River Landscapes and Land Use: Investigating patterns and relationships in Wales

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1. Abstract

Policy is beginning to encourage the reversal of fragmentation of the British landscape, and there are many studies now looking at how best to connect habitat, and woodland habitat in particular. Rivers are believed to be important natural linkages in the landscape, and some studies highlight their current contribution to connectivity in Wales. Understanding the patterns of land use between and within rivers can help contribute to plans to increase connectivity, and help understand the implications of such plans.

This study utilised GIS data and software to examine land use patterns in Welsh river catchments, with reference to the longitudinal river slope (patterns between rivers) and the position within the river catchment (patterns within rivers). The cover of different land-uses was calculated from habitat data, and slope was calculated from elevation data.

The cover of "semi-natural woodland", "settlement" and "agriculture" were all found to have a negative relationship to river slope. The reverse was found for "plantation and felled woodland" and "other semi-natural habitats" (which included grassland, heath and bog). Within-river, the patterns were much stronger but differed greatly between rivers. To better understand the processes occurring in the Welsh landscape future studies should look to additional landscape characteristics and to look further within rivers. Scale may also be important, as it is predicted that the size of the area examined around a river will have an effect on the relationship found, but it was outside the scope of this study to investigate such effects.

2. Contents

3. Introduction

3.1. Habitat Fragmentation

Environments are naturally patchy (Darimont *et al.,* 2004; Chapa-Vargas & Robinson, 2006), but humans have greatly increased this fragmentation of habitats and resources (Hetherington *et al.* 2008). Fragmentation is the division a habitat or landscape into patches, which can have a profound effect on the way they interact with the landscape as patches are separated by a different habitat or land-use (Peterken, 2002; Andrén, 2004). This matrix can be hostile to organisms, preventing residency or even restricting movement, and in addition to removing habitat humans have increased the prevalence of inhospitable land-uses such as roads and settlements (Peterken, 2002; Chapron *et al.* 2003; Watson, 2005; Blanco & Cortés 2007). The fragmentation of a habitat can also impact the quality of that habitat (Tubelis *et al.*, 2004; Arcos *et al.*, 2008). These factors have been described as causing the decline and loss of many species (Dinnin & Sadler, 1999; Hetherington *et al.*, 2008). The ability for organisms to move across landscapes is receiving increased emphasis as the implications of predicted global warming become clear; many organisms will need to move to remain within their tolerance limits for variables such as temperature and rainfall (Latham, 2007). Some studies have looked into increasing the connection (physical linking – thus increasing patch size) and the connectivity (ecological linking – for organisms this involves decreasing patch isolation) of habitat to counter fragmentation.

The distribution of habitat within the landscape affects the impacts and severity of fragmentation. If the habitat is divided into small patches, genetic drift will have a bigger impact on the diversity and thus adaptability of populations; some patches may also be unable to support a population in the long-term due to low chance of encountering suitable food items, shelter, or other individuals to breed with

(MacArthur & Wilson, 1967; Peterken, 2002; Humphrey *et al.*, 2003; Thomson *et al.,* 2003; Darimont *et al.*, 2004; Watson, 2007). They may also be more vulnerable to introgression from hybridisation when distributed in smaller populations (as has been suggested in wolves, *Canis lupus*: MacDonald & Sillero-Zubiri, 2004; Blanco *et al.*, 2005; LCIE, 2007). A smaller patch means that there is less "core" habitat free of edge effects as well (Humphrey *et al.* 2003; Thomson *et al.,* 2003; Ibarzabal & Desrochers, 2004; Tubelis *et al.*, 2004; Watson *et al.,* 2004; Chapa-Vargas & Robinson, 2006; Arcos *et al.*, 2008; although see Liley & Clarke, 2003). If patches are far apart from each other then the ability of organisms to move across the landscape is restricted, which can restrict gene flow (and even cause inbreeding depression); prevent recolonisation of empty patches; reduce access to certain essential resources elsewhere in the landscape such as seasonal food sources or breeding areas (CO-DBP, 2001; Santos *et al.*, 2007). For example, a number of bat species depend on particular resources in the landscape such as riverine woodland foraging areas and nesting sites, and these are segregated in space so fragmentation can restrict access to them (Henderson & Broders, 2008).

The severity of the fragmentation will depend on the ecology of a species; patches of a habitat may be effectively less isolated for one species than another if there is a difference in their ability to cross the matrix land (Kolozsvary & Swihart, 1999; Mech & Hallett, 2001; Watson, 2007). Some land-uses might restrict few organisms (usually specialists of other habitats), for example natural grasslands or plantation woodlands may be impermeable to some woodland specialist rodents but allow other rodents to disperse (Mech & Hallett, 2001). If a grassland area had 30% woodland cover it could even allow more of the woodland specialist species to travel across it, as though it were woodland (Peterken, 2002), thus allowing migration between core woodland areas. Some other land-uses will be hostile to a great number of organisms – including many anthropic land-uses such as roads (Kolozsvary & Swihart, 1999; Chapron *et al.*, 2003; Thomson *et al.,* 2003; Watson, 2005; Blanco & Cortés, 2007). It is also worth noting that habitat for one species may be an inhospitable matrix to another species –which is a habitat patch and which is the matrix depends on the organism in question. Some organisms may even live different habitats at different life stages, such as amphibians, and so fragmentation of the landscape may affect them particularly by segregating the habitats they depend on to complete their lifecycle (Kolozsvary & Swihart, 1999). Finally, it is predicted that global climate change will necessitate the movement of many species with shifting climatic conditions (Peterken, 2002; Latham, 2007). For example, if temperatures increase in Britain, populations at the southern, temperature-caused limit of their range will need to disperse northwards to remain within their thermal tolerance limits. For a slow dispersing species the whole population may be overtaken by the temperature boundary, and thus perish, but if there is no suitable habitat within dispersal range then the same outcome will result.

Fragmentation has been highlighted as a concern for woodland habitats in particular. There is a long history of human influence on landscapes across the globe and in Wales in particular, with one of the dominant processes of land-use change being deforestation (Dudley & Stolton, 2000; Humphrey *et al.*2000; Williams, 2000; Bolton & Shellberg, 2001; Antrop, 2005). When landscapes have a low cover of habitat, the spatial arrangement of that habitat becomes much more important (Andrén, 1994). Deforestation can affect habitat patch number, size, and density, as well as the amount of core and of edge habitat (Humphrey *et al.* 2000; Cayuela *et al.* 2006; Kadioullari *et al.* 2008). In Britain it has decreased the area of woodland, and fragmented woodland into smaller and more isolated areas (Peterken, 2002;

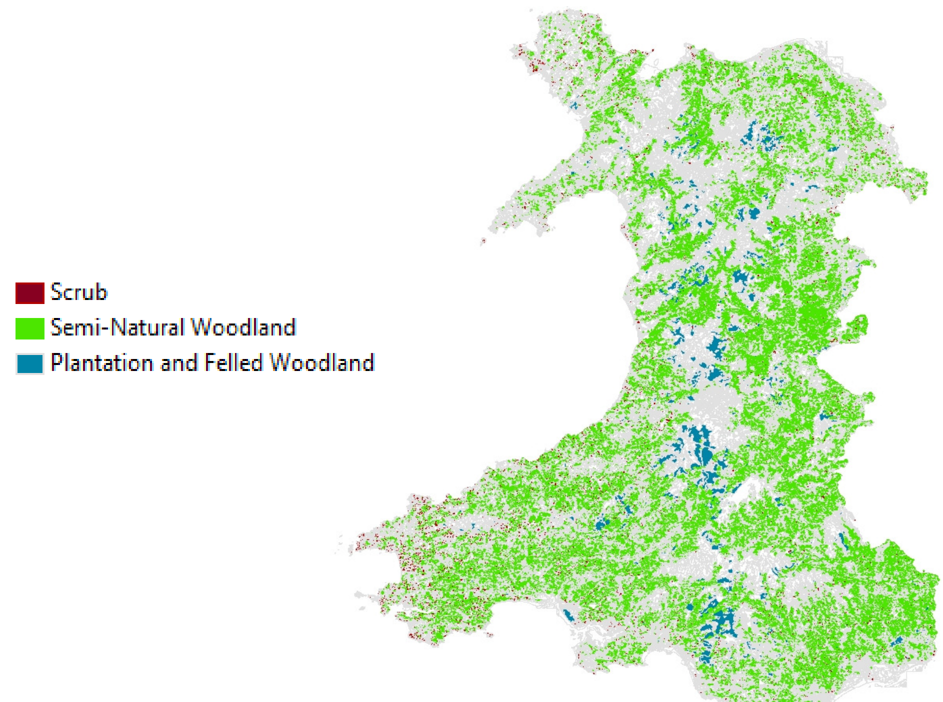
Hetherington *et al.*, 2008). Although forest cover has actually increased in recent centuries in Britain (Peterken, 2002; Swetnam, 2006), remnant fragments of woodland have not necessarily been reconnected (Humphrey *et al.* 2000, Peterken 2002). Forest species may also be particularly affected by fragmentation of habitat (Henderson & Broders, 2008), making the widespread fragmentation of forest an even greater cause for concern.

As a result of these factors, and the predictions for global climate change, the connectedness and connectivity of habitat has been the subject of some focus in Wales. There has been Europe-wide attention to the problems of fragmentation – strategies such as the Pan-European Ecological Network, endorsed in Sofia in 1995(Council of Europe, 2006), have encouraged research and plans for countering fragmentation. Studies looking at corridors and networks in Europe include those by Jongman (1995), Bani *et al.* (2002), and Jedrzejewski *et al.* (2005), and in Wales those by Latham (2007) and Latham *et al.* (2008), and by Watts *et al.* (2005).

3.2. Background to the Study

With increasing focus on management at the landscape scale in Britain, extending to interest in reversing the fragmentation of woodland habitat (see fig.A.1 for a map of woodland distribution in Wales). Latham (2007) modelled the most feasible habitat corridors to join woodland habitats in Wales, and incidentally highlighted many rivers as having high ecological connectivity; many had retained enough fragments of forest or joined up other areas of habitat well enough to come to the fore in the corridor modelling. Many rivers are thus included in potential frameworks to protect and enhance connectivity in Wales. Additionally, river corridors can be important in regional connectivity; they are described in Latham *et* *al.* (2009) as being particularly important in lowland diversity and connectivity, but also have the potential to connect upland and lowland areas that might otherwise remain quite isolated. Ensuring there is sufficient cover of habitat in river valleys can be particularly important for plant dispersal during periods of climate change, as they have microhabitats that are sheltered somewhat from the changes that occur in the wider landscape (Gregory *et al.*, 1991). Peterken (2002) describes rivers and streams as 'the natural links in the landscape'.

Fig. A.1.1: Map of Woodland and Scrub in Wales



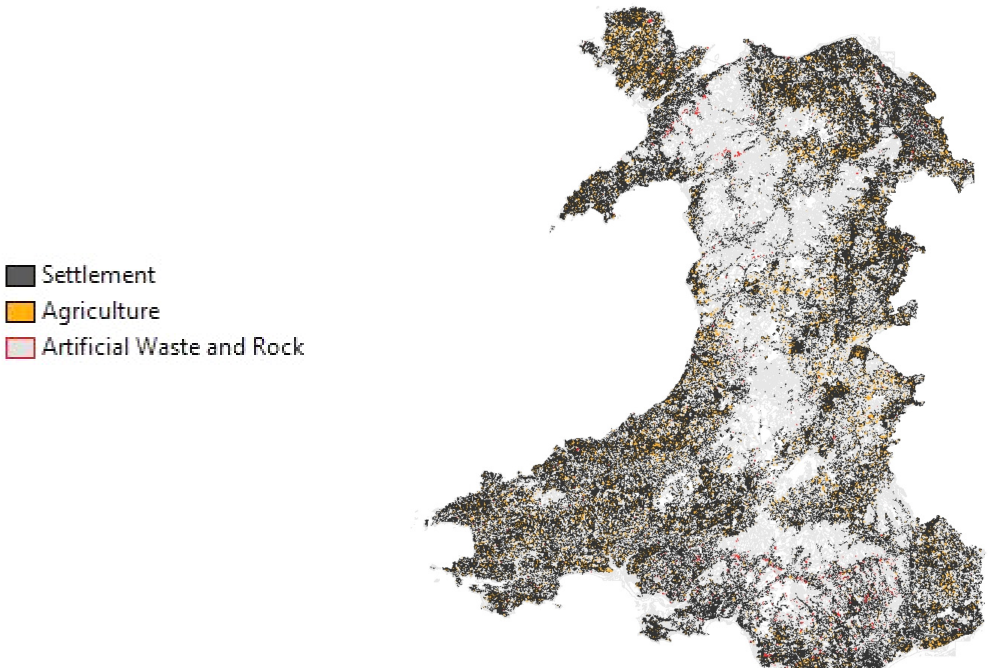
Map produced from CCW data, all right reserved.

It has not yet been investigated whether there are any differences in land use between the river catchments in Wales, or whether there are any patterns within rivers. It was suggested by Latham and Duigan that the amount of semi-natural habitat found in a catchment should be related to the character of the river, such as its steepness and location (C. Duigan, 2008, personal communication). This should be the case because human influences are mediated by the character of the landscape. Thus this study was undertaken to investigate land use in Welsh catchments, looking at some of the differences between rivers and within rivers. Knowledge of the land-use patterns in catchments can help to predict and respond appropriately to problems such as with water quality, erosion, and nutrient imbalance in freshwater ecosystems (Rowland *et al.*, 2002). With plans to connect habitats in Wales, in particular semi-natural woodland, any patterns that can help predict current distribution of habitat or future changes in land use will be of interest and potentially useful in decision-making.

3.3. Patterns of land use and land use change

The literature gives a number of reasons for a potential pattern of land use based on landscape characteristics. Aside from physical factors such as altitude, which could prevent forest from establishing naturally, there are the anthropogenic land use change processes such as deforestation, which in particular has had such a large impact on the current landscapes in Britain and even across the globe (Williams, 2000; Antrop, 2005). Deforestation has been a long-lasting and widespread process in Wales, bringing woodland cover down after the last Ice Age to 10% or less by the sixteenth century (Dudley & Stolton, 2000). The extent of human impact as measured in the CCW Phase I data is demonstrated in fig. A.2, a map of human land-uses in Wales.

Fig.A.1.2: Map of Anthropic Land-uses



These processes of anthropogenic modification are driven by social and political forces (Moog & Chovanec, 2000; Chen *et al.,* 2001; Hersperger & Bürgi, 2008), but are also constrained or influenced by the physical landscape (Pan *et al.,* 1999; de Blois *et al.*, 2001; Chen *et al.* 2001; Wood & Handley, 2001; Fu *et al.* 2006a, Cojocaru *et al.* 2008; Käyhkö & Skånes, 2008; but see also Pato *et al.*, 2008). Going back in time, prehistoric land use patterns were non-random; land would be chosen for settlement or agriculture based on certain characteristics of that land. The land around rivers is productive and has access to water, and so it is attractive to people as well as producing natural habitats with rich communities (Bolton & Shellberg, 2001). For example, Neolithic people preferred sites with a gentle slope on a floodplain for settlements (Williams, 2000) and perhaps for agriculture as well (Brown 1997), so stretches of river with a shallow slope are more likely to have experienced deforestation in this period than those with a steep slope. Slope also affects how easy the site is to manage for agriculture (Fu *et al.* 2006b), and areas with a steep slope are likely to experience higher erosional forces that can damage crops or decrease soil fertility (Pimentel & Kounang, 1998). Slope is credited as a major influence on both soil and runoff in Chen *et al.* (2001), and generally decreases from the source of a river down to the river mouth (Carbiener & Schnitzler, 1990; Noble & Cowx, 2002; Ekness & Randhir, 2007; Hebert & Kundell, 2008). It has been found to affect modern land use (in China - Fu *et al.* 2006b; in the US – Cojocaru *et al.* 2008; in Mozambique - Jansen *et al*. 2008).

In addition to slope, there are a number of other characteristics that affect habitat and land use that change longitudinally along a river, and these include the underlying geology, the width of the floodplain, width of the river, the river hydrology and the valley shape (Carbiener & Schnitzler, 1990; Pitcher & Hart, 1993; Bolton & Shellberg, 2001; Noble & Cowx, 2002; Snelder *et al.*, 2004; Ekness & Randhir, 2007; Hebert & Kundell, 2008; Käyhkö & Skånes, 2008). The flood regime also varies along the river, which can affect the turnover of habitat (Arscott *et al.* 2002). Even along rivers relatively unaffected by human land uses it is possible to see longitudinal zonation of vegetation as a result of these physical factors (Myers 1935), and they can be used to classify the sections of a river and predict concurrent changes in fauna (Moog & Chovanec, 2000; Snelder *et al.* 2004). More to the point in human-dominated landscapes, they can in turn affect human land uses into the modern day (Domon, Bouchard & Gariépy, 1993; Pan *et al.,* 1999; de Blois *et al.,* 2001; Domon & Bouchard, 2007); for example the geology, valley width and floodplain width may all influence the fertility of the soil and thus its value for agriculture. Slope and soil type have been found to influence both land-use patterns and recent land use change in China (Fu *et al.*, 2000; Chen *et al.*, 2001; Fu *et al.* 2006b), with semi-natural woodland and grassland being associated with the steeper slopes and poorer soils. Steep slopes may even see a return from agriculture to natural land uses (Fu *et al.,* 2006b; Becker *et al.,* 2007). A study of the Nicolina catchment in the US found that agriculture and construction decreased with elevation, and forests increased with elevation (Cojocaru *et al*. 2008). Agriculture and settlement also generally decreased with slope in this study, whereas forest peaked at an intermediate slope (in the 5-10° slope category).

3.4. The Importance of Catchment Habitat

Rivers can be important in the connectivity of forest across the Welsh landscape, and as linear features are often used preferentially by terrestrial animal species to travel between resources, patches and entire regions (Peterken, 2002; Downs & Racey, 2006; Henderson & Broders, 2008). However, Connectivity can refer to the potential for transfer of matter or energy between areas or ecosystems as well transfer of organisms (Ward & Stanford, 1995; Ward *et al.* 1999). Humans have impacted this form of connectivity along rivers by converting floodplain habitat to other uses, and by modification of the river, for example deepening or straightening the channel, and building artificial banks, weirs or dams (Ward & Stanford, 1995; Ward *et al.* 1999; Nilsson & Berggren, 2000; Bolton & Shellberg, 2001; Wohl, 2005).

The land-use around a river is extremely important to the functioning of that river and its ecosystem, by affecting the amount and quality of water in the river (Bolton & Shellberg, 2001; Mapili, 2007). The aquatic and terrestrial ecosystems have strong links in freshwater habitats, and the river ecosystem can be largely fuelled by organic inputs from the terrestrial habitat around it, in particular in the upland reaches or "rhithron" zone where in-stream productivity is generally low (Johnson & Gage, 1997; Moog & Chovanec, 2000; Bolton & Shellberg, 2001; Allouche, 2002; Lock, 2008). In the lower reaches, or "potamon" zone, in-channel plant production generally increases, and can include algal and phytoplanktonic production as well as that by macrophyte plants (Moog & Chovanec, 2000; Allouche, 2002; Lock, 2008). The aquatic and terrestrial ecosystems normally interact via the floodplain to a greater degree in this region however; this moves material to and from the aquatic ecosystem, so there is still a large degree of interaction between the two systems (Bolton & Shellberg, 2001; MacDonald, 2008). The direction of nutrient transfer often depends on season, with floodplains being periodically inundated by floodwaters and then exposed as they abate (Ward *et al.*, 1999; MacDonald, 2008). It is clear that the presence and type of habitat adjacent to a river ecosystem will have an effect in both the upper and lower reaches; furthermore, the longitudinal connectivity of rivers means that impacts on upland sections of river are propagated downstream and so may affect the entire river downstream (Naiman *et al.* 1988; Ward & Stanford, 1995; Nilsson & Berggren, 2000; Ekness & Randhir, 2007).

Land-use in a catchment can affect the organic inputs into a river – the amount of dissolved organic matter, leaf litter and large woody debris that natural or semi-natural woodland would supply (Linstead & Gurnell, 1999; Bolton & Shellberg, 2001; Nakamura & Yamada, 2005; Tullos & Neumann, 2006; Lock, 2008). The watershed of a river can include extensive areas of land some distance from the channel itself, and water flowing to the channel as runoff or groundwater flow will bring matter to the river so that inputs to the aquatic system depend on more than just the riparian strip directly adjacent to it (Bolton & Shellberg, 2001; Broadmeadow & Nisbet, 2004). Removing semi-natural habitat in a catchment can deleteriously impact a river by a decrease or change in these inputs, but it can also decrease water quality via additional inputs – organic matter such as sewage, nutrients (e.g. fertilisers from agriculture), toxic chemicals (such as pesticides and herbicides), and even soil can make their way into rivers as a result of human land-use change (Carbiener &

Schnitzler, 1990; Gosselink *et al.*, 1990; Doyle, 2005; Nakamura & Yamada, 2005; Ekness & Randhir, 2007; Chang *et al.,* 2008).

Soil inputs can increase due to changes in certain natural processes – interception and infiltration affect the amount of runoff and force of impact of precipitation striking the ground (Pimentel & Kounang, 1998). Vegetation on the ground can cause resistance to runoff (Hessel *et al.* 2003; Bolton & Shellberg, 2001; MacDonald *et al.* 2008); it also helps dissipate wind, the other source of erosion, and is found to decrease soil erosion in general (Pimentel & Kounang, 1998; Kondolf *et al.,* 2007). Some land uses or arrangements of elements can increase runoff speed, and faster runoff means more erosive power; rivers are sensitive to land use change and human activity (Walling, 1999).

Woodland and shrubland have been shown by the LISEM soil erosion model to have consistently lower erosion rates than other land-uses (Hessel *et al.* 2003), and conversion to agriculture can increase runoff and erosion by seven and twenty-one times respectively compared with levels in woodland (MacDonald *et al.* 2002). Increase in woodland and scrub can decrease erosion in areas where it is a particular problem (Fu *et al.* 2000), both by sheltering the soil and adding structure to it with roots and dead matter. Certain activities actively increase erosion in an area, such as ploughing, harvesting trees by loosening the soil (Hessel *at al.* 2003). Leaving or creating habitat around rivers, such as a buffer strip directly adjacent to the channel, is recommended for the health of those rivers by Forestry agencies; this can help counter effects from human activity by filtering runoff and reducing bank-side erosion (Thomson *et al.,* 2003; Broadmeadow & Nisbet, 2004; Mapili, 2007; Effert *et al.*2008).

Soil erosion can impact the terrestrial system by removing nutrients, damaging plants, and decreasing infiltration rates (causing secondary erosion); the atmosphere can be affected, with a potential feedback loop via global warming if this increases rainfall as predicted; finally, eroded sediments will have large impacts on the aquatic ecosystems they reach (Wood & Armitage, 1997; Pimentel & Kounang, 1998). If sediment loading of a river increases, this can influence nutrient levels, decrease light levels, abrade macrophyte plants, impair filter feeding, respiration and predation in animals, and may even by fatal to vulnerable life stages for example salmonid eggs and juveniles (Wood & Armitage, 1997; Pimentel & Kounang, 1998; Walling, 1999; Bolton & Shellberg, 2001; Julien & Bergeron, 2006). Most of the soil eroded by water is transported into streams (Pimentel & Kounang, 1998).

The hydrology of a river is also affected by land-use, which can have implications for river morphology, water supply and flood control (Ekness & Randhir, 2007; Kondolf *et al.,* 2007; MacDonald, 2008). Vegetation will decrease runoff speed and thus the rate at which water enters the river channel. This can cause a delay in the peak discharge after a rainfall event, and reduce the peak flow of water, in addition to increasing the base flow (MacDonald, 2008). This effect depends on the complexity of the vegetation, for example the vertical stratification of plants, and the spatial arrangement of vegetational elements. An area of woodland has a number of vertical strata which helps to intercept more precipitation than a monoculture crop or an area of grassland, whereas an area of woodland arranged in strips may have little effect in slowing down runoff compared with an area of small woodland patches if water can flow unimpeded between the strips (MacDonald, 2008). A similar principle applies to vegetation along the banks or floodplain of a river, which can reduce the river flow by increasing the hydraulic roughness or forcing the river to take a less direct route

(Bolton & Shellberg, 2001; Wohl, 2005; MacDonald, 2008). This has the additional benefit of reducing scouring of the riverbed and adding to the heterogeneity of microhabitats within the river (Linstead & Gurnell, 1999; Ekness & Randhir, 2007).

Vegetation also increases infiltration of water into soil, by slowing water down, penetrating soil with roots, and absorbing some of the water that has already infiltrated the soil. By decreasing runoff and runoff speed, and increasing infiltration, the amount of water reaching rivers quickly is reduced and thus floods and droughts are less likely (Bolton & Shellberg, 2001; Cayuela *et al.,* 2006; Ekness & Randhir, 2007; Kondolf *et al.,* 2007). Conversely, removing much or all of the vegetation or changing its arrangement can lead to a flashier river, which is more likely to flood after a storm event but also run dry in periods when less rainfall occurs.

Benefits of catchment woodland can include the ecosystem services of cleansing air and filtering water, in addition to conserving soil and reducing floods, and these services have financial and health benefits to the human populations in the area (Thomson *et al.,* 2003; Cayuela *et al.,* 2006; Kondolf *et al.,* 2007). The woodlands can also lock up carbon and so have global benefits in helping balance out some of the human impacts on global climate (Righelato & Spracklen, 2007; Low & Booth, 2008).

Rivers can in turn influence the terrestrial habitats around them, if both ecosystems are functioning correctly (Ward *et al.* 1999; Bolton & Shellberg, 2001; Wohl, 2005). Floodplain woodlands are important habitats for many plant and animal species (Arscott *et al.* 2002; Arcos *et al.* 2008), and although now rare or absent from the UK it is the natural condition for the floodplains (Latham *et al.*, 2000; MacDonald *et al.* 2008). In addition to benefitting rivers, it is a valuable and rare ecosystem worthy of conservation in its own right – Annex 1 of the Habitats Directive describes it as the richest ecosystem in Western Europe (MacDonald, 2008). If there were more woodland habitat in catchments it would provide opportunity for more of these riparian woodland communities to develop.

River catchments can be particularly diverse in habitats, plants and animals as this diversity occurs both along environmental gradients – between aquatic and terrestrial areas, between upland and lowland areas - and in patches within the landscape (Naiman *et al.* 1988; Ward *et al.* 1999; van Coller *et al.* 2000).The lower reaches of a river can have a higher turnover of habitat due to flooding and other processes (Arscott *et al.* 2002), and the high heterogeneity of floodplains can in part be attributed to subsequent successional communities, at different stages in different patches (Naiman *et al.*, 1988; Kalliola & Puhakka, 1994; Bolton & Shellberg, 2001). Thus natural floodplain woodland is a mosaic of patches each at different points in time and under slightly different conditions, linked to each other and the river ecosystem by connectivity of organisms, matter and energy. The diversity of adjacent habitats allows a number of specialist species to coexist in the landscape, including those that depend on multiple habitats (e.g. wooded rivers being used by bats that depend on woodland, on rivers, and those that require the two: Wermundsen & Siivonen, 2008).

4. Method

4.1. Predictions

It was predicted that settlement and agricultural land uses are negatively correlated with the longitudinal slope of rivers in Wales, and that some semi-natural land uses will subsequently increase with slope (including semi-natural woodland). Within rivers, settlement and agriculture should be associated with the lower reaches, where the catchment is less steep and has more fertile soil, whilst semi-natural woodland and managed (plantation and felled) woodland should be more prevalent upriver where the reverse is often the case.

4.2. Datasets

The data used were:

- River data – Digital shapefiles from the Environment agency (courtesy of I. Harris at the University of Wales, Bangor), and where absent from the dataset Ordnance Survey 1:10,000 map tiles from Digimap were used to create shapefiles.
- Land use data - Habitats of Wales, Phase I Data (revision 2) from the Countryside Council for Wales.
- Elevation data – DEM 10m grid for Wales from Ordnance Survey Great Britain (courtesy of the University of Wales, Bangor).

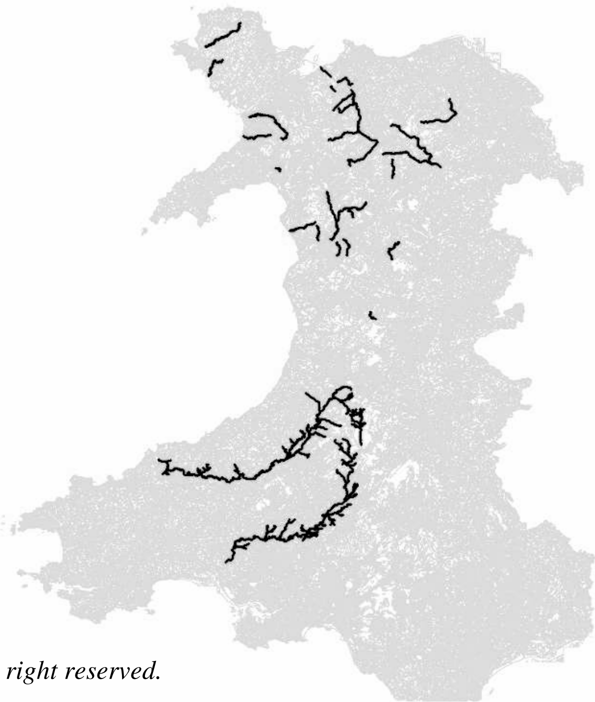
4.3. Data processing

The Phase I Data, originally in MAPINFO format, were converted for use in ArcGIS 9.2 using ESRI's MIF to Shape converter in the ArcGIS Toolbox.

Welsh rivers were chosen to create a range of forms, locations and land uses. Where available, river shapefiles were then obtained for these rivers. Where these were absent, they were created using Ordnance Survey map tiles and the ArcMap editor set to "create new feature". It was necessary to ensure that all data added to ArcMap were set to use "OSGB", the British National Grid coordinate system.

The river shapefiles were then used to create buffers for the selected rivers using the ArcMap buffer tool. The initial buffer was set to 1.1km, although it was planned to introduce additional, smaller, sizes of buffer later on. Some rivers were left out of the study due to their small size, as it became apparent that they were not suitable for a study with a buffer of 1.1km. In total, 68 river catchments were included in the study (fig. A.2.1, and a full list is included in the Table of results, in appendix fig. B.2.1).

Fig.A.2.1: A Map of rivers included in the study.



Map produced from CCW data, all right reserved.

When it became apparent that analysis of land use patterns within rivers would best be achieved by buffering the river sections rather than the whole rivers (and this would also allow separation of rivers that were on the same layer), the ArcGIS extension application "Buffer With Attributes" (Tilton 2005) was used to produce a 1.1km buffer composed of separate polygons (each buffering a different section of the river polylines) that retained the information regarding river source and location as attributes. The polygons making up a section of river were then selected, and the data exported to a relevantly named file.

Buffer shapefiles were used to clip the datasets (using the Clip tool and the Spatial Analyst Raster Calculator in ArcMap for the land-use data and elevation data respectively) to a more manageable size, so that only habitat data and elevation data within the study areas would be included in the layer. This cut down the time for processing the data, particularly noticeable when clipping data for each river or river section. The buffers for individual rivers and river sections were used to clip the habitat data into corresponding sections which could be analysed. Habitat data was extracted to a .dbf file using the summarize option in the attributes table of each habitat clip (as per ESRI 2007).

The .dbf files were opened using Microsoft Excel, and the data were used to calculate the total area of the clip, as well as the area for the categories “semi-natural woodland” (including Phase I categories A1.1.1, A1.2.1 and A1.3.1), “scrub” (categories A2.1 and A2.2), “plantation and felled woodland” (categories A1.1.2, A1.2.2, A1.3.2, A4.1, A4.2 and A4.3), “agriculture” (categories B1.2, B2.2, B3.2, B4, B6 and J1.1), “artificial waste and rock” (categories I2.1, I2.2, I2.3 and I2.4) and “settlement” (categories J1.5, J3.4 and J3.6). *See appendix, fig. B.1, for key to Phase I Habitat codes.*

The area of land for which the use was undetermined was subtracted from the total area, as was the area of open water (to prevent bias caused by larger rivers contributing more of this land use type to their catchment) and intertidal land (to prevent bias within rivers caused by the prevalence of this type of land use in the lower reaches of rivers). This net total was subsequently used to calculate the % cover of each category of land use, as well as the remaining land uses in the category “other land use”. This latter was often dominated by grassland, marsh and heathland type habitats in the rivers studied, although the methods were not designed to describe any patterns in these habitat types.

The start and finish altitude of each river was recorded using the identify tool in ArcMap, set to identify the Elevation data layer (it was necessary to zoom in to a point where the 10m resolution on this layer would allow consistent sampling of the layer at a given point). The river length was recorded using the attributes table of each river polyline, leaving out duplicate sections and taking an average if a river was "braided" into multiple channels.

These data were used to calculate in Microsoft Excel the overall, longitudinal, slope of each river in the study. Slope (in percent) is the height lost along the river divided by the river length and multiplied by a hundred. The loss of height is calculated by subtracting the finish altitude from the start altitude.

4.4. Statistical tests

The two-tailed Pearson test of linear correlation was used in SPSS v.16 to investigate the relationship between the slope of each river and the cover of each of the land use categories within the catchment, as well as the relationship between land use categories.

The same test was used to investigate relationships within-river, namely that of the land use categories to location within the river (how far upriver the section in question is located) as well as those between the land use categories. There was insufficient time to extract and analyse data for the sections of every river, so this analysis is restricted to the largest rivers of the Teifi, Tywi and Conwy.

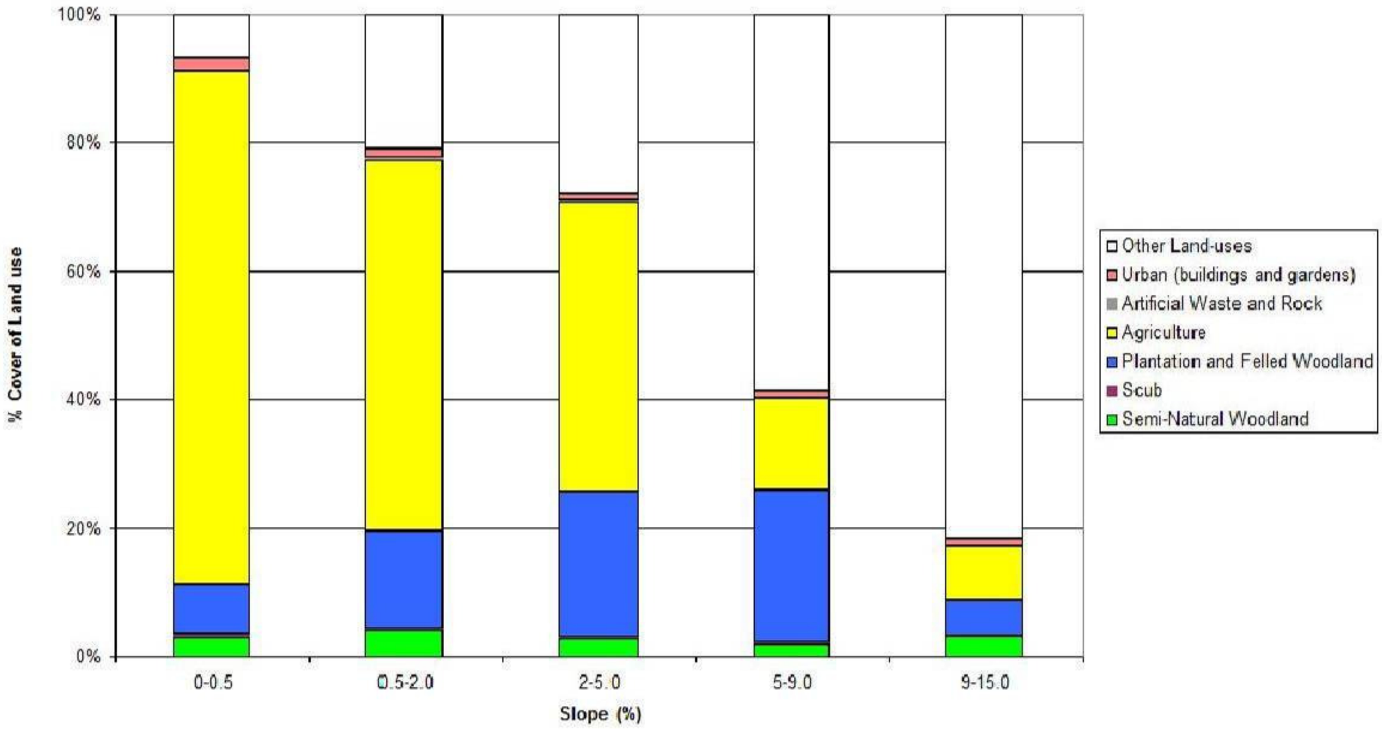
5. Results

5.1. Data for Entire Rivers

5.1.1Patterns between Welsh Rivers

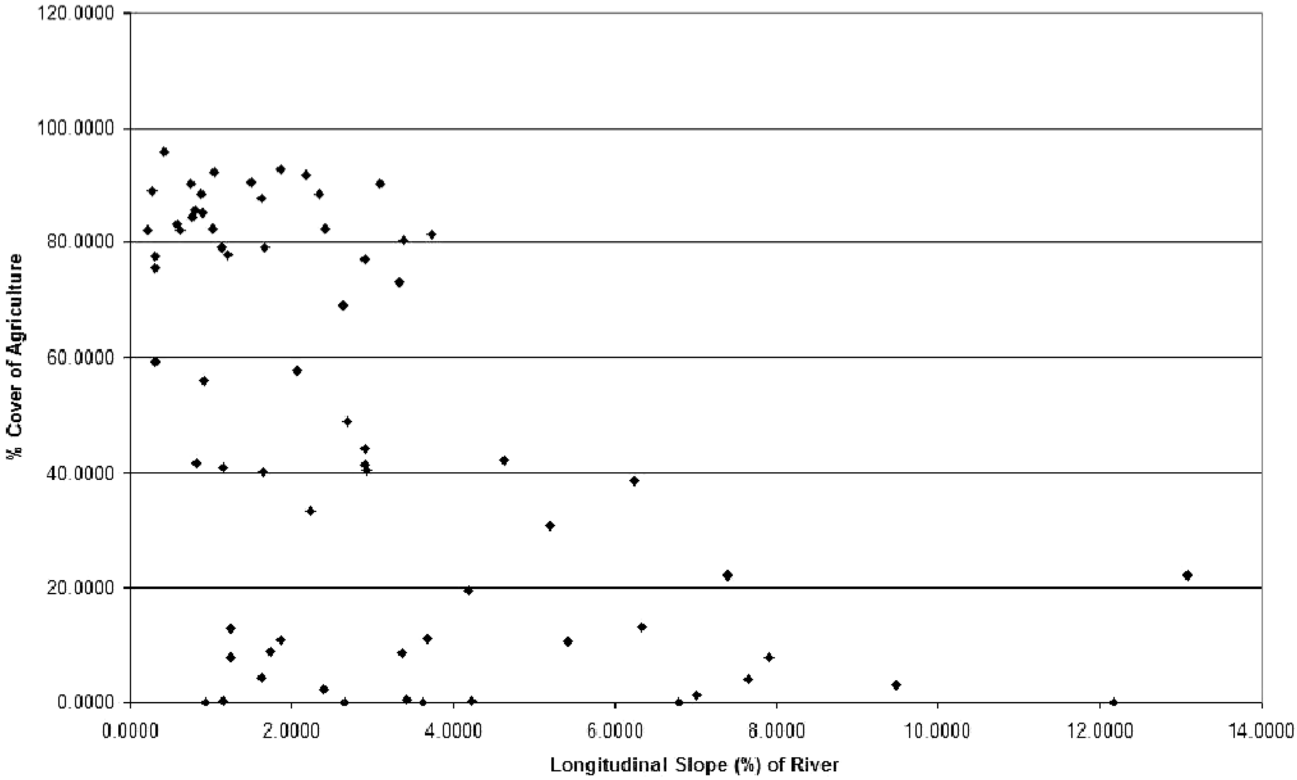
The results are summarised in fig.A.3.1. The full results table can be found in the appendix, fig. B.2.1.

Fig.A.3.1: Proportions of land use in Welsh rivers by Slope class (standard slope descriptors, as per Barcelona Field Studies Centre 2009)



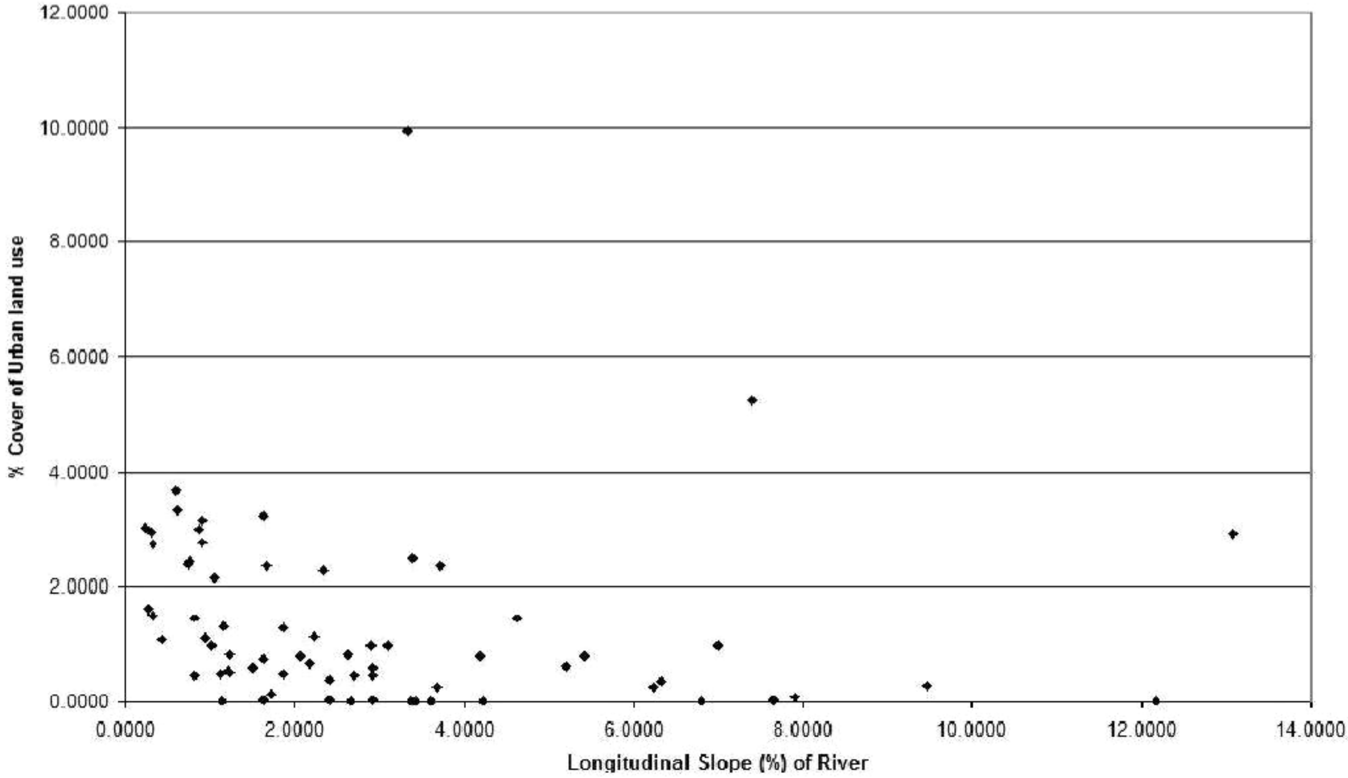
The two relationships immediately apparent in the data (fig. A.3.1) were between Slope of the river and the cover of both Agriculture and Settlement (seen further in fig.A.3.2 and fig.A.3.3). Plantation and Felled Woodland seemed to be at highest proportions at intermediate steepness, whilst the Other Land-uses category increased with slope (fig. A.3.1). The Artificial Waste and the Scrub categories both have a very minimal presence in the dataset, with neither achieving a cover of 5% or more in any river (fig. B.2.1).

Fig.A.3.2: Cover of Agriculture in rivers against Slope of rivers



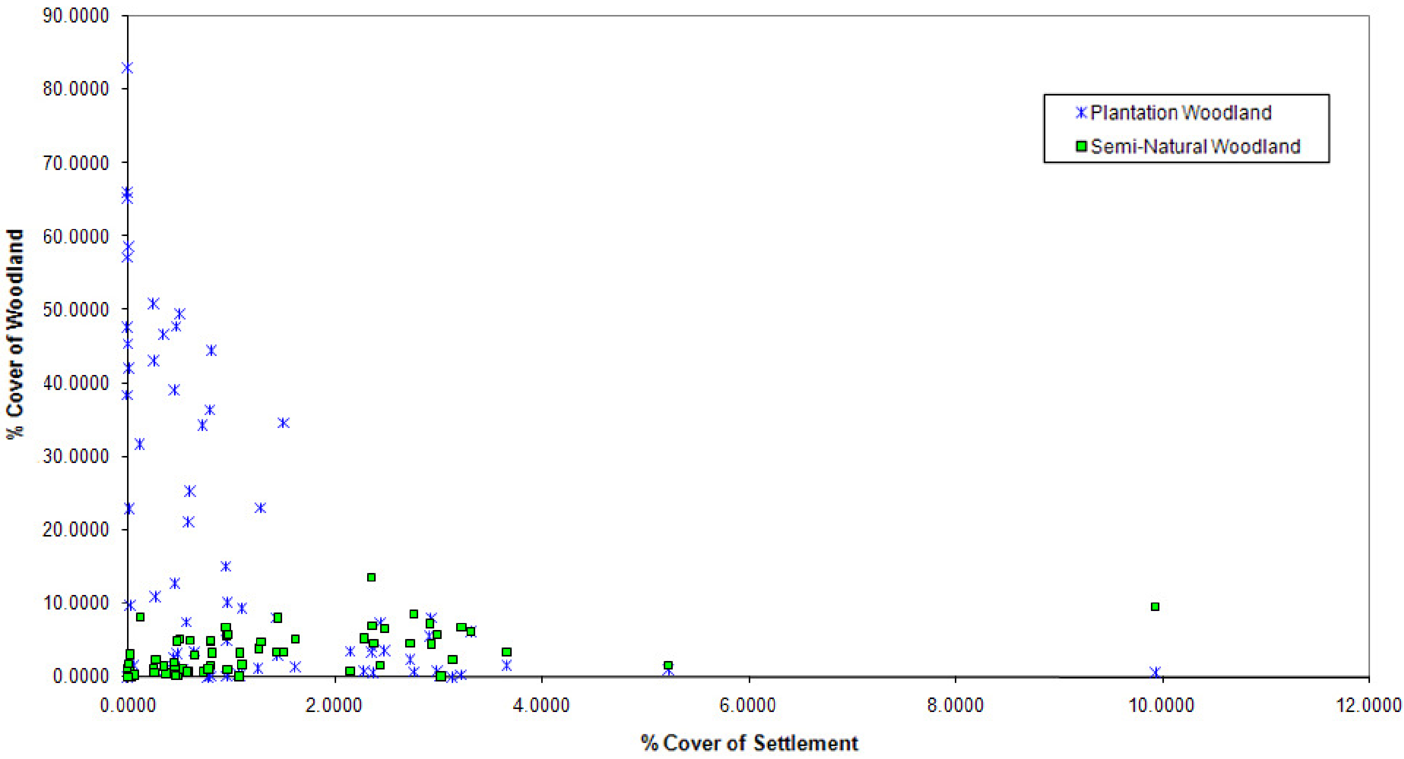
From fig. A.3.2 it is quite apparent that longitudinal slope and the amount of agriculture in a catchment are negatively correlated.

Fig.A.3.3: Cover of Settlement in rivers against Slope of rivers



From fig. A.3.3 it seems that the amount of settlement in a catchment is negatively correlated with the slope of the catchment, although there are a few rivers which do not conform to the general pattern.

Fig. A.3.4: Woodland Cover vs. Settlement Cover in Welsh rivers



In fig. A.3.4 it can be seen that the covers of the two types of woodland have different relationships to Settlement land-use; Plantation and Felled Woodland has a sharp decline in cover as the settlement in the river increases, whereas Semi-Natural Woodland slowly increases as settlement increases.

5.1.2. Statistical Tests for Relationships between Welsh Rivers

The following relationships were found to be significant to 99%:

- Longitudinal slope of the river and cover of Agriculture were negatively correlated (P= -0.531, n=68, p=<0.001).

- Cover of semi-natural woodland was positively correlated with cover of scrub (P= 0.432, n=68, p=<.001) and cover of settlement (P= 0.504, n=68, p=<0.001).
- Cover of plantation and felled woodland was negatively correlated with cover of semi-natural woodland (P= -0.342, n=68, p=0.004), scrub (P= -0.383, n=68, p=0.001), agriculture (P= -0.654, n=68, p=<0.001) and settlement (P= -0.472, n=68, p=<0.001).
- Cover of agriculture was positively correlated with cover of scrub (P= 0.402, n=68, p=0.001) and settlement (P= 0.466, n=68, p=<0.001).
- Cover of settlement and cover of scrub were also positively correlated (P= 0.530, n=68, p=<0.001).

The following relationships were found to be significant to 95%:

- Cover of semi-natural woodland and cover of agriculture were positively correlated (P= 0.302, n=68, p=0.012).

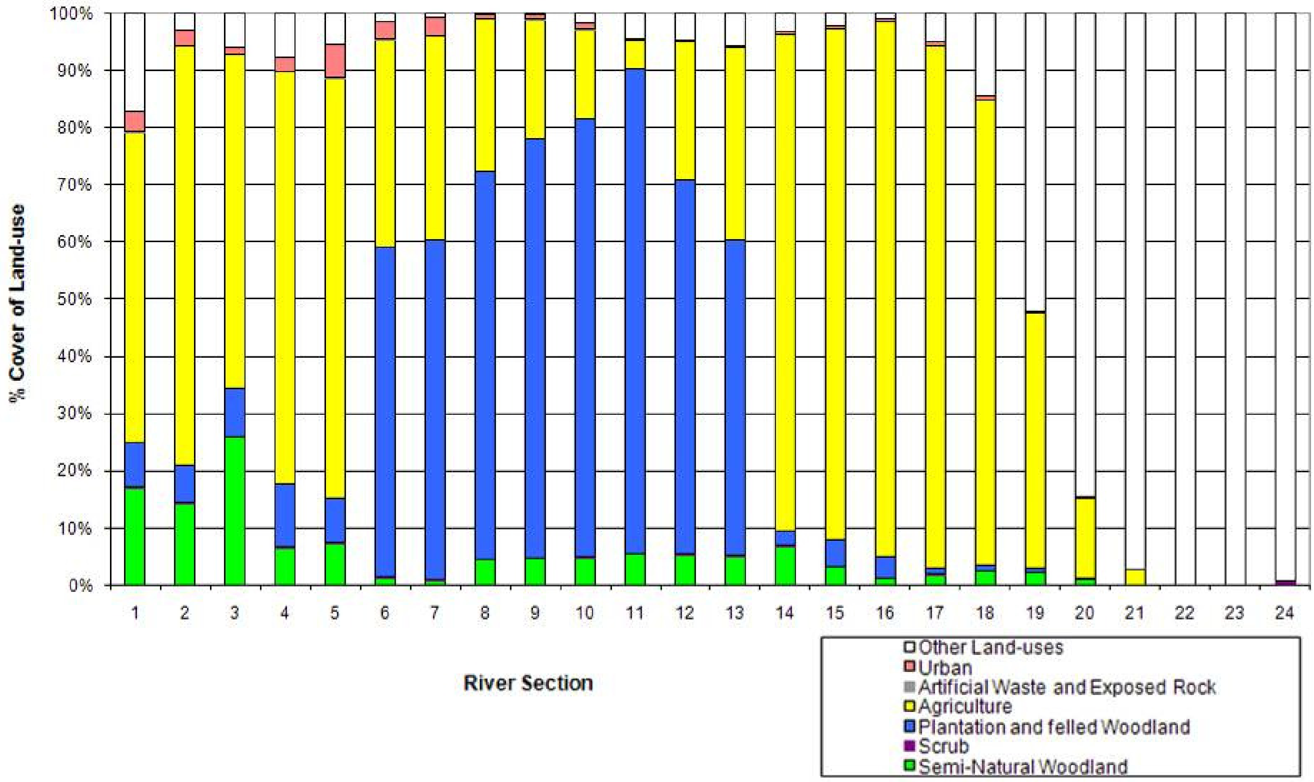
5.2. Data for River Sections

5.2.1. The Afon Conwy

5.2.1.1. Patterns in the Afon Conwy

In the high-resolution analysis of the Afon Conwy (broken down into 24 sections, fig. A.3.5), there are a few patterns that are apparent, though these are somewhat more complex than those generally seen in the between-river analysis. The four latter-most sections have very few land uses, being almost completely dominated by the “other land-uses” category. Before this stage, however, agriculture and plantation and felled woodland between them account for the majority of land-use. Plantation and felled woodland is dominant at intermediate sections of the river, around sections 6-13, whereas agriculture is prevalent before and after this stage. Both the semi-natural woodland and the urban land-use categories reach their highest cover in the lower reaches of the river, and generally decrease with upriver progression.

Fig.A.3.5: Land-use patterns within the Afon Conwy



Besides dominance in the upper reaches, the Other Land-uses category is also notable for a small peak in the very lowest section of the Conwy. Neither the Artificial Waste nor the Scrub categories are particularly prevalent (see also fig. B.2.2 in the appendix), being far outstripped by the other land-uses in terms of area.

5.2.1.2. Statistical Test of Correlations in the Afon Conwy

The following relationships were found to be significant to 99%:

- Progression upriver and was negatively correlated with cover of semi-natural woodland ($P= -0.704$, $n=24$, $p=<0.001$) and settlement ($P= -0.743$, $n=24$, $p=<0.001$).
- Cover of settlement and of artificial waste and exposed rock were positively correlated ($P= 0.807$, $n=24$, $p=<0.001$).

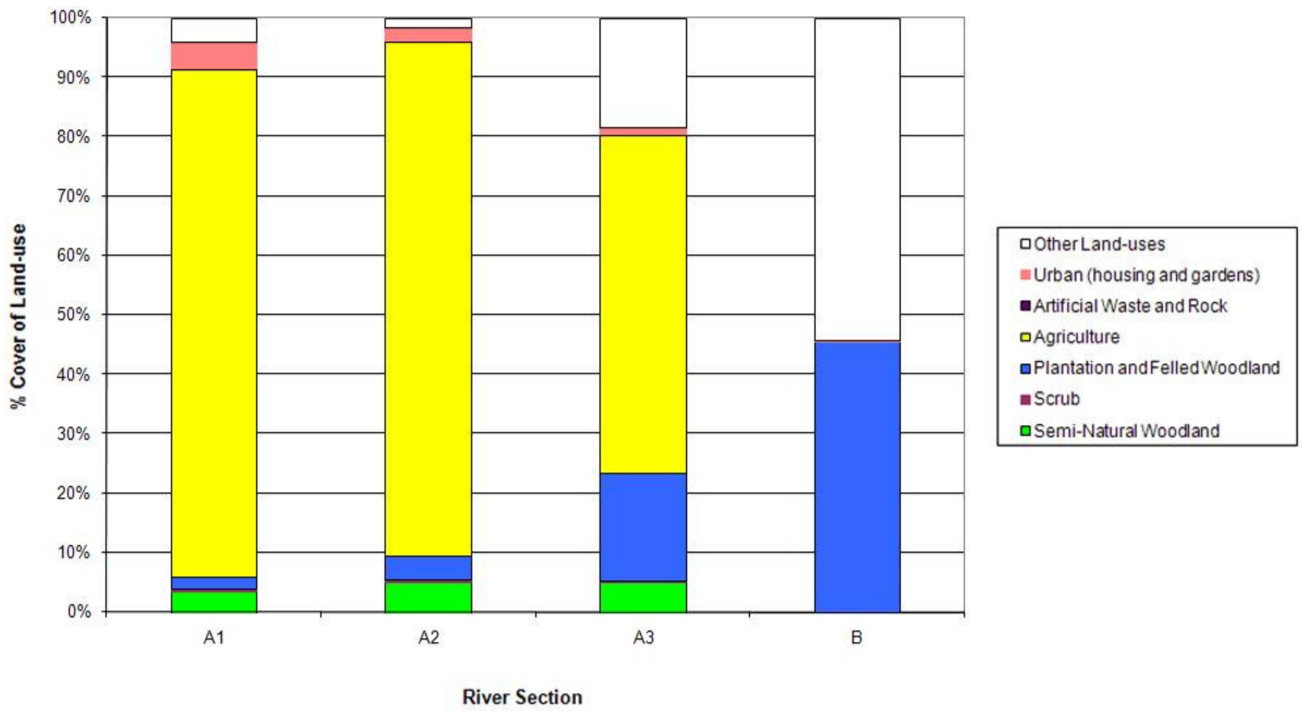
The following relationships were found to be significant to 95%:

- Progression Upriver and Cover of Artificial Waste and Rock were negatively correlated (P= -0.426, n=24, p=0.038).

5.2.2. The Afon Tywi
5.2.2.1. Patterns in the Afon Tywi

Agriculture cover decreased from the lower reaches through to the upper reaches, as did cover of urban land-uses (fig. A.3.6). Plantation and Felled woodland actually increased in the progression upriver, whereas there was no clear linear pattern for cover of semi-natural woodland. Neither the Artificial Waste nor the Scrub land-uses were particularly apparent in any section (see also fig. B.2.2 in the appendix). The "other land-uses" category generally increased in cover with progression upriver, although cover in the lowest section of the river was higher than in the second-lowest section (fig. A.3.6).

Fig.A.3.6: Land-use patterns within the Afon Tywi



5.2.2.2. Statistical Test of Correlations in the Afon Tywi

The following relationships were found to be significant to 99%:

- Cover of plantation and felled woodland was negatively correlated with cover of agriculture (P= -0.998, n=4, p=0.002).

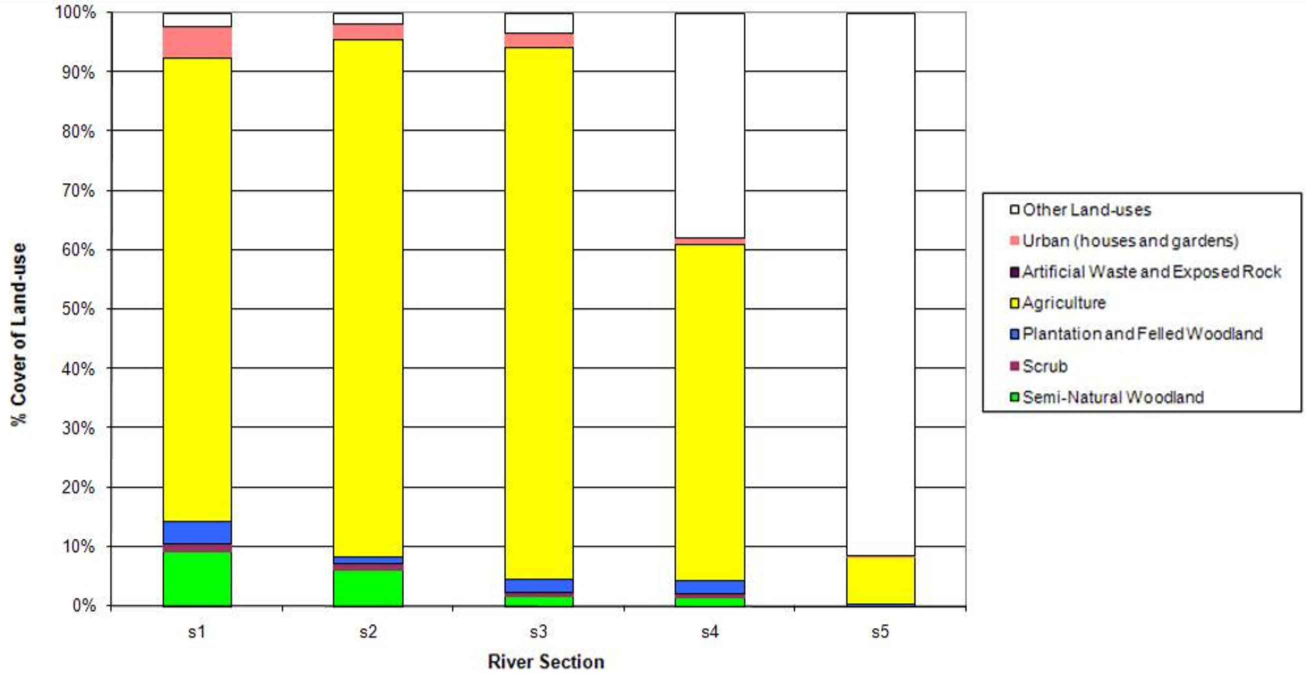
The following relationships were found to be significant to 95%:

- Progression upriver was negatively correlated with cover of scrub (P= -0.976, n=4, p=0.024) and settlement (p= -0.988, n=4, p=0.012).
- Cover of scrub was negatively correlated with cover of plantation woodland (P= -0.985, n=4, p=0.015) and positively correlated with cover of agriculture (P= 0.973, n=4, p=0.027).

5.2.3. The Afon Teifi

5.2.3.1. Patterns in the Afon Teifi

Fig.A.3.7: Land-use patterns within the Afon Teifi



Agriculture actually seems to be highest in the middle sections of the Teifi River (fig. A.3.7), whereas most other land-uses decrease with progression upriver (the Other Land-uses category is the exception). Although Plantation and Felled

Woodland decreases in the upper sections of the river, the relationship between cover and river section doesn't appear to be linear. The Other Land-uses category once again increases upriver, coming to dominate the catchment by section s5. Neither the Artificial Waste nor Scrub categories are very apparent in the catchment (see also appendix, fig. B.2.2).

5.2.3.2. Statistical Test Correlation in the Afon Teifi

The following relationships were found to be significant to 95%:

- Progression upriver was negatively correlated with cover of semi-natural woodland (P= -0.945, n=5, p=0.015), scrub (P= -0.918, n=5, p=0.028) and settlement (P= -0.953, n=5, p=0.012).
- Cover of semi-natural woodland was positively correlated with scrub (P= 0.915, n=5, p=0.30) and with settlement (P= 0.922, n=5, p=0.026).

6. Discussion

6.1. Discussing the results

6.1.1. Patterns between Welsh rivers

It was expected for agriculture and settlement to decrease with increasing slope (fig.'s A.3.1, A.3.2 and A.3.3). The steeper the river is longitudinally, the greater the amount of the land within the catchment that will be of low suitability to these land uses.

Open semi-natural habitats such as grasslands, heath and wetlands were much more dominant in the steeper rivers than expected, so that both woodland type land-uses were not linearly related to slope (fig. A.3.1). In fact, only agriculture was linearly related to slope, as shown in the statistics.

In terms of relationships between land-uses, it was surprising that cover of semi-natural woodland was associated with settlement and agriculture cover (fig.'s A.3.1, A.3.4), although not that the latter two would be associated with each other. However if one looks at Semi-Natural Woodland and Plantation Woodland together, the total woodland increases in the intermediate slopes (as might be expected from Fu *et al.* 2006b). It is simply that more of the total woodland is managed for human use with increasing slope, although for reasons unknown, until the Other Land-uses category begins to dominate (fig. A.3.1).

6.1.2. Patterns within rivers

It was expected that many of the same patterns found with slope would be apparent within rivers, in relation to the distance upriver. There were in fact some very different relationships found, as rivers had a great degree of individuality. The different patterns could result from different topographies or from different histories of human use in the catchments.

The correlations of the land-uses with progression upriver in the Afon Conwy (fig. A.3.5) were those most similar to the relationships with slope between all rivers (fig. A.3.1) – this may be because there actually is an increase in slope with progression upriver in the Conwy, or because this river fits better with the average river than the Teifi and Tywi.

Moving up the Afon Tywi, Plantation and Felled Woodland actually increased steadily to the end rather than peaking at the intermediate stage (fig. A.3.6). In the Afon Teifi both woodland types decreased with progression upriver (fig. A.3.7), and Plantation and Felled Woodland actually accounted for very little of the catchment land-use in any section. Both patterns are unexpected when considering the relationships found with river slope, and assuming slope generally increases within the river as one moves from the lower to the upper reaches. This may not be the case in some of these rivers, and the distribution of woodland in the Tywi is not entirely unusual based on the literature either (both grassland and woodland can be associated with poorer and steeper soils, from Fu *et al.* 2006b).

The prevalence of settlement and agriculture in the lowland reaches of rivers means that these lowland areas are subject to a lot of negative human impacts (woodland is described as very vulnerable to agriculture land use by Domon, Bouchard & Gariépy, 1993), and may be vulnerable to encroachments in the future. As a result they require protection, but habitat in the uplands may currently be much more pristine and thus already of conservation value. The lack of woodland cover in the very upper reaches of rivers, or in the steepest rivers, has implications for erosion and flooding, and if the extent of forest is limited by historical human influence rather than altitudinal limits to tree growth it might be worth increasing uplands woodland cover. The benefits could extend to the terrestrial and freshwater ecosystems in the area, as well as the downstream habitats and settlements.

If these rivers were to function as corridors of semi-natural habitat, they would need increases in semi-natural cover from that seen in fig.'s A.3.5, A.3.6 and A.3.7. Even looking at total semi-natural habitat, assuming that many species can use any semi-natural habitats to traverse a landscape, if following Andrén (1994) one should aim for 30% cover so there is a long way to go. Although some habitats have more presence in the lowlands, in terms of total semi-natural cover it is the lowland reaches which require the most attention (with the majority of the "other land-use" in the uplands attributed to open semi-natural habitats).

6.2. Limitations of the study

It would be worth subdividing some of the land-use categories, especially Other Land-uses as this category dominated the upper reaches and steeper rivers. It was noted that it was often open semi-natural habitat which caused this dominance, but no patterns could be analysed. Fu *et al.* (2006b) found grassland associated with steep slopes and poor soils so a pattern is expected.

Collaboration with CCW meant Phase I data was easy to access, but are now dated (surveys were up to 1999). The conclusions about land-use distribution could be more contemporary by using more recent data, such as Landsat 2000 satellite data. Including a series of time periods (such as Landsat 1973, 1989 and 2000) would allow study of land-use change, and give a clearer picture of the processes involved and of the future of the Welsh landscape (see: Pan *et al,,* 1999; Chen *et al.,* 2001; Tagene, 2002; Swetnam, 2006; Tayyebi *et al.,* 2008).

The GIS software has a few limitations. The software didn’t allow clips of data to be divided up as desired into sections, which required the individual buffering of each polyline segment. The choice of buffer polygons was thus limited by the existing polyline and its distribution of segments, and it was not very feasible to re-do a polyline due to the length of time required and the subsequent change to all layers and tables. As buffers were restricted to a round-ended style (including all land within the set distance of the polyline segment), there was a degree of overlap of land between polygons and thus between sections of a river.

There was insufficient time to analyse all rivers for within-river patterns, or to examine all of the selected rivers in high resolution as in fig. A.3.5. Comparison of a low resolution and high resolution analysis of the Conwy showed that although the analysis had less power at low resolution, the relationships found held true in the high resolution, thus the low resolution analyses have validity but don’t show the full picture.

Analysing patterns on a river-by-river basis misses out on a lot of detail within the rivers, and the analysis would be a lot more powerful if the river sections were also analysed for slope. Whilst the overall, longitudinal slope of the river can give an indication of how much steep land there is within the river, there can be a lot of variation in the topography of each river which is undetected. This might explain some of the variation found between the three longest rivers when land-use was compared with location within the river. Ideally, a future study would look at the steepness of the land (perhaps in any direction) and how land-use changes with it, to see if patterns observed in other studies (e.g. Fu *et al.*, 2006b) hold true in Welsh catchments.

Time constraints also meant it was not possible to examine the effects of scale on the relationships found – it is predicted that land use varies with distance from the river as in Zhou *et al.* (2006), and thus different relationships and patterns could be found in land within a 100m buffer than that found within a 1100m buffer of the river. It is predicted that the potential problems for human use of land very close to the river (such as bank instability and flooding) coupled with schemes to encourage riparian buffer strips will mean that natural land-uses are more prevalent closer to the river channel in Welsh catchments. This may lead to a breakdown of the relationships found in this study when using smaller buffers.

Additional physical factors could be analysed as potential influences on land use, such as lateral slope (as in van Coller *et al.*, 2000), geology (see Pan *et al.*, 1999), or soil characteristics (see Fu *et al.,* 2006b). Another option is to include the % area that has protected designation, e.g. as National Reserve, Local Reserve, SSSI, or in agri-environmental schemes. The occurrence of such management schemes could be compared with the land-use proportions in each catchment to see if they make a widespread and observable difference to the land use.

7. Conclusions

Broad patterns of change can be described along rivers, although this can be dependent on the river. This can include decreasing agriculture and settlement as one moves from the river mouth to the river source, although this is not always the case. When comparing between different rivers using the longitudinal slope, patterns are less clear but hold more generality. Agricultural land-use generally decreases with increasing slope, as does the amount of settlement land-use. As rivers are generally steeper in their upper reaches and invariably have a gentle slope in lower reaches, it is not a complete surprise that both river slope and location within a river will affect the land use in this way.

Knowing where different land uses are focussed within catchments informs the planning process (Gosselink *et al.,* 1990; Wood & Handley, 2001; Tegene, 2002) and further studies into the processes of land use change could help habitat networks and policy make allowances for future change. To increase connection of woodland habitats, and improve ecological functioning of upland river sections, afforestation could be focussed in the uplands of river catchments (where many catchments have little semi-natural woodland cover). This can allow some woodland species to migrate up hillsides or traverse landscapes in response to climatic changes, such as increasing temperatures.

The location of human land-uses such as settlement and agriculture could help decide which areas of semi-natural habitat require most protection. The current distribution of habitat can be used in plans to improve the traversibility of the landscape, or to target specific problems e.g. pollution of river from upstream land-use. The individuality of each river means that they would benefit from strategies that take into account that individuality. However, general patterns can be used to define national goals, for example there is a general lack of upland woodland that has implications for erosion and flood control in Welsh rivers.

A study with more time could look at how land use changes over time to predict future trends, or could include additional detail (i.e. of land use or slope). Although slope has a large influence on land-use, the factors that could influence land use also include the geology, soil characteristics, frequency of flooding and the management practices in the catchments. These would also be worth investigating in Wales, according to the findings in other studies and in other parts of the World.

8. Acknowledgements

Firstly, heartfelt thanks go to Catherine Duigan and Tristan Hatton-Ellis at the Countryside Council for Wales, for initial concepts, guidance, and data sourcing.

Secondly, I am extremely grateful to Ian Harris of the University's School of Environment and Natural Resources. He also helped with data sourcing, but in addition he provided some vital GIS instructions and advice.

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10. Appendices

Fig. B.1: Key to Phase I Habitats Codes

Code for Phase 1 habitat survey of Wales	Name for Phase 1 habitat survey of Wales	Code for Phase 1 habitat survey of Wales	Name for Phase 1 habitat survey of Wales	Code for Phase 1 habitat survey of Wales	Name for Phase 1 habitat survey of Wales
A	Woodland and scrub	E1.7	Wet modified bog	H6.6	Dune heath
A1	Woodland	E1.8	Dry modified bog	H6.7	Dune scrub
A1.1	Broadleaved woodland - semi-natural	E2	Flush and spring	H6.8	Open dune
A1.1.1	Semi-natural broadleaved woodland	E2.1	Acid/neutral flush	H8	Maritime cliff and slope
A1.1.2	Planted broadleaved woodland	E2.2	Basic flush	H8.1	Hard cliff
A1.2	Coniferous woodland	E2.3	Brophyte-dominated spring	H8.2	Soft cliff
A1.2.1	Semi-natural coniferous woodland	E3	Fen	H8.3	Crevice/ledge vegetation
A1.2.2	Planted coniferous woodland	E3.1	Valley mire	H8.4	Coastal grassland
A1.3	Mixed woodland	E.3.1.1	Modified valley mire	H8.5	Coastal heath
A1.3.1	Semi-natural mixed woodland	E3.2	Basin mire	H.8.6	Coastal heath/coastal grassland mosaic
A1.3.2	Planted mixed woodland	E.3.2.1	Modified basin mire	I	Exposure and waste
A2	Scrub	E3.3	Flood-plain mire	I1	Natural rock exposure
A2.1	Dense scrub	E.3.3.1	Modified flood plain mire	I1.1	Inland cliff
A2.2	Scattered scrub	E4	Bare peat	I1.1.1	Acid/neutral inland cliff
A3	Parkland/scattered trees	F	Swamp, marginal and inundation	I1.1.2	Basic inland cliff
A3.1	Scattered broadleaved trees	F1	Swamp	I1.2	Scree
A3.2	Scattered coniferous trees	F.1.1	Scattered swamp	I1.2.1	Acid/neutral scree
A3.3	Scattered mixed trees	F2	Marginal and inundation	I1.2.2	Basic scree
A4	Recently felled woodland	F2.1	Marginal and inundation - marginal vegetation	I1.3	Limestone pavement
A4.1	Felled broadleaved woodland	F2.2	Inundation vegetation	I1.4	Other rock exposure
A4.2	Felled coniferous woodland	G	Open water	I1.4.1	Acid/neutral rock
A4.3	Felled mixed woodland	G1	Standing water	I1.4.2	Basic rock
B	Grassland and marsh	G1.1	Standing water - eutrophic	I1.5	Cave
B1	Acid grassland	G1.2	Standing water - mesotrophic	I2	Artificial rock exposure and waste
B1.1	Unimproved acid grassland	G1.3	Standing water - oligotrophic	I2.1	Quarry
B1.2	Semi-improved acid grassland	G1.4	Standing water - dystrophic	I2.2	Spoil
B2	Neutral grassland	G1.5	Standing water - marl	I2.3	Mine
B2.1	Unimproved neutral grassland	G1.6	Standing water - brackish	I2.4	Refuse-tip
B2.2	Semi-improved neutral grassland	G2	Running water	J	Miscellaneous
B3	Calcareous grassland	G2.1	Running water - eutrophic	J1.1	Arable
B3.1	Unimproved calcareous grassland	G2.2	Running water - mesotrophic	J1.2	Amenity grassland
B3.2	Semi-improved calcareous grassland	G2.3	Running water - oligotrophic	J1.3	Ephemeral/short perennial
B4	Improved grassland	G2.4	Running water - dystrophic	J1.4	Introduced scrub
B5	Marshy grassland	G2.5	Running water - marl	J.1.5	Gardens
B.5.1	Marshy grassland Juncus dominated	G2.6	Running water - brackish	J2	Boundaries
B.5.2	Marshy grassland Molinia dominated	H	Coastland	J2	Hedges
B6	Poor semi-improved grassland	H1	Intertidal	J2.1	Intact hedge
C	Tall herb and fen	H1.1	Intertidal mud/sand	J2.1.1	Intact hedge - native species-rich
C1	Bracken	H1.1.1	Intertidal - mud/sand - zoostera beds	J2.1.2	Intact hedge - species-poor
C1.1	Bracken	H1.1.2	Intertidal - mud/sand - green algal beds	J2.2	Defunct hedge
C1.2	Scattered bracken	H1.1.3	Intertidal - mud/sand - brown algal beds	J2.2.1	Defunct hedge - native species-rich
C2	Upland species rich ledges	H1.2	Intertidal cobbles/shingle	J2.2.2	Defunct hedge - species-poor
C3	Other tall herb and fern	H1.2.1	Intertidal - shingles/cobbles - zoostera beds	J2.3	Hedge with trees
C3.1	Tall ruderal herb	H1.2.2	Intertidal - shingles/cobbles - green algal beds	J2.3.1	Hedge with trees - native species-rich
C3.2	Non-ruderal herb and fern	H1.2.3	Intertidal - shingles/cobbles - brown algal beds	J2.3.2	Hedge with trees - species-poor
D	Heathland	H1.3	Intertidal rocks/boulders	J2.4	Fence
D1	Dry dwarf shrub heath	H1.3.2	Intertidal - boulders/rocks - green algal beds	J2.5	Wall
D1.1	Dry acid heath	H1.3.3	Intertidal - boulders/rocks - brown algal beds	J2.6	Dry ditch
D1.2	Dry basic heath	H2	Saltmarsh	J2.7	Boundary removed
D.1.3	Scattered dry heath	H2.3	Saltmarsh/dune interface	J2.8	Earth bank
D2	Wet heath	H2.4	Scattered salt marsh plants	J3	Built-up areas
D3	Lichen/bryophyte heath	H2.6	Salt marsh	J3.4	Caravan site
D4	Dry heath/acid grassland mosaic	H3	Shingle above high tide mark	J3.5	Sea-wall
D5	Wet heath/acid grassland mosaic	H.3.1	Mud/sand above mhw	J3.6	Buildings
D6	Basic dry heath/calcareous grassland mosaic	H.3.2	Shingle/gravel above mhw	J.3.7	Track (not comprehensively digitised)
E	Mire	H4	Rocks/boulders above mhw	J4	Bare ground
E1	Bog	H5	Strandline vegetation	J5	Other habitat
E1.6	Sphagnum bog	H6	Sand dune	NA	Not accessed land
E1.6.1	Blanket bog	H6.4	Dune slack	?	Habitat code illegible on the original vegetation map
E1.6.2	Raised bog	H6.5	Dune grassland		
			JNCC, March 2008	Modified by Heenan, March 2009	

Fig. B.2.1: Table of results - Rivers across Wales

RIVER	% cover: Semi-Natural Woodland	% cover: Scrub	% cover: Plantation Woodland	% cover: Agriculture	% cover: Artificial Waste	% cover: Settlement	% cover: Other	Longitudinal slope (%)
Alaw	0.0700	0.2992	0.4005	95.8826	0.0009	1.0795	2.2674	0.4300
Alwen	1.4128	0.0294	39.1392	41.6606	0.0016	0.4557	17.3007	0.8160
Arran	7.2420	0.0480	5.5727	22.0197	0.0000	2.9198	62.1977	13.0764
Bran b	3.3599	0.1631	34.6026	59.2880	0.0000	1.5100	1.0764	0.3176
Brefi	0.6413	0.0765	34.2532	40.1370	0.0263	0.7316	24.1341	1.6406
Breinant	6.9616	0.2012	4.1316	81.3522	0.0027	2.3672	4.9835	3.7247
Brennig-Berwyn	0.6885	0.0410	21.1107	40.4516	0.0336	0.5919	37.0828	2.9282
Camddwr	0.1836	0.3647	3.2544	79.1215	0.0061	0.4845	16.5851	1.1322
Ceirw a	0.6518	0.1986	42.1515	4.0722	0.0000	0.0173	52.9087	7.6446
Ceirw b	1.0529	0.0615	1.1353	77.8089	0.0022	0.5355	19.4036	1.2141
Cennan	5.8219	0.3227	0.8428	88.3697	0.0032	2.9955	1.6442	0.8786
Cerdin	4.6066	0.7320	0.6933	90.3315	0.0000	2.3791	1.2576	0.7484
Ceri	8.5949	1.6134	0.7616	85.1930	0.0616	2.7724	1.0031	0.8988
Cib	6.5025	0.1759	3.5808	80.2754	0.0025	2.4855	6.9773	3.3901
Cloidach	3.8438	0.1446	1.1790	92.7889	0.0000	1.2661	0.7776	1.8746
Clywedog a	1.5751	0.0382	36.3921	57.6511	0.0019	0.7995	3.5422	2.0724
Clywedog b	4.9980	1.2357	25.3954	30.8817	0.0917	0.6061	36.7914	5.1974
Clywedog c	0.0095	0.0000	9.7432	44.2571	0.0000	0.0331	45.9572	2.9127
Clywedog d	1.2258	0.0133	47.6564	8.5652	0.0000	0.0000	42.5393	3.3712
Conwy	4.7398	0.1486	23.0809	41.0081	0.0575	1.2903	29.6748	1.1537
Cothi	5.1674	0.2160	1.3888	88.9034	0.0000	1.6254	2.6990	0.2741
Crafnant	6.7856	0.3433	15.1061	1.2189	0.3616	0.9539	75.2307	7.0081
Crigyll	0.0559	0.3785	0.1263	82.1685	0.3180	3.0289	13.9239	0.2282
Cwm Llechen	2.3678	0.0597	10.9966	2.9886	0.0120	0.2724	83.3029	9.4726
Ddu a	1.5248	0.1905	1.0311	22.2249	0.1579	5.2299	69.6409	7.3945
Ddu b	4.7238	0.1172	0.1583	69.2792	0.0000	0.8041	24.9173	2.6365
Ddu c	5.0283	0.0264	0.3337	19.6978	0.0071	0.7992	74.1074	4.1928
Ddu d	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	100.0000	12.1684
Doethie	3.0959	0.0147	22.9137	4.3347	0.0131	0.0258	69.6020	1.6266
Dulas (teifi)	1.5925	0.2268	7.4057	84.4259	0.0030	2.4477	3.8984	0.7664
Dulas (tywi)	3.2379	0.4168	0.2157	0.1218	0.0000	1.0851	94.9228	0.9348
Eden	3.2812	0.0719	44.5073	12.9729	0.0000	0.8130	38.3537	1.2405
Ffrwd Cynon	0.9544	0.4725	4.9974	77.1365	0.0021	0.9645	15.4727	2.9043
Glasffrwd	1.2257	0.0391	50.8941	11.3099	0.0356	0.2559	36.2396	3.6796
Gwenffrwd (teifi)	5.2543	1.6030	0.7979	88.5388	0.0066	2.2877	1.5118	2.3455
Gwenffrwd (tywi)	8.1270	0.0666	31.7330	8.7785	0.0000	0.1221	51.1727	1.7304
Gwenlais	2.0255	0.3163	2.7526	48.7086	0.0564	0.4540	45.6866	2.6971
Gwyddenig	6.2255	0.2383	6.2569	82.0854	0.0000	3.3235	1.8704	0.6140
Gwyrfai	1.6580	0.1671	9.3403	33.2231	0.3971	1.1095	54.1048	2.2276
Hirnant	0.0273	0.0000	65.9590	0.1479	0.0000	0.0016	33.8642	4.2191
Lledr	5.2209	0.0316	49.4961	7.9011	0.0000	0.5105	36.8398	1.2382
Llyfni	2.3861	0.4577	0.0637	56.0389	4.6501	3.1420	33.2616	0.9117
Marchnant-Meurig	0.1873	0.2887	12.7351	41.3760	1.3179	0.4619	43.6330	2.9134

Mawddach	4.8794	0.1156	47.7454	10.8304	0.0177	0.4774	35.9341	1.8728
Mynach	0.4371	0.0000	1.0217	82.3134	0.0038	0.3714	15.8527	2.4103
Nant Bai	1.4500	0.1472	46.6997	13.1661	0.2442	0.3523	37.9406	6.3238
Nant Carfan	0.5667	0.0295	43.0203	38.6312	0.0862	0.2602	17.4059	6.2345
Nant Creuddyn	0.7621	0.1182	3.5254	92.3184	0.0000	2.1548	1.1210	1.0439
Nant Crug-yr-wyn	0.0000	0.0000	38.4139	0.0000	0.0000	0.0000	61.5861	6.7975
Nant Dyfel	0.6720	0.0312	7.4909	90.4437	0.0000	0.5750	0.7872	1.5006
Nant Fylchi	2.9436	0.0761	3.5038	91.8620	0.0000	0.6511	0.9634	2.1738
Nant Gurrey-fach	6.7912	0.2089	0.3249	87.7594	0.0105	3.2270	1.6780	1.6304
Nant Gwinau	0.0000	0.0000	82.9806	0.0000	0.0033	0.0056	17.0105	2.6617
Nant Hir	5.6498	0.4904	0.1108	90.2365	0.0000	0.9634	2.5491	3.0988
Nant Pibwr	3.4257	0.9026	1.6709	83.2540	0.0196	3.6667	7.0605	0.5899
Nant Rhydol	0.2942	0.0214	1.5716	7.9268	0.0000	0.0637	90.1223	7.9059
Nant Rhyd-y-fuwch	9.5350	1.1684	0.6718	73.2343	0.1498	9.9335	5.3072	3.3396
Nant y Gerwyn	0.0269	0.0000	65.2170	0.4037	0.0000	0.0038	34.3486	3.4236
Plysgog	13.5261	0.3385	3.4521	79.1003	0.1619	2.3624	1.0586	1.6657
Pysgotwr Fawr	1.7570	0.0134	58.6065	2.2819	0.0000	0.0131	37.3282	2.4039
Roe	8.0738	0.4332	2.9802	42.1847	0.0000	1.4538	44.8743	4.6312
Sawdde	3.3992	0.2871	8.1184	85.6292	0.0133	1.4369	1.1160	0.8113
Teifi	4.5353	1.0244	2.3711	75.5181	0.0361	2.7350	13.7799	0.3195
Tywi a	4.4629	0.3742	8.1111	77.5411	0.0385	2.9385	6.5337	0.3022
Tywi b	0.0171	0.0000	45.4023	0.3368	0.0000	0.0078	54.2360	1.1493
Tywi Fechan	0.0000	0.0000	57.1210	0.0000	0.0000	0.0039	42.8751	3.6165
Ydw	5.7822	0.1134	10.1968	82.4549	0.0044	0.9700	0.4782	1.0217
Ysgethin	1.0581	0.1703	0.0181	10.6397	0.0000	0.7810	87.3328	5.4175

Fig. B.2.2: Table of results – Within rivers

RIVER	Section	% cover: Semi-natural Woodland	% cover: Scrub	% cover: Plantation Woodland	% cover: Agriculture	% cover: Artificial Waste	% cover: Settlement	% cover: Other
Conwy	1	16.8497	0.2241	7.7057	54.2908	0.2113	3.4719	17.2466
(High res)	2	14.1269	0.0680	6.5736	73.4385	0.0000	2.5624	3.2306
	3	25.6695	0.0000	8.4899	58.5592	0.0000	1.1312	6.1502
	4	6.3582	0.1275	11.0637	72.1736	0.0000	2.4615	7.8154
	5	7.1251	0.1606	7.7537	73.2368	0.4819	5.7214	5.5204
	6	1.2654	0.0588	57.6351	36.2622	0.2775	2.9240	1.5770
	7	0.6370	0.0620	59.4492	35.8293	0.0000	3.1130	0.9095
	8	4.3626	0.0000	67.7350	26.7274	0.0000	1.0437	0.1313
	9	4.6534	0.0000	73.2903	20.9996	0.0429	0.6716	0.3422
	10	4.7672	0.0187	76.6018	15.7313	0.0283	1.0429	1.8097
	11	5.4042	0.0000	84.7960	4.9359	0.0000	0.3682	4.4956
	12	5.3064	0.0359	65.2928	24.2781	0.0000	0.2165	4.8704
	13	4.9098	0.0857	55.2795	33.7134	0.0000	0.2616	5.7500
	14	6.7231	0.0589	2.6093	86.7269	0.0000	0.3968	3.4849
	15	2.9824	0.0000	4.9393	89.3306	0.0000	0.4231	2.3246
Conwy	16	1.0129	0.0000	3.7790	93.6208	0.0000	0.3438	1.2435
(High res)	17	1.7729	0.0195	0.9423	91.5188	0.0000	0.6854	5.0611
	18	2.3687	0.0000	1.0441	81.2185	0.0000	0.6501	14.7186

	19	2.0486	0.0000	0.7568	44.8113	0.0000	0.1304	52.2529
	20	0.8842	0.0000	0.1955	14.0635	0.0000	0.0672	84.7896
	21	0.0000	0.0000	0.0000	2.5502	0.0000	0.0000	97.4498
	22	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	100.0000
	23	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	100.0000
	24	0.0000	0.6679	0.0000	0.0000	0.0000	0.0000	99.3321
Conwy	s1	13.0661	0.1234	8.2159	67.2910	0.1629	3.3142	7.8265
(Low res)	s2	3.1429	0.0292	67.2338	26.6960	0.0720	1.7762	1.0500
	s3	5.1039	0.0357	51.9771	38.1214	0.0000	0.3118	4.4499
	s4	1.5995	0.0040	1.3059	63.0886	0.0000	0.3526	33.6493
	s5	0.0000	0.1709	0.0000	0.7012	0.0000	0.0000	99.1278
Teifi	s1	9.0762	1.4467	3.8459	78.1153	0.0654	5.1540	2.2965
(Low res)	s2	5.9924	1.2045	1.1172	87.3120	0.0012	2.3946	1.9781
	s3	1.7405	0.5170	2.1878	89.8380	0.0146	2.2648	3.4374
	s4	1.3779	0.7865	2.1299	56.7962	0.0620	0.8385	38.0090
	s5	0.3080	0.0224	0.0116	8.1662	0.0000	0.0667	91.4251
Tywi	A1	3.4817	0.4426	2.0380	85.5837	0.0038	4.3933	4.0569
(Low res)	A2	5.0134	0.3461	3.9953	86.7135	0.0053	2.3250	1.6015
	A3	4.9121	0.2336	18.2149	57.0007	0.1046	1.1597	18.3744
	B	0.0171	0.0000	45.4023	0.3368	0.0000	0.0078	54.2360