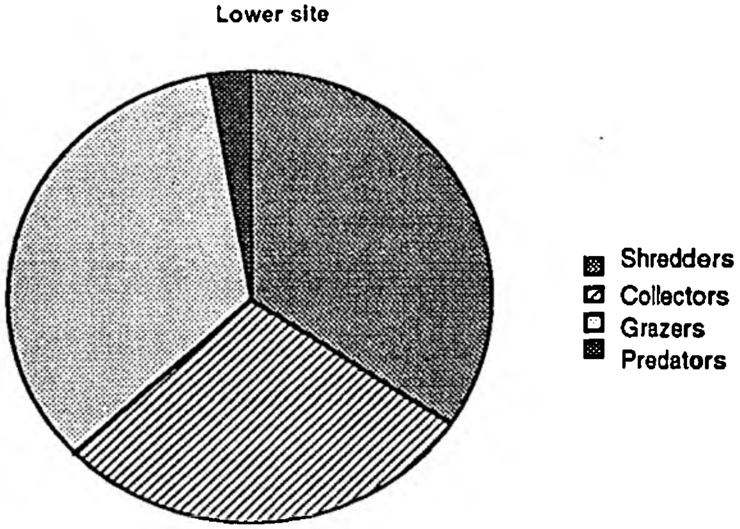
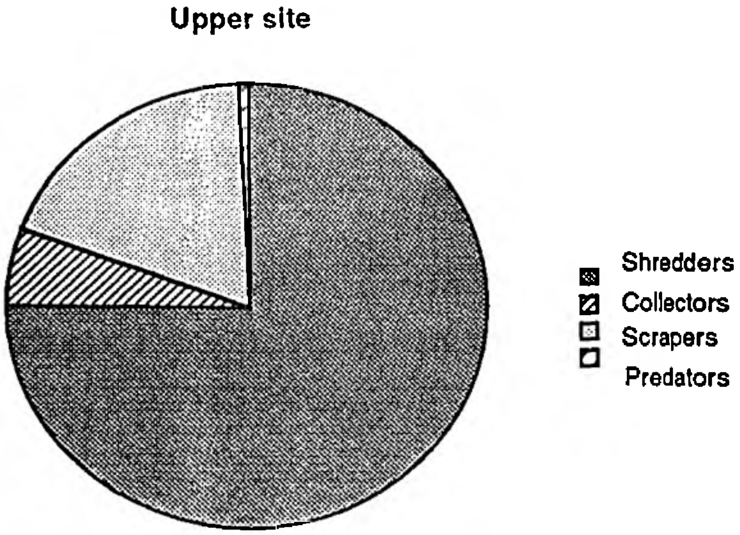
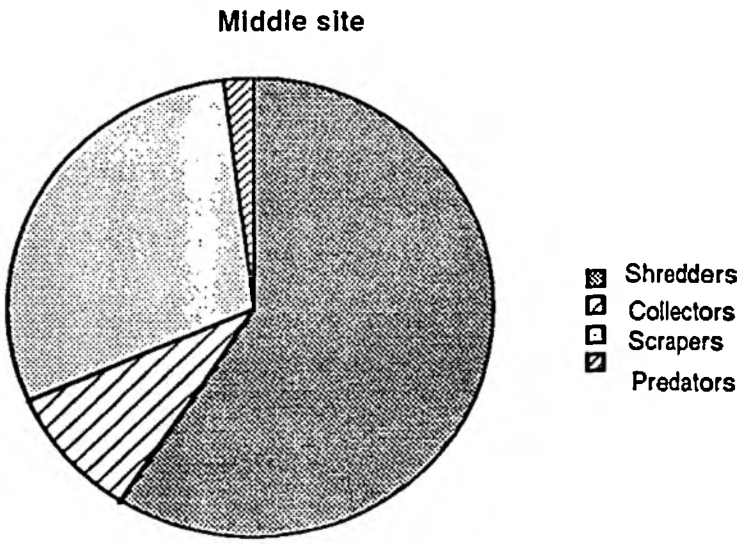
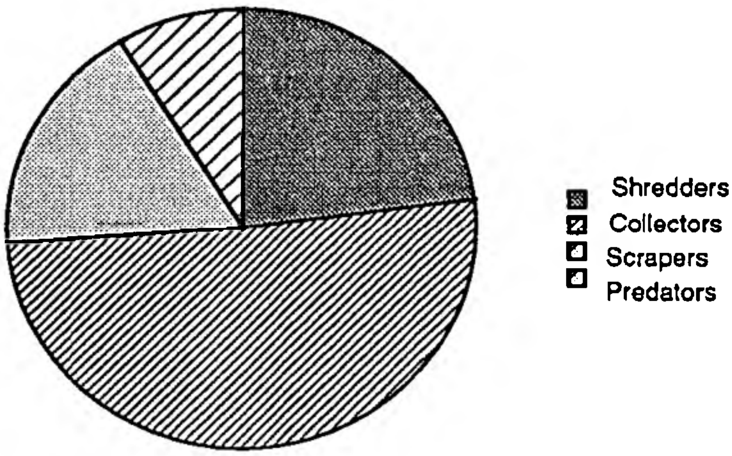


Figure 4. Change in proprtion of feeding guilds with distance from source in the non-wooded stream





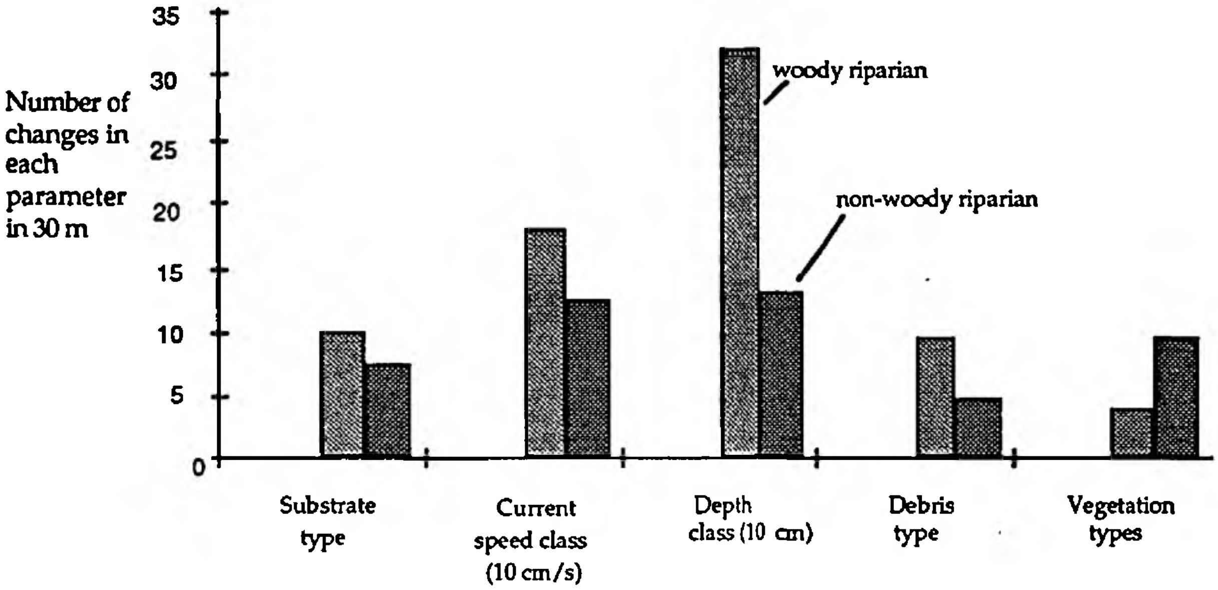
Melton



The proportion of shredders decreases with distance downstream more slowly in the stream with riparian trees than that without, but there is no evidence that there is a decline in total quantity of coarse organic matter which causes this shift; it could equally be an increase in fine particles, as occurs for example from sewage effluent.

Despite the inconclusive results from the comparison of family richness and functional changes, there are some clear differences. In physical structure, the wooded stream sites are generally more varied, with frequent changes in character (Figure 5).

Figure 5. The number of changes in aquatic vegetation type, detritus type, current speed class and depth class in a 30 m stretch in the two stream types.

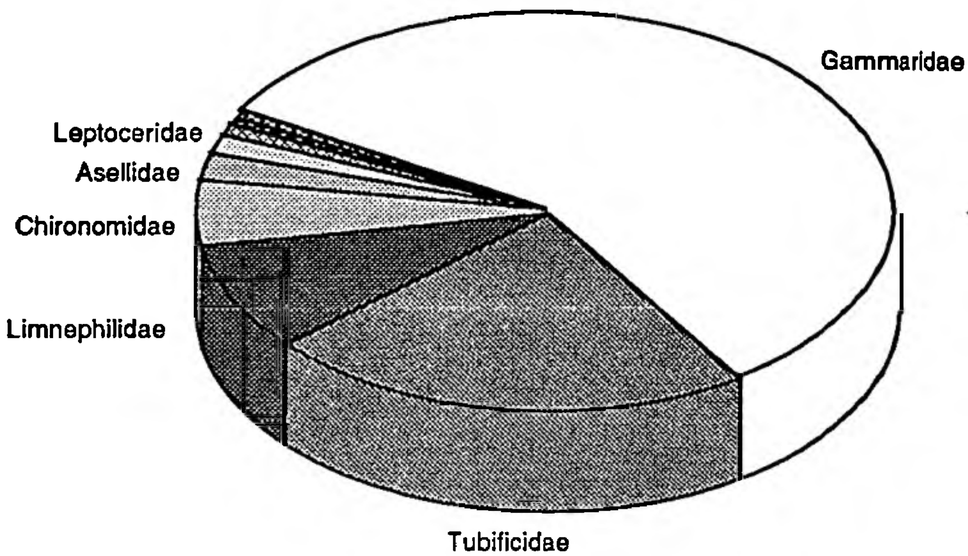


In taxonomic composition, there are distinct families associated with the wooded sites, typically detritivores such as Taeniopterygidae (Plecoptera) and cased caddis families such as Limnephilidae and Phryganeidae. The downstream site on the non-wooded stream, recording the highest taxonomic richness (34 families) did so because it contained a number of families associated with lower reach macrophyte beds, such as odonata families. There is some evidence from elsewhere that one impact of tree removal and the opening of streams to light is to shift their invertebrate communities to a more 'downstream' character, and these results may provide evidence for this change.

Detailed analysis of the family composition of individual habitats within the stream channel shows that detritus-based habitats do play an important role in maintaining richness, providing distinctly different communities than main-channel large particle habitats or the slack fine particle habitats. Examples are shown in Figures 6 and 7.

Figure 6. Examples of the family composition of habitats dependent upon riparian trees

Leafy debris in shallow sluggish water



Matted tree roots (Salix, Alnus) in shallow edge

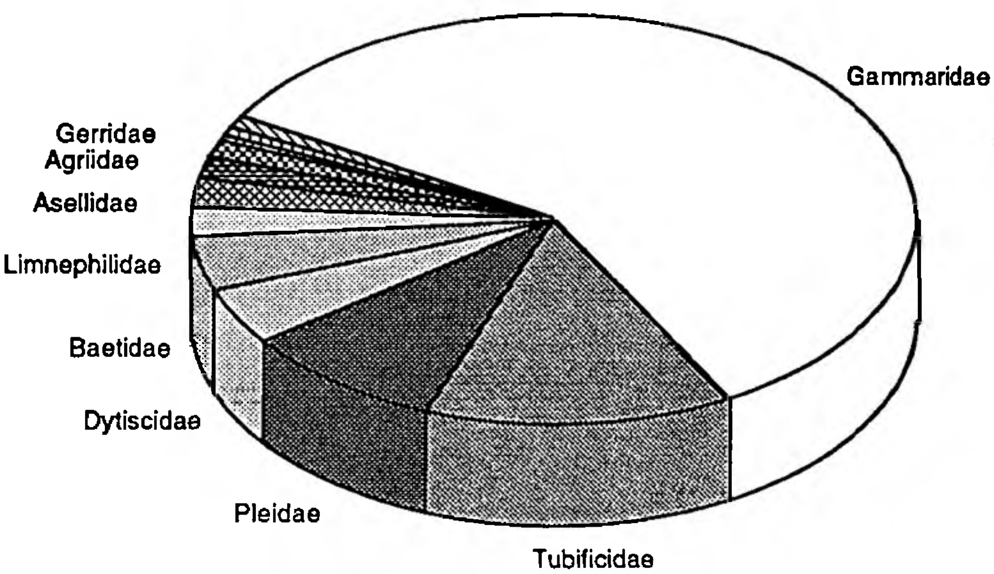
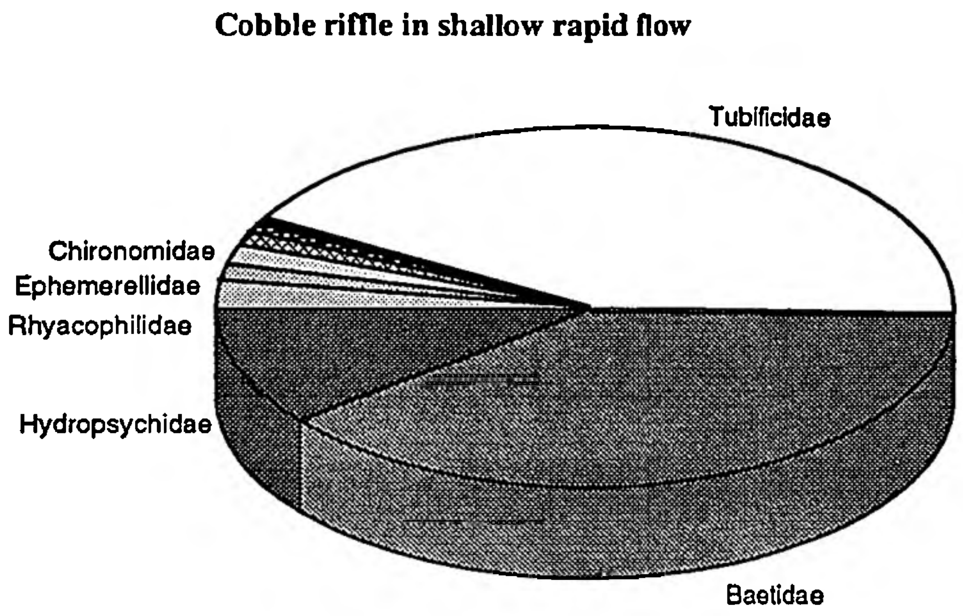
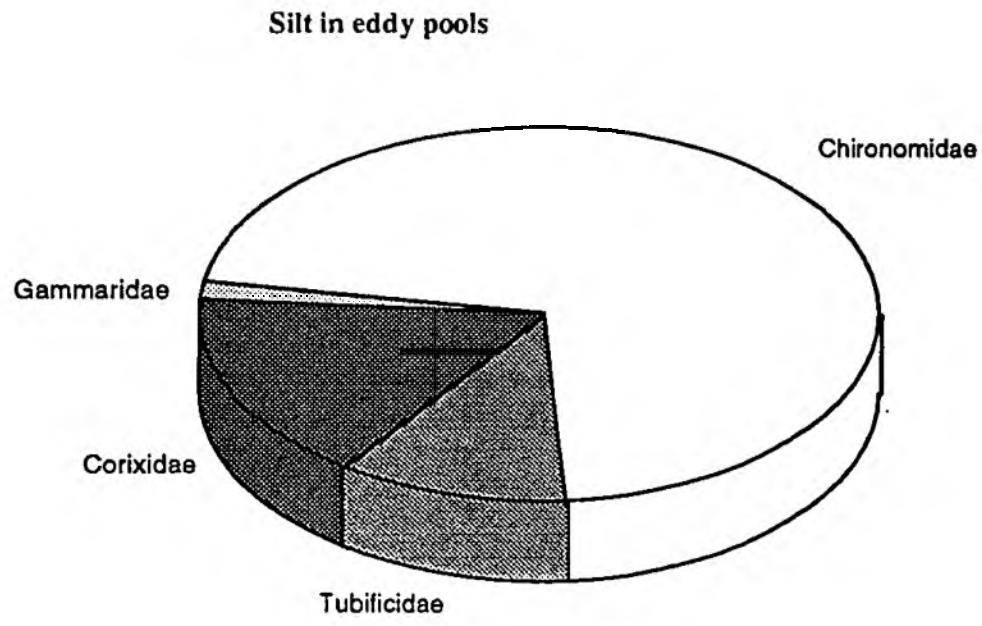


Figure 7. Comparative family composition of main river habitats - riffle and pool





The indications from these studies, which are continuing with greater taxonomic analysis and more extensive field work, are that trees provide clear functional habitats with distinct assemblages of species and greater abundances than other habitats. They are not a substitute, rather they are part of the 'full complement' of headwater stream habitats.

PRACTICAL ASPECTS OF RIPARIAN TREE MANAGEMENT

Current County Council landscape policy

The following section examines the landscape policy and schemes to promote waterside management and tree planting of the six County Councils that lay within the Great Ouse catchment.

Bedfordshire

It is the policy of Bedfordshire County Planning Department to retain and manage riparian trees wherever possible. This policy extends to trees and coppices at some distance from river banks which are also of high landscape and wildlife value. They advise that, where access is required for operational work, bankside trees should be coppiced and pollarded in preference to their complete removal. If the latter is unavoidable, replacements for the removed trees are expected to be planted when work has ceased.

Grants available for small scale tree planting, woodland regeneration, pollarding, coppicing and pond restoration are available under Landscape Conservation Grants. This scheme provides a 40% level of grant aid to a maximum of £500 per scheme. Such a grant is not available where the proposed work is a condition of planning permission.

Northamptonshire

General policy towards trees in the county of Northamptonshire is set out in the Environment Section of the County Structure Plan. The County Council undertakes to promote the retention, enhancement and sympathetic management of habitats of ecological and landscape importance. Specific protection for trees can be afforded by Tree Preservation Orders, acquisition and management agreements made by the local planning authorities. Policy towards riparian trees in particular is not set out although the document states that planning permission for development in floodplain areas will not normally be granted where the nature conservation of a river valley would be 'materially affected'. The recent decline in the number of trees within the county due to a combination of old age, disease, poor management and modern farming methods has prompted a number of tree planting schemes. 'Conservation Grants for Farmers and Landowners' is one such project. Under this scheme, up to 50% of the total cost of planting is met by the Council provided that the trees can be readily seen by the public from roads and rights-of-way. Furthermore, planting proposals must be approved and judged to be suitable by the

Planning Department. The scheme covers planting proposals from a single tree to sites of up to 0.25 ha. Other conservation work can also be proposed and the same level of financial assistance be given. These include management of small woods, replacement and management of groups of trees which form important landscape features, creation and restoration of ponds and pollarding of riparian willow and alder.

Norfolk

'Grants for Countryside Conservation' are available for tree planting from Norfolk County Council. The conditions of the scheme are basically the same as for Northamptonshire County Council in that areas of land must be less than 0.25 ha and all work must be approved. Similarly, other landscape conservation work eligible for grant aid includes amongst others farm woodland management and pollarding. The level of grant for such work however is up to 40%. A 'Landscape Improvement Project' was set up in South East Norfolk in response to the particularly severe tree losses sustained in this area during the major storm of 1987. This project differs from the other grant scheme in that financial assistance is given for the rehabilitation and restoration of storm damaged woodland and other habitat types. Both schemes require the landowner to maintain trees and replace losses for the first five years following planting.

Buckinghamshire

Buckinghamshire County Council offer 'Conservation and Landscape Rehabilitation Grants' similar to the above Councils. Up to 50% of the labour and material costs of tree planting, small wood management and conservation of other landscape features are met by the Council. The latter including the pollarding or repollarding of riparian willows and alders since these are considered aesthetically important features of the Buckinghamshire countryside. Top-up grants are also available for landowners in receipt of forestry Commission planting grants for new woodland (it is the Forestry Commission that provides grant aid for woodland planting over 0.25 ha). The Council will pay an extra £300 per hectare provided that the proposals comply with the Buckinghamshire Forestry Strategy, in outline; the maintenance and enhancement of existing landscape pattern, provision for nature conservation and allowance for possible future public access. The Council acknowledges the need to replace woodland and revitalize management practices and has a long term strategy to take the county into the next century.

Cambridgeshire

The 'Rural Strategy', published in 1988, set out to describe how Cambridgeshire County Council would guide future changes in the use and management of rural areas in the county. This report was extended to produce 'Landscape Guidelines' for Cambridgeshire giving theoretical guidance to those who influence the countryside (planners, engineers, developers, landowners) (Anon, 1990a). Since past flood alleviation and drainage operations have been gernerally unsympathetic to river corridors, the report outlines procedures for drainage engineers to lessen the impact of future works. The need is to design schemes that, whilst achieving engineering goals, will be sympathetic with the wider landscape setting and indigenous wildlife. A creative rather than blanket approach to river engineering is advised. The report also identifies distinctive landscape areas within Cambridgeshire at present, one such 'Character Zone' being the Ouse Valley. The authors propose guidelines for enhancing the valley suggesting the creation of a riverside landscape corridor through the allocation of zones 10m-30m wide and increasing where possible up to 200m or more either side of the river. Within these zones, willow, poplar and alder could be planted and characteristic riparian habitat created (marsh, wet grazing meadow and shallow margins with aquatic macrophytes). Copses could also be established within larger zones and riverside hedgerows enlarged to create larger scale landscape structures. The report proposes that such innovations could be included within farm landscape plans given that the landowner is allocated some financial assistance.

The County Council's advisory service, The Rural Group, provide Countryside Tree Packs for sites up to 0.25ha. These packs contain native trees and shrubs suited to different localities for which the landowner must make a contribution of between £45-£80. To be eligible, the chosen site must be prominent within the landsape and visible to the public; adjacent to roads and public rights of way, on the edges of towns and villages or around isolated buildings in open landscapes.

Suffolk

Suffolk County Council Planning Department operates nine targeted grant schemes for Landscape Conservation. Farm Conservation Plan Planting, Waterside Landscapes and the Anglian Woodland Project are three such schemes. Eligible work for the Waterside Landscapes scheme includes the desilting of farm ponds and pollarding and replanting of riverside trees. The Anglian Woodland Project gives grant aid to farmers for coppicing and ride management in farm woodlands that are less than 4 hectare. Where replanting is required over an area less than 0.25 hectare then the grant would also cover this cost otherwise a Forestry Authority grant would have to be sought. The Farm Conservation Plan Planting scheme allows farmers to plant on farms of more than 20 hectares with a Farm Conservation Plan approved by the County Council. The level of financial support is 40% and the general conditions for applying for grant aid and carrying out work is the same as for other County Councils.

Other sources of grant aid for conservation and management

Financial assistance can also be obtained from statutory bodies such as the Ministry for Agriculture, Food and Fisheries (MAFF), the Forestry Authority and the Countryside Commission. The Farm and Conservation Grant Scheme is one of several schemes promoted by MAFF. They provide 40% of the cost of planting shelterbelts and hedgerow for farmers. The Forestry Authority operate several grants under their Woodland Grant Scheme. The Established Grant is given for planting, restocking and natural regeneration on areas normally over 0.25ha and 15m wide. This 'base' grant is fixed at certain banding levels depending on size of area and whether conifer or broadleaved trees are intended to be planted. Supplementary grants can be also be awarded where certain other criteria are met, for example, planting on arable land or improved grassland and planting new woods for informal public recreation.

Countryside Stewardship is an initiative of the Countryside Commission undertaken in collaboration with English Nature and English Heritage. This scheme offers management agreements to farmers and land managers to enhance and conserve certain targeted landscapes and their wildlife habitats. Eligible individuals enter into a 10-year agreement whereby they receive annual payments. A proposal is accepted if it offers good potential for achieving environmental and recreational improvements. One such targeted landscape is the waterside landscape. Grant aid is given for the re-creation and conservation of wetland and waterside landscapes such as alder/willow carrs and reedbeds.

Commoner riparian tree biology

The following is a species account of some of the commoner riverine trees found in Britain and more specifically in the lowland areas. However there is only a brief selection of willow and poplar species due to their extensive hybridisation. There is also a section on some of the growth characteristics of willow and alder which enable them to survive in saturated conditions.

Family Salicaceae - willow and poplar

The family Salicaceae consists of the genera *Populus* and *Salix*. The family has an extensive distribution worldwide and many species are native to Great Britain.

Salix

Salix (willows, osiers and sallows) hybridise very easily and there are approximately 300 to 500 species, the great majority of which are found in the temperate or colder climates in the northern hemisphere. *Salix* range from alpine shrubs a few centimetres high to trees 18m or more, the larger species occurring along streams and rivers or in swampy areas. Trees of this genus will grow on most soils providing there is an ample supply of water. They are dioecious trees, that is they have sexes on different plants, and their stems have remarkable regeneration powers especially when leafless. *Salix* sticks pushed into suitable ground quickly take root and have a very rapid growth rate. Willows are vulnerable to many diseases and pests. Insect pests are numerous and include willow aphids which cause wood staining, distortion and ultimately death.

Salix alba - 'White Willow'
White willow is found in lowland regions from western Europe to central Asia. In Britain it is both a native and planted species of riversides and watermeadows. In lowland areas of eastern Britain and Ireland white willow is locally common by rivers and streams but becomes scarcer moving westwards across the country. It is a vigorous, fast-growing tree found on richer soils and can grow up to a height of 25m. It is however often pollarded.

It frequently hybridises with other species and there are many described variants, the most common in England being the cricket bat willow (*Salix alba* var *caerulea*). This is a willow of vigorous growth and is wide-spread and common in south-east England from East Anglia to Hampshire, preferring deep, moist lowland soils. It originated in Norfolk about 1700 and it is now frequently planted to combine environmental enhancements together with some economic benefits.

Salix cinerea - 'Grey/Common Sallow
Salix cinerea ssp. *cinerea* , the grey or common sallow has a wide distribution throughout Britain and in the fenlands of South and East Britain. It is native and abundant in Norfolk in damp woods, marshes, fens and carrs. *Salix cinerea* spp. *olefolia* (the rusty sallow) is abundant everywhere in Britain except in Norfolk and the surrounding counties where it tends to be replaced by *cinerea* spp. It grows on acid or base soils by streamsides, edges of bogs and marshes, moist woodland margins and hedgerows.

Salix caprea – 'Goat Willow'
A small tree or shrub, one of the first willows to flower in spring and widespread; often found as a colonist of waste ground as well as streamside habitats.

Salix fragilis - 'Crack Willow'
Crack willow is a large tree growing up to 27m with widespreading branches. It can frequently be found by streamsides and on wet ground throughout the south-eastern counties of England and the Midlands. It may be native to south-east Britain.

Salix pentandra - 'Bay Willow'
This willow grows as a shrub or small tree up to 7m high. It is frequently found by streamsides and on wet ground at low altitudes in northern Britain but is probably not indigenous south of a line from Aberystwyth to Yarmouth. Bay willow is rare in East Anglia.

Salix purpurea - 'Purple Willow'
Purple willow is a shrub of up to 5m, native and widely distributed throughout Britain. It is frequent in East Anglia by streamsides, fens and damp woodlands.

Salix triandra - 'Almond Willow'
Almond willow is a tall shrub or small tree from 4 to 6m, locally abundant south and east of a line connecting the Humber and Severn esturaries. It is both native and planted and is quite common in East Anglia by streams, woods and osier holts.

Salix viminalis - 'Common Osier'
This willow is a large, vigorous shrub or small tree up to 6m in height. It is a very common native species of rivers, streamsides, lakes and marshes, perhaps indigenous in eastern and central England.

Populus
Poplars are both deciduous and dioecious. They are surface rooting trees that will mostly thrive on all soil types but prefer a reasonably good soil and an ample water supply. In clay soils the extensive root system and high transpiration rate results in soil shrinkage. In shallow chalky soils most black poplars become chlorotic and can die within 30 years of planting. Poplars prefer better drained soils to willows which are only periodically flooded. They sucker extensively but are intolerant of competition and have a relatively short life span. Most poplars though are tolerant of atmospheric pollution and can be coppiced. Poplars hybridise readily and many hybrids are even more vigorous than their parent species.

Main pests of the poplar include the poplar borers. These are a species of Longhorn beetle of the genus *Saperda* which can penetrate the bark, enter the wood and effectively girdle and kill the tree. Grubs of the Poplar Leaf Beetle (*Chrysomela populi*) can also reduce the leaves to skeletons, severely retarding growth.

Populus alba - 'White poplar'
This is either a native or anciently introduced non-woodland tree growing up to 30m. White poplar can survive on chalky soils and is resistant to salt and winds. It only infrequently

occurs in Norfolk and surrounding lowland counties.

Populus tremulus - 'Aspen'

Aspen is a native tree commonly growing throughout Britain up to 20m high on river gravels and mountain screes, where it suckers freely, helping to consolidate the soil. However these suckers are not formed in dense shade. It is a weakly competitive tree living less than 50 years. Seedlings germinate within a week, if at all, and for an extended period are vulnerable to drought.

Populus nigra - 'Black Poplar'

The true European black poplar is native to Britain in the form of var. ***betulofolia***, the downy black poplar, but many of the true black poplars have been to a greater extent supplanted by hybrids of balsam and black poplar. The black poplar is the largest poplar in Britain growing up to 35m. It is native along river valleys in Britain south of the Mersey and Humber and is an introduced species in Cornwall and West Wales. The black poplar likes deep, moist lowland soils and is widely but sparsely distributed along river valleys in most of south England. It was once the most common farmland tree in east England.

One variant is the Lombardy poplar (*Populus nigra* var. *italica*) which is a large, narrow, columnar tree which is particularly good for screening. However it is prey to many diseases, the most serious being a bacterial canker caused by the bacterium *Aplanobacter populi*. It occurs occasionally in Norfolk as a planted tree.

Family Betulaceae - alder and birch, genus *Alnus* (alder)

Alder is a monoecious tree which grows up to 40m high. Primarily a pioneer and an opportunist species, it is native to Britain and is common throughout the British Isles except Shetland, growing up to an altitude of 1600ft. Alder grows on permanently and seasonally wet soils provided that the water is not stagnant. Therefore it is commonly found in wet places in woods and by lakes and streams. It can grow in both mineral soils with a highly drained surface and on amorphous, highly organic soils with a permanently high water table. Alder will also grow in soils from pH 3.4 to 7.2 but appears to be more tolerate of strongly acid peat in eastern England.

Wet valley alderwoods occur by rivers and streams forming a narrow fringe, often within other woodland types. Trees such as maple, birch, wych elm and oak cannot survive where the water table is permanently at or near the surface. Alder however often thrives alongside *Salix cinerea* and *Salix fragilis*.

Three subtypes of alder woodland have been classified (Peterken 1981):

- Sump alderwoods found in depressions where the water movement is mainly up and down. The alder carrs of the Norfolk Broads is an example.
- Base-rich springline alderwoods of small stream valleys and gentle slopes below springs where the water movement is mainly lateral. The soil usually is more alkali than pH6. These type of alderwoods are common in the Weald, south-west England and parts of East Anglia.
- Base-poor springline alderwoods which are similar to subtype 2 but grow on soils of approximately pH5. These woodlands are common in Wealdon Sands.

In Britain, young alder plants can often be found on the sand and shingle of the inner side of meander bends and mature trees on the eroded outer banks. Saplings are usually found on riversides within reach of spates. Alder seedlings are very vulnerable to drought within their first summer. Where seeds fall onto free draining soil, dessication of seedlings may occur unless there are floods close to the time of germination.

The other trees commonly found in river corridors are treestrial species growing away from the more saturated soils: the common hawthorn (*Crataegus monogyna*), elder (*Sambucus nigra*) and ash (*Fraxinus excelsior*).

Adaptations of riparian trees to saturated conditions

Trees that grow by the waterside have to be able to cope with fluctuating water levels, from long term waterlogging to periodic flooding. Most native trees can survive some degree of waterlogging. They are few however that can survive permanent inundation.

Soil that has a high water table is poorly aerated due to the displacement of air by water in the soil spaces. Micro-organisms and plant roots also deplete the oxygen dissolved in the soil water. The height of the water table therefore restricts the rooting depth of plants and hence reduces the volume of soil exploitable for water and nutrients. Waterlogged soils are also nutrient poor due to leaching and dilution.

In poorly aerated soils alder rootlets become mycorrhizal, effectively increasing the surface area of the root system (McVean 1956b). Alder also develops root nodules containing nitrogen fixing bacteria which allows it to utilise atmospheric nitrogen. Nodules are however not found far below the normal water level where the soil is completely anaerobic. A high water table therefore loses the tree some benefit of its nitrogen fixing organisms.

If the water table rises above the soil surface alder generally produces adventitious roots from the bole. Heavily branched and spongy, like other submerged roots, they may grow into the soil or remain floating on top of the water. At Dernford Fen water stands up to a metre up the alder trees. However none have died but most have stunted growth with many dead branches and adventitious roots.

Where the water table is just below the water surface the thick leading roots of the surface system break through and grow along the top of the surface litter. Here nodule growth is particularly active and the nodules are much larger.

Alders have two root types; a deep rooting system capable of growing in a reducing medium and surface nutritional rootlets bearing nodules which require a higher oxygen concentration. Lenticels, which are small raised pores that permit the passage of gases, grow on the stem roots and nodules of waterlogged seedlings and saplings. McVean concluded that this might increase the efficiency of the aeration system and assist the respiration of the nitrogen fixing organisms.

It is known that the ability to form adventitious roots helps a plant to survive and grow in saturated soil conditions. Krasny *et al.* (1988) studied the ability of four species of willow to develop adventitious roots in response to a flooding event by examining seedlings in a study area on the Tanana River, Alaska. They found that sandbar willow (*Salix interior*), feltleaf willow (*Salix alaxensis*) and the balsam poplar (*Populus balsamifera*) developed a higher mean number of adventitious roots per seedling than aspen (*Populus tremuloides*), which is an upland species not widely found in the floodplain. They then related the ability to form adventitious roots with the distribution of the species on the floodplain.

Willows also adapt to poorly aerated soils by enlarging their aerenchyma or cortical air spaces. These aerenchyma are characteristic of many wetland species. Kawase and Whitmajor (1980) conducted experiments into aerenchyma development in waterlogged plants by placing cuttings of *Salix fragilis* under waterlogged conditions. Some were placed in moist clay pot chips as a control. The roots in water developed aerenchyma but the control roots did not (Figure 40). They then conducted similar experiments on *Helianthus annus* and *Lycopersicon esculentum* which also developed aerenchyma under waterlogged conditions. This confirmed that roots produced in a poorly aerated environment contain larger airspaces. The aerenchyma development was particularly advanced in the water grown roots of *Salix fragilis*.

Aerenchyma provides an air transport system from aerial parts of the plant to the root system. Kawase and Whitmajor therefore concluded that aerenchyma development is one of the means by which *Salix fragilis* is able to tolerate waterlogged conditions.

Practical management of mature trees

There are no specific guidelines relating to riverine tree management although general descriptions of work that has been completed along river corridors is given by different organisations (Severn Trent Water Authority 1980, NCC 1989 and British Waterways Authority 1981). The Forestry Commission however bases its broad management principles upon the government's policy towards broadleaved woodland (Anon. 1986).

The following are the underlying management principles used by the forestry commission for all woodland management and which also apply to waterside trees. The two main types of broadleaved woodland management used on an individual tree basis are coppicing and pollarding.

Coppicing

Coppicing involves the cutting back of tree trunks to ground level. Adventitious roots then regrow to produce a dense thicket of branches (Evans 1984). This can usually be repeated many times and has historically been used as a means of regenerating broadleaves at short intervals to produce small roundwood.

A tree should be cut at an angle when coppicing so that the remaining stump will shed rainwater. A low cut will maximise the yield which can be gained and will also increase the tendency for the shoots to develop their own independent root system. The bark should always be left on the stump. The Forestry Commission recommends that chainsaws should be used as these have the effect of reducing the number of coppice shoots compared with the axe (Evans 1984). According to Lewis and Williams (1984) however, there is no difference between axe cut and chain saw cut coppice.

The ideal time of year for coppicing is from October to March. Coppicing during winter months will be facilitated by the absence of foliage and will also permit a full seasons growth for the new shoots. There is however no silvicultural reason for cutting at this time of year, it will be successful at any time of the year except late summer because the shoots will not be hardened before the winter frosts.

In terms of wood yield, 2.5 tonnes per hectare per year can be expected from oak and alder and up to 6 tonnes per hectare per year from poplar and willow (Begley and Coates in Evans 1984).

The above applies to the coppicing of broadleaves in general. There are certain factors that have to be considered when coppicing riverine trees in particular (Lewis and Williams

1984).

Coppicing can be used to stabilize bankside trees where trunks and stems curve out from the base causing the tree to lean out over the river. Such growth may shift a trees centre of gravity making it hazardous and unstable, especially if the roots are undercut by the river. Once coppiced, it is advisable to maintain such a management practice since trees which are allowed to grow large are liable to split at the base causing partial trunk collapse. This is not only dangerous but may result in the death of the tree where wood rot sets in. Crack willow are especially prone to this. Coppicing should therefore be practiced at 6-12 yearly intervals so preventing excessive vertical growth. Cricket bat willow requires special management and should be coppiced on a 12-15 year cycle.

On wider rivers the bushy regrowth from coppiced alders and willows provides useful bank protection. Coppicing on short intervals 3-6 years keeps the trees as bushes and encourages root growth which will bind and protect the bank. Whereas the RSPB recommends this particular practice, the forestry commission advise against vegetation being allowed to the waters edge.

The reduction in tree cover following coppicing also has a short term beneficial effect on ground flora.

<u>Pollarding</u>

Pollarding is the same as coppicing in all respects except that the new shoots emerge on the top of a short trunk 1.6-3.0m high rather than at ground level. Shoots at this height escape browsing by cattle and deer. It was a widespread alternative to coppicing and accounts for the multi-stemmed nature of many of our older trees.

At present, pollarding is mostly restricted to riverside willows, particularly Salix alba , which are used as wind breaks. Other less frequently pollarded species include oak, ash, elm and poplar. Alder is almost never pollarded.

Pollarding produces larger timber than coppicing. The period between repollarding depends on the type of tree and the product that is required, for example, if firewood is required from ash, 10-20 years is the normal interval. Repeated pollarding seems to increase the lifespan of the tree in the same way as coppicing. The lack of the need to fence leads to an abundance of pollards along rivers with grazing meadows beside them.

It is recommended that when pollarding, a tree should be cut as close as possible to the callus. The woody debris should be then be cleared away to discourage rot since the ensuing change in stem diameter can sometimes promote fungal growth making the tree potentially hazardous. Leaning pollards should never be half trimmed as this will imbalance the tree and encourage the trunk to split. Pollarding may be preferred to multi-stemmed coppicing where a tree lies below the flood level. Once initiated, this practice must be maintained in the same way as coppicing.

Other management considerations of riparian trees

The forestry commission recommend that dense-foliaged trees should not be allowed any closer than 10 metres from small headwater streams so as to prevent them from becoming overgrown (Anon. 1990b). They further state that high forest trees should be kept away from watercourses to allow ground and shrub flora to develop between trees and rivers thus permitting light penetration. Alder can cause excessive shading and acidification on infertile geologies. However provided that broadleaved trees and shrubs are interspersed with open gaps to give half shade conditions and access, such riverine trees are considered to enhance the fishing potential of wooded rivers (Evans 1984).

The removal of riparian trees in headwater streams will have the effect of increasing stream flow through an increase in run-off. Tree removal will also effect water quality causing an increase in suspended and desposited sediments, nutrients and dissolved solids, organic material, light availability and temperature. In addition, a decrease in the amount of oxygen in the water which will effect algae, macroinvertebrates and fish communities (Campbell and Doeg 1989).

Riverine tree planting strategies

There are several factors that have to be considered prior to the planting of trees on a riverine site. Certain characteristics of the site must be examined such as soil type and pH, exposure and hydrological regime (rainfall, waterlogging and inundation). Choice of tree species will in part depend on the trees that might already be present. Where this is the case, a choice has to be made between diversification or augmentation of existing stands. This choice will also depend on the ultimately desired visual effect which in turn will relate to planting scheme. Native broadleaves are naturally the preferred choice of tree species due to their ability to support a diversity of birds, insects and small mammals. Provision must be made for the protection of newly planted trees from possible interference by humans and grazing animals.

Site conditions

Factors such as soil type, exposure and flood regime must be considered when examining a potential site. The classification of soil for forestry purposes is concerned with the chemical properties which affect nutrient availability and the physical properties which influence root development and hence tree stability. The physical factors affecting root growth and function are depth of soil, soil water regime and aeration. The nutrient holding capacity of a soil depends on the physical factors and also its mineral composition.

The degree to which a riverine site is exposed is determined by topography, aspect and altitude. Early establishment of trees may be difficult on exposed sites. At a later stage, stands may be susceptible to windthrow.

Waterlogging is perhaps the most important consideration. Trees planted on riverbanks will inevitably be subject to inundation and certain riverine species are more tolerant of such conditions than others. Willow and alder are notably the species that can withstand the greatest degree of saturation. Ash, oak and hazel may be planted on banksides where there is no waterlogging (Anon. 1990a). This is a particular problem for establishing trees and a percentage of newly planted trees will be lost due to waterlogging each year.

Choice of tree

Trees can be planted at different stages of early growth; as transplants, whips or standards. In general, the smaller the tree the greater the chance it has of surviving. They are also cheaper to buy and easier to plant. Smaller trees are however more vunerable to choking by weeds and vandalism.

Transplants are sturdy 2-3 year old plants with a large proportion of root in relation to shoot which gives them good powers of survival and growth especially in poor soils. They generally outgrow standards in a few seasons to provide healthier and better formed trees. They are cheaper than standards and can usually be purchased in bulk. They do however require extensive protection from machinery and animals and careful management for 3-5 years.

Whips and feathered trees are more expensive and less sturdy than transplants, but are cheaper and easier to establish than standards. They are often short enough not to need stakes but sufficiently tall to prevent their leading shoots being damaged by hares and rabbits. Weeding is less critical, but protection from larger grazing animals is necessary.

Standard trees should be chosen only where individual or small groups of trees are required. They are less vulnerable to competition from weeds, but are expensive and drought susceptible. They are more difficult to establish and require tree stakes, ties and protection from machinery and browsing animals.

Tree protection

Different recommended means of protection exist for trees of various heights and girths. Below 900mm, young trees require guards to protect them from rabbits and hares. There are a number of commercially available guards. Above 900mm in height, staking is required to provide support for the growing tree. Mowing guards, which protect from machinery, can be constructed and posts with wire and should be used to protect against large grazing animals.

Planting

In general, it is recommended that trees should be planted no less than 2.4m apart from each other. Trees planted along a riverbank should be staggered irregularly for aesthetic reasons and also to allow for intermittent unshaded areas. Heavily foliaged trees should not be planted within 5m of the headwater of streams. Ideally, a strip of trees two-thirds as wide as the stream bed should be planted on either bank of larger rivers and streams.

Where the water table is within 30cm of the ground surface mound planting is recommended. This involves setting the tree 45cm above ground level in a mound of topsoil. The following is a summary of the procedure for mound planting:

- Stand the roots in water overnight prior to planting
- Cut back damaged and dead branches to reveal healthy growth
- Strip the surface vegetation from the ground for the full width of the root system
- Dig a large enough pit to accommodate the roots
- Fork over the base of the pit to improve drainage
- Drive the stake into the windward side of the pit, off centre
- Return upturned turves and backfill into the pit and put the tree in
- Put the earth back in in layers and trample it to remove air
- The tree should then receive approximately 20 litres of water
- Trees should be planted from October to December or March to April.

DISCUSSION AND NEED FOR FURTHER INFORMATION

This section is best writen after consultees (within as well as selected without?) have read the draft report. Items which ought to be considered include:

- The role of information about trees in river corridor surveys and subsequent conservation recommendations

- The role of information about trees in fisheries surveys and further use of the data

- The role of conservation bodies in riparian tree and shrub conservation

- The role of landowners and education about the importance of stock grazing.

- Future educational efforts – e.g. to tie in with ideas about prodtion of small leaflets for fisheries clubs about 'do-it-yourself' habitat improvements.

- Linking in this project report with others – e.g. post-project appraisal, Suffolk rivers catchment conservation proposals, use of REDS.

REFERENCES

Anon. (1981) Alluvial Forests in Europe, Nature and Environment Series, No. 22, Council of Europe, Strasbourg.

Anon. (1983) The Nature Conservation Value of the Nene Valley. Nature Conservancy Council/Northamptonshire Trust for Nature Conservation.

Anon. (1986) Guidelines for the management of broadleaved woodland, Forestry Commission Publications.

Anon. (1989) Birds of the River Ise and Slade Brook - a River Corridor Survey, University of Leicester unpublished B.Sc. thesis.

Anon. (1990a) Cambridgeshire Landscape Guidelines - Cambridgeshire County Council Rural Strategy, Landscape Design Associates, Peterborough.

Anon. (1990b) Forest Nature Conservation, Forestry Commission Publications.

Anderson, N.H. and Sedell, J.R. (1979) Detritus processing by macroinvertebrates in stream ecosystems, *Annual Review of Entomology*, 24, 351-377.

Anderson, B.W. and Ohmart, R.D. (1984) Riparian birds in the riparian/agricultural interface. *Californian Riparian Systems, Ecology, Conservation and Productive Management,* edited by R.E. Warner and K.M. Hendrix, 190-195, Berkeley: University of California Press.

Ash and Barkham (1962) Changes and variability in the field layer of a coppiced woodland in Norfolk, England, *Journal of Ecology*, 62, 697-712.

Ash and Woodcock (1988). Operational use of river corridor surveys in river management. *Journal of Institute of Water and Environmental Management*, 2(4).

Baltz, D.M. and Moyle, P.B. (1984) The influence of riparian vegetation on stream fish communities of California. In *Californian riparian systems, ecology, conservation and productive management*, edited by R.E. Warner and K.M. Hendrix, Berkeley: University of California Press.

Barber, P. and Lucas Phillips, C.E (1975) Trees around us. London: Wiedenfeld and Nicolson.

Beschta, R.L. and Platts, W.S. (1986) Morphological features of small streams: significance and function, *Water Resources Bulletin*, 23, 369-379.

Bilby, R.E. and Likens, G.E. (1980) Importance of organic debris dams in the structure and function of stream ecosystems, *Ecology*, 61, No. 5, 1107-1113.

Blackman and Rutter (1946) Studies in analysis of plant environment, *Annals of Botany*, 10, 361-390.

Boussu, M.F. (1954) Relationship between trout populations and cover on a small stream. *Journal of Wildlife Management*, 18, 229-239.

Brookes, A. (1987) Recovery and adjustment of aquatic vegetation within channelisation works in England and Wales, *Journal of Environmental Management*, 24, 365-382.

Brookes, A (1988) Channelized rivers: perspectives for environmental management. London: John Wiley and Sons.

Brown, A.H.F. and Oosterhuis, L. (1981) The role of buried seed in coppice woods, *Biological Conservation*, 21, 19-38.

Buckhouse, J.C. (1985) Water and people: common denominators in riparian zones. In *Riparian Ecosystems and their Management: Reconciling Conflicting Issues* edited by R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Ffolliot, and R.H. Hamre, 369-370, First North American Riparian Conference, USDA Forest Service General Technical Report RM-120.

Burks, G.F. and Wilson, R.C. (1939) A vegetation inventory from aerial photographs, *Photogrammetric Engineering*, 5, No. 1, 30-42.

Burnett, J., Clegg, M., Shannon, M., *et al.* (1978) *The Yorkshire Derwent: A Case for Conservation,* Published privately.

Burns, J.W. (1985) Public values and riparian systems. In *Riparian Ecosystems and their Management: Reconciling Conflicting Issues* edited by R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Ffolliot, and R.H. Hamre, 226-227, First North American Riparian Conference, USDA Forest Service General Technical Report RM-120.

Campbell, K. and Doeg, T.G.(1989) The impact of timber harvesting and producion on streams. *Australian Journal of Marine and Freshwater Research*, 40, No. 5, 519-539.

Colvin, B. (1965) Trees for Town and Country. London: Lund Humphries.

Cross, S.P. (1985) Responses of small mammals to forest riparian perturbations. In *Riparian Ecosystems and their Management: Reconciling Conflicting Issues* edited by R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Ffolliot, and R.H. Hamre, 269-275, First North American Riparian Conference, USDA Forest Service General Technical Report RM-120.

Crozier, C.R. and Boerner, R.E.J. (1984) Correlations of understorey herb distribution patterns with microhabitats under different tree species in a mixed mesophytic forest, *Oecologia (Berlin)*, 62, 337-343.

Cummins, K.W. (1974) Structure and function of ecosystems, *Bioscience*, 24, 631-641.

Cummins, K.W. and Klug, M.J. (1979) Feeding ecology of stream invertebrates, *Annual Review of Ecological Systems*, 10, 147-172.

Dawson, F.H. (1981) The reduction of light as a technique for the control of aquatic plants - an assessment, *Proceedings Aquatic Weeds and their Control*, 157-164.

Dawson, F.H. and Hallows, H.B.(1983) Practical application of shading material for macrophyte control in watercourses, *Aquatic Botany*, 17, 301-308.

Dawson, F.H. and Haslam, S.M.(1983) The management of river vegetation with particular reference to shading effects of marginal vegetation, *Landscape Planning*, 10, 147-169.

Dryden, R. (1990) Land use/habitat survey and channel profiles of the Black Bourn/Sapiston River, Euston to Ixworth, NRA/SuffolkWildlifeTrust.

Eaton, J.W. (1986) Waterplant ecology in landscape design. In *Ecology and Design in Landscape*, edited by A.W. Bradshaw, D.A. Goode and E.H.P. Thorpe, 285-303, Blackwell Scientific Publishers.

Eldin, E.H. (1966) Trees, Woods and Man. London: Collins.

Evans, J. (1984) Silviculture Of Broadleaved Woodland, *Forestry Commission Bulletin*, No.62.

Fisher, S.G. and Likens, G.W. (1973) Energy flow in Bear Brook, New Hampshire: an integrative approach to stream ecosystem metabolism, Ecological Monographs, 43,421-439.

Ford, E.D. and Newbould, P.J. (1977) The biomass and production of ground vegetation and its relation to tree cover through a deciduous woodland cycle, *Journal of Ecology*, 65, 201-212.

Fordham, M. and Tunstall, S.M. (1990) The trade-off between flood alleviation and environmental values. Middlesex Polytechnic Flood Hazard Research Centre, Publication 175.

Fuller, R.M. (1988) Aerial photographs as records of changing vegetation patterns. In *Ecological Mapping from Ground, Air and Space*, edited by R.M. Fuller, 57-69, Swindon: NERC.

Green, C.H. and Tunstall, S.M. (1990) The amenity and environmental value of river corridors, *Middlesex Polytechnic Flood Hazard Research Centre*, Publication 171.

Gregory, K.J. (1990) Riparian vegetation and river channel process. In *Conservation of Rivers*, edited by P.J. Boon and G.E. Petts, 1-17, Chichester: John Wiley.

Ham, S.F., Wright, J.F. and Berrie, A.D. (1981) Growth and recession of aquatic macrophytes on an unshaded section of the river Lambourn, England, from 1971 to 1976, *Freshwater Biology*, 11, 381-390.

Ham, S.F., Cooling, D.A., Hiley, P.D., McLeish, P.R., Scorgie H.R.A. and Berrie, A.D (1982) Growth and recession of aquatic macrophytes on a shaded section of the river Lambourn, England, from 1971 to 1980, *Freshwater Biology* , 12, 1-15.

Harmon, M.E. *et al.* (1986) Ecology of coarse woody debris in temperate ecosystems, *Advances in Ecological Research*, 15, 262-267.

Haslam, S.M. and Wolseley, P.A. (1981) River vegetation , its identification , assessment and management. Cambridge: Cambridge University Press.

Helliwell, D.R. (1976) The effects of size and isolation on the conservation value of wooded sites in Britain, *Journal of Biogeography*, 3, 407-416.

Hickin, E.J. (1984) Vegetation and river channel dynamics. *Canadian Geographer*, 28, 111-126.

Holmes, N.T.H. (1986) Wildlife surveys of rivers in relation to river management, Water Research Centre, Marlow, Buckinghamshire.

Hooke, J.M. (1980) Magnitude and distribution of rates of river bank erosion, *Earth Surface Processes*, 5, 143-157.

Hoover, S.L., King, D.A. and Matter,W.J. (1985) A wilderness riparian environm iebell, D.R. Patton, P.F. Ffolliot, and R.H. Hamre, 223-226, First North American Riparian Conference, USDA Forest Service General Technical Report RM-120.

House, M.A. and Sangster, E.K. (1990) Public participation in river corridor management. Middlesex Polytechnic Flood Hazard Research Centre. Publication J19.

House, M.A. and Gardiner, J.A. (1990) River catchment planning and public perception of river corridors for recreation and amenity: the U.K. scene. Middlesex Polytechnic Flood Hazard Research Centre. Pub. J17.

Jarvis, P.H. (1964) Interference by *Deschampsia flexuosa* (L.) Trin., *Oikos*, 15, 56-78.

Kawase *et al.* (1980) Aerenchyma development in waterlogged plants, *American Journal of Botany*, 67, 18-22.

Keller, E.A. and Swanson, F.J. (1979) Effects of large organic material on channel form and fluvial processes, *Earth Surface Processes*, 4, 361-380.

King, T.J. (1975) Inhibition of seed germination under leaf canopies in *Arenaria Serpyllifolia, Veronica arvensis* and *Cerastum holosteoides*, *New Phytologist*, 75, 87-90.

Klebenow, D.A. and Oakleaf, R.J. (1984) Historical avifaunal changes in the riparian zone of the Truckee River, Nevada. In Californian riparian systems, ecology, conservation and productive management, edited by R.E. Warner and K.M. Hendrix, 203-209, Berkeley: University of California Press.

Knight, A.L. and Bottorff, R.L. (1984) The importance of riparian vegetation to stream ecosystems. In *Californian riparian systems, ecology, conservation and productive management*, edited by R.E. Warner and K.M. Hendrix, Berkeley: University of California Press.

Knighton, D. (1984) Fluvial Forms and Processes. London: Edward Arnold Limited.

Knopf, F.L. (1985) Significance of riparian vegetation to breeding birds across an altitudinal cline. In *Riparian ecosystems and their management: reconciling conflicting issues* edited by R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Ffolliot, and R.H. Hamre, 355-358, First North American Riparian Conference, USDA Forest Service General Technical Report RM-120.

Krasny, M.E. *et al.* (1988) Adventitious rooting of four Salicaceae species in response to a flooding event, *Canadian Journal of Botany*, 66, 2597-2598.

Krause, A. (1977) On the effect of marginal tree rows with respect to the management of small lowland streams, *Aquatic Botany*, 3, 185-192.

Kraushik, N.K. (1981) From forest to fish, biology of woodland streams, *Water Pollution and Management Reviews*, 2, 17-39.

Krieg, R.A. (1970) Aerial photographic interpretation for land use classification in the New York State Land Use and Natural Resources Inventory, *Photogrammetria*, 26, No. 2/3, 101-111.

Lewis, G. and Williams, G. (1984) Rivers and wildlife handbook: a guide to practices which further the conservation of wildlife on rivers, RSPB/RSNC.

Lienkamper, G.W. and Swanson, F.J. (1986) Dynamics of large woody debris in streams in old growth Douglas-fir forests, *Canadian Journal of Forest Research*, 17, 150-156.

Mahoney, D.L. and Erman, D.C. (1984) The role of streamside bufferstrips in the ecology of aquatic biota. In *Californian riparian systems, ecology, conservation and productive management*, edited by R.E. Warner and K.M. Hendrix, Berkeley: University of California Press.

Marston, R.A. (1982) The geomorphic significance of log steps in forest streams. *Anals of the Association of American Geographers*, 72, 99-108.

Mason, C.F. and Macdonald, S.M. (1990) The riparian woody plant community of regulated rivers in eastern England, *Regulated Rivers: Research & Management*, 5, 159-166.

Mason, C.F., Macdonald, S.M. and Hussey, A. (1984) Structure, management and conservation value of the riparian woody plant community, *Biological Conservation*, 29, 201-216.

McVean, D. N. (1953) Account of *Alnus glutinosa*, *Journal of Ecology*, 41, 447-466.

McVean, D. N. (1956a) Ecology of *Alnus glutinosa*, III Seedling establishment, *Journal of Ecology*, 44, 195-218.

McVean, D. N. (1956b) Ecology of *Alnus glutinosa*, IV Root system, *Journal of Ecology*, 44, 219-225.

Meyer, P.A. (1985) Economic and social values in riparian systems.

Mosley, M.P. (1981) The influence of organic debris on channel morphology and bedload transport in a New Zealand forest stream, *Earth Surface Processes and Landforms*, 6, 571-579.

Murgatroyd, A.L. and Ternan, J.L. (1983) The impacts of afforestation on stream bank erosion and channel form, *Earth Surface Processes and Landforms*, 8, 357-369.

Newbold, C., Honnor, J. and Buckley, K. (1989) Nature conservation and the management of drainage channels. NCC/Association of Drainage Authorities.

NRA (1990) Personal communication with Conservation Liaison Officer on aspects of Severn Trent's river corridor survey methods.

Parkyn, L., Harper, D.M. & Smith, C. D (1993) Riparian & Instream Habitats for Aquatic Communities. R&D Project Report 291, National Rivers Authority, Bristol.

Patterson, D.W., Finch, C.U. and Wilcox,G.I. (1981) Streambank stabilization techniques used by the Soil Conservation Service. In R.E. Warner and K.M. Hendrix, Californian Riparian Systems Conference.

Peterken, G. F. (1981) Woodland conservation and management. London: Chapman and Hall.

Peterson, R.C. and Cummins, K.W. (1974) Leaf processing in a woodland stream, *Freshwater Biology*, 4, 343-368.

Petts, G. and Foster, I. (1985) Rivers and Landscape. London: Edward Arnold Limited.

Quinn, J.M. *et al.* (1990) Riparian retirement effects on instream habitat and water quality: some New Zealand experiences. (Paper given at York conference Sept 1990), Nature Conservancy Council.

Ratcliffe, D.A. (1977) Nature Conservation: aims methods and acheivements, *Proceedings of the Royal Society of London*, B197, 11-29.

Reice, S.R. (1974) Environmental patchiness and the breakdown of leaf litter in a woodland stream, *Ecology*, 55, 1271-1282.

Reiley, J & Page, S.P. (1991).

Robison, E.G. and Beschta, R.L. (1990) Coarse woody debris and channel morphology interactions for undisturbed streams in Southeast Alaska, U.S.A., *Earth Surface Processes and Landforms*, 15, 149-156.

Ross, M.S. *et al.* (1986) Seasonal and successional changes in light quality and quantity in the understorey of boreal forest ecosystems. *Canadian Journal of Botany*, 64 , 2792-2799.

Saarinen, T.F. (1974) *Perceptions on the Environment.* Association of American Geographers, Publication 13 (Washington).

Shields, F.D. and Nunnally, N.R. (1984) Environmental aspects of clearing and snagging, Journal of Environmental Engineering, American Society of Civil Engineers, 110, 152-165.

Simons, L.H. (1985) Small mammal community structure in old-growth and logged riparian habitat. In *Riparian Ecosystems and their Management: Reconciling Conflicting Issues* edited by R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Folliot, and R.H. Hamre, 335-358, First North American Riparian Conference, USDA Forest Service General Technical Report RM-120.

Slater, F.M. *et al.* (1987) A practical approach to the evaluation of the conservation status of vegetation in river corridors in Wales, *Biological Conservation,* 40, No.1, 53-68.

Smith, B.D. (1980) The effects of afforestation on the trout of a small stream in Southern Scotland, *Fish. Management*, 11, No. 2,39-58.

Smith, R.P. (1989) *The distribution and habitat requirements of chub* (Leuciscus cephalus *L) in several lowland rivers of eastern England.* Ph.D. thesis, University of East Anglia.

Spurr, S.H. (1960) Photogrammetry and photointerpretation, New York: The Ronald Press Company.

Stellingwerf, D.A. (1967) Interpretation of tree species and mixtures on aerial photographs, *Biogéographie*, 4, No. 2, 83-91.

Sydes, C. and Grime, J.P. (1981a) Effects of tree litter on herbaceous vegetation in deciduous woodland, 1. Field investigations, *Journal of Ecology*, 69, 237-248.

Sydes, C. and Grime, J.P (1981b) Effects of tree litter on herbaceous vegetation in deciduous woodland, 2. An experimental investigation, *Journal of Ecology*, 69, 249-262.

Thorne, C.R and Tovey, N.K. (1981) Stability of composite river banks, *Earth Surface Processes and Landforms*, 6, 469-484.

Triska, F.J.and Kennedy, V.C. (1983) Effect of simulated canopy cover on regulation of nitrate uptake and primary production by natural periphyton assemblages. In *Dynamics of Lotic Ecosystems* edited by T.D. Fontaine and S.M.Bartell.

Vannote R.L., Wayne Minshall, G., Cummins, K.W., Sedell, J.R.and Cushing, C.E. (1980), The river continuum concept, *Canadian Journal of Fisheries and Aquatic Sciences*, 37, No. 1, 130-137.

Whitford, P.B. (1949) Distribution of woodland plants in relation to succession and clonal growth, *Ecology*, 30, 199-207.

Wilkinson, G. (1981) History of Britain's trees. London: Collins.

Willoughby, L.G. (1974) Decomposition of litter in freshwater. In *Biology of Plant Litter Decomposition*, edited by C.H. Dickinson and G.J.F. Pugh, Academic Press.

Winterbourn, M.J. and Townsend, C.R (1991) Streams and rivers: One-way flow systems. In *Fundamentals of Aquatic Ecology*, edited by R.S.K. Barnes and K.H. Mann, Blackwell Scientific Publications.

Witkowski, F. (1991) Aerial photo-classification of the vegetation and land use along selected parts of the Great Ouse drainage basin. MSc. Thesis, University of Leicester.

Wolman, M.G. (1959) Factors affecting erosion of a cohesive river bank, *American Journal of Science*, 257, 204-216.

Young, R.N. (1991) Airphotos in Education, *The Landscape Overview*, unpublished, 1-21.

Zimmerman, R.C.,Goodlet,J.C.and Comer,G.H.(1967) The influence of vegetation on channel form of small streams, *International Association of Hydrological Sciences, Berne Symposium*,75, 255-275.