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The Relationship between Vegetation, Micro-topography and Edaphic factors in a Lowland Floodplain Grassland System, South East England.

Presented by

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Abstract:

Lowland Wet Grasslands are internationally important because they support high biodiversity. Traditionally regular low intensity management in combination with periodic flooding has created habitat providing ecological niches for a wide diversity of flora and fauna, but changes in management practices particularly agriculturally in the past 60 years has made it globally threatened. In South East England intensification of agriculture, water regulation and urban encroachment has been recognised as the main causes of lowland wet grassland decline and biodiversity losses resulting in poor species diversity. This research assessed the relationship between Vegetation, micro-topography and edaphic soil factors using primary data collected during a vegetation, microtopography and edaphic factor survey of the floodplain grassland at the Knepp Castle Estate southeast England.

Five distinct zones of vegetation were identified during an initial visual walk through of the site; lower river bank, middle river bank, top river bank, middle floodplain and top floodplain. Ten 1x1m quadrats were randomly placed within each zone with twenty D-GPS points taken randomly within each and soil samples were taken for laboratory analysis. Species varied across the zones, some exhibited restriction where as others displayed a more competitive and adaptive presence across one or more zones.

A number of indicator species were identified along these elevational gradients; *Phragmites australis, Dactylis glomerata Glechoma hederecea Festuca ovina* and *Trifolium repens.* Regression results displayed a significant positive relationship between microtopographical heterogeneity and species richness and between soil pH and species richness.

The research results offer a greater understanding of the inherent relationship between these factors in lowland wet grasslands and displays implications for restoration and conservation management practices of lowland wet grasslands.

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I wish to thank the landowner Charlie Burrell and estates manager Jason Emrich for granting permissive access to the Knepp Castle Estate upon which the study site was located and also to Theresa Greenaway of the Sussex Biodiversity Record Centre who assisted in this.

Lastly I dedicate this thesis to my parents and friends for supporting me in this thesis.

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I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any university for a degree, and does not incorporate any material already submitted for a degree.

Signed: Dated:

1 Introduction

1.1 Research Context

Habitat loss and degradation has caused a rapid decline in biodiversity and become a worldwide concern with growing political recognition. High profile conventions such as RAMSAR (1971) (RAMSAR, 2010), the Bern Convention (1979) (Europa, 2006) and the UN Convention on Biological Diversity (1992) (CBD, 2010a) and strategies have acted to raise awareness and support for the implementation of effective environmental actions aimed primarily at conservation of biodiversity through protection and/or restoration of habitats (Bennet, 2004; Rosenqvist *et al,* 2007; Seto and Fragkias, 2007; CBD, 2010b; Morand, 2010,)

Wetlands, one of the World's most important and productive ecosystems have received extensive protective consideration (Mitch and Gosselink (2007); Demuth *et al* (2006); RAMSAR (2010); JNCC (2010a). They are functionally important in the provision of; clean water for dependent human populations; habitats of great ecological significance acting as reservoirs to plant genetic diversity, and large populations of bird, invertebrate, amphibian, fish, reptile, and mammal species; and in offering a great beneficial economic and recreational resource in agriculture, fisheries and tourism. Furthermore they're also important components of biospheric hydrological and chemical cycles for example, oxygen production, carbon sequestration and nitrogen fixation (Keddy, 2000, Gordon *et al,* 2010, Mitsch *et al,* 2009).

Despite the ecological and biospherical importance of wetlands, according to the JNCC (2010a) "owing mainly to continued drainage, pollution, over-exploitation or other unsustainable uses of their resources, are also among the World's most threatened ecosystems”. Decline and growing recognition of their multi service functions have amplified positive perspectives of wetlands and led from to an increasingly valued view of these landscapes and resulted in greater international conservation, management and protection (Ramsar, 2010).

Semi-natural lowland wet grasslands are sites of high conservation nature value (Critchley *et al,* 2002), considered a type of wetland habitat not equal to ecosystems but forming “a significant components of them” (Joyce and Wade, 1998), they are recognised as providing ecosystem services including “water regulation, carbon sequestration, landscapes and wildlife (indigenous plants, birds and invertebrates), and recreation and amenity” (Rural Economy and Land Use Programme, 2010). Known to rely on traditional regular low intensity management (e.g. mowing or grazing) to preserve their characteristic flora often encouraging a richer species diversity “lowland semi-natural biotopes are often limited” (Benstead *et al,* 1999) having seen a rapid decline due to a legacy of insensitive land-use changes such as land drainage, agricultural intensification, flood defence, and neglect (Joyce and Wade, 1998; Rural Economy and Land Use Programme, 2010).

Benstead *et al* (1999) describes wet grasslands as “typically characterised by; an abundance of low growing grasses, periodic but not continuous flooding by fresh or brackish water, or a high water table at or near the soil surface for much of the year, and regular management usually mowing (cutting) or grazing”. This broad label denotes wet grasslands occur at the interface between terrestrial and aquatic habitats and require some form of disturbance (natural or artificial) to offset the dictates of vegetation succession to climax woodland (Paal, 1998; Marrs *et al,* 1986; Berg, 2008; Rosenthal, 2009).

In Europe, few wet grasslands are natural in occurrence and exceptions include only plant communities confined to early successional stages by limiting climatic or edaphic factors (i.e.. temperature, high altitude, soil pH) (Krebs, 2001; Tansley, 2003) and/or natural disturbance (i.e. herbivory, fire) (Parsons *et al,* 2007). European examples include "ice-governed meadows in Sweden, and spring fed carex (true sedge) grasslands in central and Western Spain" (Benstead *et al,* 1999).

Most European wet grasslands have developed as a result of human activity", such as the clearance of forests and drainage of marshes, saltmarshes and bogs in conversion of "river floodplains, lake margins and coastal marshes" for agriculture (Benstead *et al,* 1999). Therefore they are "primarily a lowland habitat" termed generically as 'lowland wet grasslands' typically occurring in river valleys less than 200 m above sea level, behind sea defences or in areas of limited drainage, and consisting of land managed as hay meadow or pasture subject to periodic flooding or high water tables (Joyce and Wade, 1998) that contain plant communities of Neutral grassland, Fen meadow and Swamp (Rodwell, 1998).

The lowland wet grassland type upon which is the focus of this thesis is that in a lowland freshwater floodplain grassland system representing a low lying area of land adjacent to the River Adur in West Sussex, UK that experiences occasional or periodic flooding defined broadly by the environment agency as "land where water has to flow or be stored in times of flood" (EA, 2009a). A number of morphological features inherent in floodplains are known to create a diverse ecological gradient due to the different environmental conditions they construe.

Like most wetlands, the major challenges for management policies and practice are achieving a balance between the multiplicity of purposes. In Lowland wet grasslands these include; "farming, nature conservation, recreation and control of flooding" (Rural Economy and Land Use Programme, 2010). Illyés *et al* (2009) cites how finding "effective conservation" and "ecologically cost-effective management regimes" that "maintain the ecological functionality and biodiversity of a community" present a major challenge to management of semi-natural grasslands. Muller and Brandl (2009) emphasise implementation of effective management can only be achieved "if data are available on assemblage-environment relationships".

The importance of the need to understand relationships inherent within wet grasslands is emphasised by the need to accommodate the implications of climate change (Rural Economy and Land Use Programme, 2010; Thompson *et al,* 2009) within management regimes allowing adjustment for future effects of changing temperature and hydrology (e.g. intensity and duration and flooding). In England, "winters getting warmer and wetter, while summers become hotter and drier" (EA, 2009) and "even the most optimistic predictions show us locked into at least 50 years of unstable climate (Natural England, 2009). Hydrology will change (Thompson *et al,* 2009; Demuth *et al,* 2006; Knight *et al,* 2009) and wet grassland community composition will change in response to the effects of raised water levels as demonstrated in Toogood *et al* (2008) and Toogood and Joyce (2009).

Micro-topography is widely recognised as an important physical feature in wetland ecosystems including wet grasslands (Williams, 1990; Lewis, 1995; Joyce and Wade, 1998; Keddy, 2000; Mitsch and Gosselink, 2007). Research has demonstrated greater microtopographical heterogeneity promotes variability in both hydrological/physiochemical process conditions leading to increased niche habitat diversity thus greater biotic richness (Zedler and Zedler, 1969; Wong, 1974; Moser *et al,* 2007; Bruland and Richardson, 2005; Illyés *et al,* 2009; Martin *et al,* 2007; Vivian-Smith, 1997) and biomass, and subsequently linked to carbon cycling and store capacity. Therefore it has become an established key consideration in wetland restoration schemes and management regimes (Benstead *et al,* 1999; Bledsoe and Shear, 2000; Alsfeld *et al,* 2009) both in meeting international biodiversity targets and potential for addressing and furthering the understanding biogeochemical implications for climate change (Alms *et al,* 1999; Belyea and Malmer, 2004; Sullivan *et al,* 2008).

1.2 Research Approach

Focus in this thesis is on furthering the understanding of wet grassland vegetation in a lowland floodplain landscape and in particular developing knowledge on the relationship between vegetation, micro-topography and edaphic factors using primary collected field data and subsequent analyses. The study was located in South East England, UK at the Knepp Castle Estate, West Sussex as the site contains floodplain grassland adjacent to the River Adur where intensive agriculture and associated management practices ceased in 2001 (Knepp, 2010), and a restoration project established in 2004 followed by pre-feasibility/scoping/planning (Janes *et al,* 2006) and an ecological baseline study (Greenaway, 2006) with project participants including the Environmental Agency (EA), Natural England, DEFRA, English Heritage, Sussex Wildlife Trust and the Knepp Castle Estate (RRC, 2010; SORP, 2010). “The site river and floodplain restoration project has the potential to be a valuable national demonstration site” (Janes *et al,* 2006) contributing “towards the implementation of Water Framework Directive” (concurrently national and international) objectives, “the Environment Agency‘s —’Creating a Better Place’ strategy, and Biodiversity Action Plan habitat creation targets” (RRC, 2010; DEFRA, 2009; UK BAP, 2010). These measures deem the site highly suitable for the assessment of small scale changes in micro-topography and edaphic factors in relation to the presence and absence of vegetative species, in the context of lowland wet grasslands in South East England where such biotopes are limited (Joyce and Wade, 1998).

1.3 Research Aims and Objectives

1.3.1 Aim

Aim: To investigate the relationship between vegetation, micro-topography and edaphic factors in a lowland floodplain grassland system.

1.3.2 Objectives

Objective 1: Conduct a random stratified vegetation survey of the floodplain grassland.

Objective 2: Record micro-topography within each quadrat.

Objective 3: Record soil pH within each quadrat.

Objective 4: Record micro-topography and soil moisture using transects of the floodplain.

1.4 Research Questions

1. Is micro-topography indicative of vegetation zonation?
2. Is vegetation zonation indicative of environmental gradients?
3. Is soil pH indicative of environmental gradients?
4. Does micro-topographical heterogeneity correlate with species-richness?
5. Can micro-topography be used as an indicator of soil moisture?

1.5 Thesis Structure

Chapter 1:

Chapter 1 is preface to the research setting the research context, approach, aims and objectives, and thesis structure.

Chapter 2:

Chapter 2 establishes and reviews important literature pertaining to the principles and concepts involved in this research.

Chapter 3:

Chapter 3 introduces the study site, its location and background information.

Chapter 4:

Chapter 4 defines and critically discusses the methodological approaches used in sampling vegetation, micro-topography, soil pH and soil moisture in this study and the principles involved. Including the analytical software and statistical techniques utilised.

Chapter 5:

Chapter 5 presents the results of the analysis undertaken within the scope and resource of this thesis.

Chapter 6:

Chapter 6 will discuss the key finding of the analysis, limitations to the study and make recommendations for further study.

Chapter 7:

Chapter 7 summarises and concludes the findings of this study.

2 Literature Review

2.1 Introduction

Mitsch *et al* (2009) define ecosystems as “a complex of ecological communities and their environment, forming a functioning whole in nature” (reworded from Patten and Jørgensen, 1995) and emphasise the importance of “the biological communities and the abiotic environment in which they are found”. Further stating, that current scientific beliefs are that an ecosystem as a whole needs to be studied and understood in order to determine the relative “importance of any one species or community within that ecosystem” (Mitsch *et al,* 2009). However, ecosystems are rarely studied as a whole due to their complexity giving rise to a broad range of different definitions changing over time in which authors attempt to generalise. Instead the focus of research by ecologists who can dedicate their life’s research is usually to just one specific part of ecosystems (i.e. animal species, vegetation or groups of organisms), but less commonly interactions between biotic and abiotic parts of ecosystems.

Wetlands are a three component ecosystem and greatly varied in type; the landscape hydrology “influences and changes the physiochemical environment”, such as soils and chemistry, then these and both (hydrology and physiochemical environment) determine biotic community found within. However there is also feedback from the biotic community which determines hydrological and edaphic factors. Forcing functions of climate (solar energy, temperature patterns and precipitation) link with “the geomorphology of the landscape to influence where and when water is present long enough to cause wetlands to exist” (Mitsch *et al,* 2009).

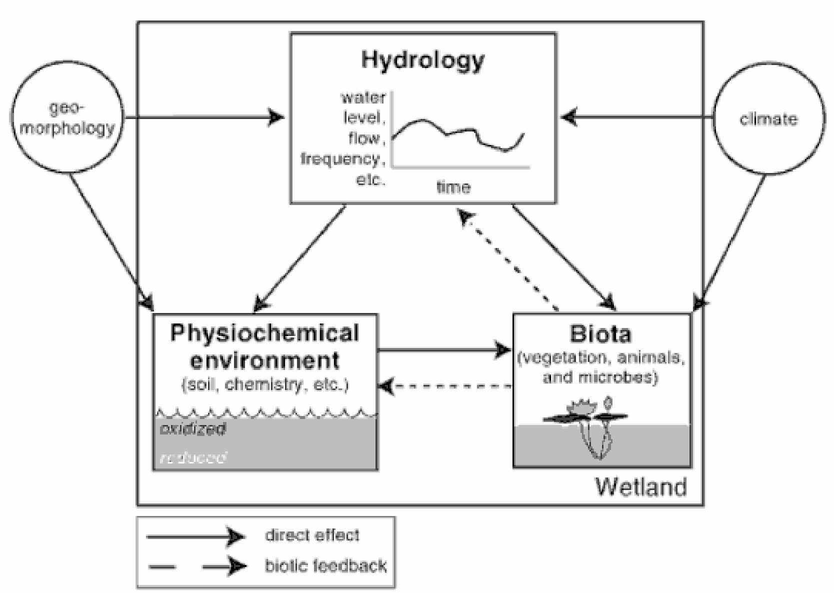

Figure 2-1: Wetland ecosystem conceptual model and "the three component basis of a wetland definition: hydrology, physiochemical environment, and biota. Note that these components are not independent and that there is significant feedback from biota" (Mitsch and Gosselink, 2007; Mitsch *et al,* 2009).

All wetlands are defined and differentiated based on variations in these three components (hydrology, physiochemical environment and biota) giving rise to a broad range of associated habitats. Throughout the globe wetlands are found from the tropics (e.g. mangroves) to the Artic (e.g. peat bogs) at the interface between aquatic and terrestrial ecosystems whether inland or coastal (Williams, 1990). The international Ramsar Convention defines wetlands as;

"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres and may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands" (Ramsar Convention Secretariat, 2006).

This definition illustrates the extensive variety of habitats designated as wetlands and highlights the importance of water (Toogood *et al,* 2008; Toogood and Joyce, 2009; Thompson *et al,* 2009) as the underlying primary factor controlling environmental formation and establishment, and the associated flora and fauna (Ramsar Convention Secretariat, 2006).

Five major wetland types are generally recognised as;

- "Marine (coastal wetlands including coastal lagoons, rocky shores, and coral reefs);
- Estuarine (including deltas, tidal marshes, and mangrove swamps);
- Lacustrine (wetlands associated with lakes);
- Riverine (wetlands along rivers and streams); and
- Palustrine (marshes, swamps and bogs)" (Ramsar Convention Secretariat, 2006).

However, "the Ramsar Convention has adopted a classification of wetland type which includes 42 types, grouped into three categories: Marine and Coastal Wetlands, Inland Wetlands, and Human-made Wetlands" (i.e. "fish, shrimp ponds, farm ponds, irrigated agricultural land, salt pans, reservoirs, gravel pits, sewage farms and canals") (Ramsar Convention Secretariat, 2006) with all combined designated sites currently totalling "185,464,092 hectares" (RAMSAR, 2010).

Wet grassland floodplain systems under the Ramsar three category system, are both an inland wetland and a human-made wetland since floodplains naturally exist, but human induced management regimes have altered both biota and hydrology which of course feeds back on the physiochemical environment.

The distribution, presence, and abundance of all organisms are the result of evolutionary genetic adaption via a process of natural selection to their surrounding environment. All species exhibit limitations to their geographical range which act in determining their presence in a given environment. These limiting factors surround variations in abiotic components (physiochemical - i.e. hydrology, temperature, light, soil structure, fire, oxygen, carbon-dioxide, salinity, pH, soil nutrients) and biotic factors (i.e. mobility, dispersal ability, accessibility, behaviour, interspecies interactions including predation, competition, commensalism, mutualism, parasitism and disease) (Krebs, 2001; Tansley, 2003). Exceptions to this are the artificial introduction of species to environments where they would otherwise not naturally occur, generally termed 'invasive species'.

These abiotic and biotic factors interact and vary in time and space. This continual change in environmental conditions and community is known as an 'environmental gradient'. It is important to note, organisms exhibit varying degrees of tolerance along the changing conditions of an environmental gradient and it can be an extreme of one or combination which ultimately determines presence/absence and level of abundance (Krebs, 2001) (figure 2-2). A classic example of a limiting factor known to exert influence on plant community presence is soil pH. Fewer species are adapted to extremes at either end of the pH scale, communities are sometimes referred to based on pH (i.e. neutral grassland, acid grassland) (Grime *et al,* 1988; RSPB, 1997; Rodwell, 1998). Soil pH is typically a factor of the type of parent materials from which a soil formed or where water leaches basic nutrients (i.e. magnesium) from a soil and replaces them with acidic elements (i.e. iron) (Date *et al,* 1995)

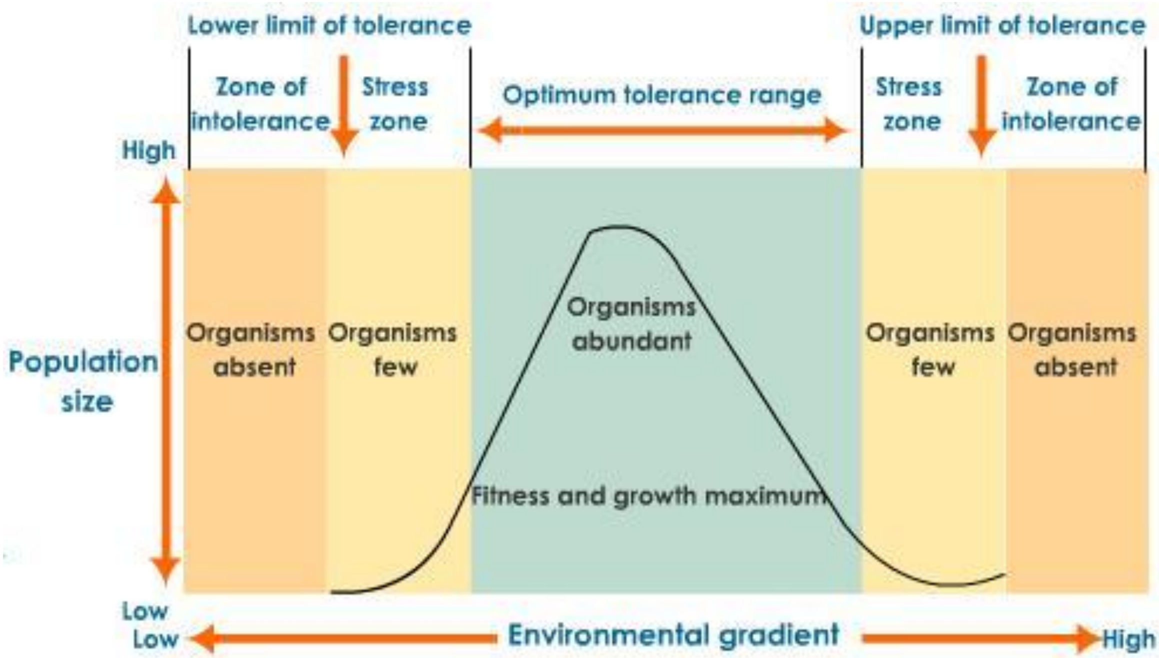

Figure 2-2: Species tolerance model along an environmental gradient (TutorVista, 2010).

In floodplain systems, geomorphic and ecological components are developmentally intertwined but are generally conceptualised as independent due to the complexity of their interaction. Geomorphic processes and subsequent landforms shape the distribution of biota, conversely biota modify geomorphic processes and landforms (Stallins, 2006). Duffey *et al* (1974) identifies hydrology, geographic location (i.e. climate, altitude, and geology), soil (i.e. nutrients) and management history as four main environmental factors influencing habitat and plant communities. In individual riparian floodplain systems, characteristics of hydrology, soil, geographical location and management factors occur along an elevational gradient which is the key theme governing zonation of plant species in the following chapters.

2.2 Hydrology

Riparian floodplain systems experience dynamic hydrology both encountering seasonal and irregular freshwater (i.e. precipitation, surface runoff, melting snow/glaciers) and ground water inputs (i.e. recharge and springs) which vary considerably in time and space (year on year, season by season, day by day) (Davie, 2008). Flooding from a river onto a floodplain occurs when the bank is overtopped. According to the SFRA (Strategic Flood Risk Assessment) for Worthing Borough Council and Adur District Council the main reasons for exceedance of channel capacity in the context of the River Adur are "intense or prolonged periods of rainfall exacerbated by wet antecedent conditions", "constrictions in river channel" and/or "blockage of structures or the river channel" (SFRA, 2008).

Plant physiology is directly linked to water availability. Crawley (2000) approximates that water "constitutes some 85-95% of the growing tissues of plants and 5-15% of the mass of seeds". Furthermore water is "the medium for biochemical reactions" (i.e. photosynthesis, respiration, growth and other physiological processes), "and the means of transport for many materials within the plant" (Crawley, 2000). Therefore water is a basic factor all autotrophic plants require and all plants are adapted to tolerate a limited range of water conditions. Flooding involves soil submergence and water-logging of soil, which are abiotic stresses that impact on species composition and productivity.

The response of vegetation to hydrological patterns is dependent on their ecophysiological traits (Jackson and Colmer, 2005; Voesenek *et al*, 2004). Lowland wet grassland habitats are often recognised as "supporting a mosaic of plant communities (e.g. swamp, mire and saltmarsh)", "including wetland features (floodplain pools, drainage channels and ditches)" (Joyce and Wade, 1998). In floodplain grasslands, "vegetation principally consists of herbaceous annual perennial Gramineae (true grasses), Cyperaceae (sedges) and Juncaceae (rushes) with winter buds just below the soil surface" (Van Eck *et al,* 2006). Many authors discuss flooding as the predominant factor governing processes determining plant distribution along elevational gradients in river floodplains (Day *et al,* 1988; Sluis and Tandarich, 2004; Setter *et al,* 1997; Banach et al, 2009; Lenssen and Kroon, 2005; Van Eck *et al,* 2006; Mommer et al, 2006). RSPB *et al* (1997) notes how soil type plays an important role on plant species composition. Permeable soils have a larger pore space and allow water to percolate up during periods of high water table. They absorb and exhibit a greater water holding capacity therefore retain soil moisture for greater duration. Impermeable soils allow for little percolation, in water event (precipitation/flooding) either pooling forms or surface runoff occurs at an accelerated rate in comparison to a permeable soil.

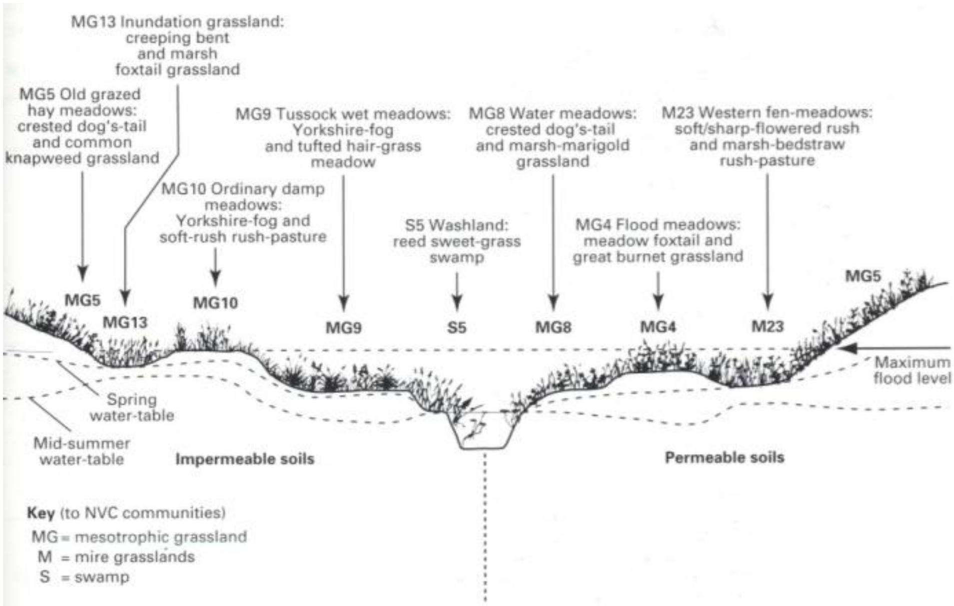

Figure 2-3: Distribution of wet grassland plant communities on a hypothetical lowland floodplain in relation to soil type and water regime (RSPB *et al*, 1997).

Day *et al* (1988) used “multivariate vegetation data to describe vegetation—environment relationships in a set of riverine wetlands” using samples collected from five marshes along the Ottawa River (eastern Canada). Using detrended correspondence analysis to illustrate major gradients, TWINSPAN analysis to classify vegetation types and ordination, results indicated water depth, and standing crop and litter gradients were the major axes significant in determining the assemblage of vegetation types of four major classes dominated by Sparganium eurycarpum, Eleocharis smallii, Scirpus americanus, and Typha latifolia. Therefore, concluding that erosion and sedimentation processes imparted by hydrology indirectly determined soil composition and thus species distribution.

Sluis and Tandarich (2004) investigated “Siltation and hydrologic regime determine species composition in herbaceous floodplain communities” in the mid western United States using four floodplains in Illinois and Missouri. They found that water depth determined species composition in permanently wet areas and silt deposition determined species composition in seasonally inundated grassland. Silt deposition where high enough inhibited seedling emergence leading to dominance by plants species possessing the ability to reproduce vegetatively by rhizomes (Sluis and Tandarich, 2004).

Setter *et al* (1997) showed how flood events directly reduced oxygen and light availability affecting plant growth in rice and displayed a genotypic difference within rice species making some more tolerant to submergence. (Banach *et al,* 2009) using a greenhouse experiment compared species tolerance to complete submergence and their acclimation patterns “using a selection of 19 species from two sites with contrasting hydrology;

permanently wet meadows in a former river foreland, and frequently submerged grasslands in a current river foreland". Treatment involved subjection of plant species to 3 weeks and 6 week periods of complete submergence. Results indicated "plants from wet meadows are likely to be less tolerant to complete submergence than plants from frequently flooded river forelands which showed in all treatments "stronger shoot elongation, as well as higher production of biomass of leaves, stems, fine roots and taproots, compared with meadow species". Thus evidencing the requirement and development of different survival strategies in response to hydrological regime change and is likely to have consequences for vegetation development if former floodplains (experiencing soil saturation/flooding only) are "reconnected to highly dynamic river bed" (Banach *et al,* 2009).

Lenssen & de Kroon (2005) investigated "whether species distributions are, instead constrained by physiological limits, and only narrowed by biotic interactions" of competition on survival and fecundity of two Rumex species" (*Rumex crispus* and *Rumex palustris)* both "within and above their distribution range along an elevation gradient in a river floodplain". Their field evidence indicated species niches at both ends could be defined in hydrological terms and that segregation of species niches may depend on spatial variability in water availability thus "promoting species richness in plant communities" (Lenssen & de Kroon, 2005).

Van Eck *et al* (2006) looked into seasonal effects on 10 floodplain grassland species in river Rhine Netherlands, "by testing the hypothesis that all species can survive longer when flooded in winter than when flooded in summer". These species were; "*Alopecurus pratensis, Arrhenatherum elatius* and *C. Presl, Daucus carota L., Elytrigia repens (L.) Nevski, Festuca rubra L., Medicago falcata L., Plantago lanceolata L., Rumex acetosa L., Rumex* *crispus L. and Rumex thyrsiflorus Fingerh*". Under winter floods all species survived longer than summer floods, though responses to flooding were species specific. Further testing revealed "a strong significant relationship between the lower distribution limits of the species in the field and their tolerance to summer floods" and zonation patterns created during occasional summer floods may retain for a long time, most likely due to species limited ability to re-colonise the floodplain lower positions. (Van Eck *et al,* 2006).

Van Eck *et al* (2004) conducted a comparative study of 20 terrestrial grassland species from mid- and high-level floodplain grasslands along the river Rhine in the Netherlands, subjecting them to total submergence for at most two months in an outdoor flooding experiment, to see if "tolerance to summer flooding correlated with distribution patterns in river floodplains?" The survival and growth responses were examined with measurements of "biomass reduction with flooding during and biomass recovery after de-submergence". Their results showed species survival to be the most important factor correlated with distribution in floodplain areas with more flood resistant species occurring principally at lower elevations whilst sensitive species showed restriction to higher elevations of the floodplain gradient. Biomass reduction by submergence was only slightly correlated with species lower distribution boundaries along the flooding gradient" (Van Eck *et al,* 2004).

Thompson *et al* (2009) modelled the hydrological impacts of climate change upon the Elmley Marshes a lowland wet grassland on the Isle of Sheppey in southeast England using a "coupled hydrological/hydraulic model to predict changes in precipitation, temperature, radiation and wind speed" using the UK climate Impacts Programme (Thompson *et al,* 2009; Hulme *et al,* 2002) using four emissions scenarios for the 2050s to adjust for precipitation and evapotranspiration changes. Their conclusion was that hydrological changes are expected to "have ecological impacts which may include the loss of some grassland species adapted to periods of high water table" (Thompson *et al,* 2009).

Toogood and Joyce (2009) investigated the "Effects of raised water levels on wet grassland plant communities" on the Pevensey Levels, southeast England, UK using monitoring of community variations using species abundance and ecological traits during 2001 – 2003 within 23 wet grassland meadows and pastures where, for nature conservation, water levels had been raised at varying times over 21 years. Results showed with increasing wetness, sites were typified with an increase in bare ground, wetland plants (sedges, helophytes, and hydrophytes) possessing stress-tolerating competitive strategies. No significant relationships were discovered "between time since water levels were raised and plant community composition", and grassland management exercised limited influence compared to water regime upon vegetation. They concluded "grassland plant communities are responsive" and exhibit "potential for rapid transition to wetland vegetation" with raised water levels, "irrespective of grazing or cutting management". Furthermore, they deduce (re) wetting is feasible for creation or restoration of wet grasslands, but challenging since wetland plant communities display high dynamism and require substantial increases in water levels and prolonged flooding to generate significant community changes (Toogood and Joyce, 2009).

Erosion and sedimentation processes imparted by hydrology indirectly determine soil composition (Day *et al,* 1988; Sluis and Tandarich, 2004) and, frequency and duration of hydrological events directly affect plant growth through reduction of light and oxygen availability (Setter *et al,* 1997; Banach *et al,* 2009). Tolerance by species to the direct effects of flooding differs significantly and these differences are mirrored in "species zonation along elevational gradients in river floodplains" (Van Eck *et al,* 2006; Lenssen & de Kroon, 2005). Van Eck *et al* (2004) and He *et al* (1999) have shown species with more tolerant traits dominate the lower, more frequently flooded positions, whereas higher elevations (hence less frequently flooded) are characterised with a greater abundance of less tolerant species. Van Eck *et al* (2006), Banach *et al* (2009), Thompson *et al* (2009) and Toogood and Joyce (2009) focussed on changes in the response by vegetation (i.e. shift in zonation, loss of competitive niche) to the changing hydrological regime imparted from climate and management.

A reoccurring theme in this chapter on hydrology is elevation or topography which is a principal component in creation of hydrological gradients in riparian floodplain systems (i.e. with increased distance and elevation from river, the duration and frequency of flood events decrease). As discussed already this elevational gradients exists due to erosion and deposition of sediment from geomorphological processes shaped by hydrology and then feeds backs by increasing the variation in hydrology over an area. A given position on an elevational gradient determines the vegetative community present due not only to variations in hydrology, but the geochemical components present imparted by past biota, hydrology (cyclical process). On a smaller scale micro-topographical differences within an elevational gradient infer greater heterogeneity in environmental conditions affecting plant community presence/absence.

2.3 Micro-topography and Edaphic Factors.

Zedler and Zedler (1969) noted how vegetation type boundaries often corresponded to "elevational changes of only a few centimetres". Wong (1974) identified topography, pH, soil moisture regime and content of soil nutrients as main factors contributing to vegetational gradients, further stating biotic variables such as competition between plant species, burning, grazing and trampling also played an important, but more local role. In recent years, micro-topography has received much focus emphasising the importance of much finer scales (i.e. to 1cm) on vegetation relationships (Vivian-Smith (1997); Burland and Richardson (2005); Martín *et al* (2007); Moser *et al* (2007); Burnside *et al* (2007)).

Vivian-Smith (1997) demonstrated using randomised factorial block treatments (homogenous vs. heterogeneous surface) and multivariate analysis that micro-topographical heterogeneity significantly altered community composition. Results indicated significant differences in species distribution to varied positions/elevations highlighting their different interspecific niche habitat preferences within small scale micro-topographical variability of 1-3 cm. Florsheim and Mount (2002) states "the structure of topography acts on hydrology forming "local variability and gradients in floodplain water depth, flow velocity, and shear stress, as well as fluctuations in the elevation and relief of floodplain landforms relative to the ground water table".

Bruland and Richardson (2005) examined "responses of hydrology, soils, and vegetation to microtopographic reestablishment at a 3-year-old RW site in North Carolina 2003" by reestablishment of micro-topographical features involving configuration of mounds (hummocks) and depressions (hollows), on otherwise level terrain (flats) of intermediate elevation. Mean water table depths were noted, in the flats as being below the soil surface and in the hollows above the soil surface by 10cm. Using Analysis of variance results indicated “significant micro-topography by time interactions for soil temperature ($p < 0.05$) and moisture ($p < 0.001$)”, indicating inconsistent differences between the zones during the growing season. Hummocks showed significantly greatly ammonium ($p < 0.001$) and nitrate ($p < 0.0001$) than hollows and flats for the majority of the growing season. Furthermore, there was a significant difference ($p < 0.001$) in species richness across the micro-topographical features with hummocks < hollows < Flats. Flats were shown to support the largest number of wetland species. Aboveground biomass ($p <0.001$) also significantly differed though following a dissimilar pattern than richness: “hummocks < flats < hollows, owing to the growth of emergent wetland herbs in hollows”.

Martin *et al* (2007) concluded from investigating the “relationship between vegetation units and micro-topography of a pasture located in a poorly drained sector of Argentina” that in flat environments micro-topographical conditions are particularly ecologically important with a strong correlation with the “distribution of plant species and productivity of forage resources”. In Moser *et al* (2007) it is stated hydrology, physiochemistry and habitat variability are all influenced by micro-topography making its use in the determination of vegetation patterns and ultimately ecosystem function important and their disking experiment in artificially engineered (created wetlands) supported past works conclusions that “increased micro-topography was associated with greater species richness, diversity, and percent cover” and also cites it as important in the “prevalence of hydrophytic vegetation”

Ward *et al* (Unpublished), studied “the effects of micro-topography and edaphic factors on vegetation community structure” on managed coastal grasslands in Estonia. Using a phytosociological key developed in Burnside *et al* (2007) and TWINSPAN analysis to distinguish a total of seven main habitat types. Ward *et al,* (Unpublished) investigated which environmental factors had the greatest effect in determining the location of the vegetation community types within coastal wet grasslands. Using quadrats in each habitat type, soil samples were taken from each quadrat and analysed under laboratory conditions for Nitrogen (N), Potassium (K), Phosphorus (P), organic matter content (%), pH, salinity, moisture (%) and Height. Modified Mann-Whitney tests and principal component analysis (PCA) was also undertaken. Their study provided evidence "that very small differences in height above sea level of the order of 4 cm can have a significant effect on vegetation community type". Three habitats were grouped based on the environmental variables examined indicating a significant relationship between vegetation community structure and edaphic factors, except for soil which "was not found to significantly differ between any of the habitat types".

Micro-topography is clearly recognised as an important physical feature in wetland ecosystems including wet grasslands (Williams, 1990; Lewis, 1995; Joyce and Wade, 1998; Keddy, 2000; Mitsch and Gosselink, 2007). Research has demonstrated greater micro-topographical heterogeneity promotes variability in both hydrological/physiochemical process conditions leading to increased niche habitat diversity thus greater biotic richness (Zedler and Zedler, 1969; Wong, 1974; Vivian-Smith, 1997; Bruland and Richardson, 2005; Martin *et al,* 2007; Moser *et al,* 2007; Illyés *et al,* 2009) and biomass, and subsequently linked to carbon cycling and store capacity. Therefore it has become an established key consideration in wetland restoration schemes and management regimes (Benstead *et al,* 1999; Bledsoe and Shear, 2000; Alsfeld *et al,* 2009) both in meeting international biodiversity targets and potential for addressing and furthering the understanding biogeochemical implications for climate change (Alms *et al,* 1999; Belyea and L.R. Malmer, 2004; Sullivan *et al,* 2008).

Yet again, these factors interact and exert influence on each other. For example, in riparian floodplain systems topography (altitude), a function of geographic location hence climate, is considered a critical component due to its influence on hydrology and subsequently soil nutrients which both act on biota, then biota feeds back on topography (i.e. encouraging sedimentation) and thus hydrology. Management can change hydrology (i.e. by drainage measures) and biotic composition by altering hydrology and intensive agricultural practices i.e. fertilisers and grazing).

2.4 Management

Traditional low-intensive management centres round farming practices directly by grazing for domestic herbivores or indirectly by harvesting hay comprising of cutting or mowing at least once annually (Joyce and Wade, 1998). Known to rely on traditional regular low intensity management (e.g. mowing or grazing) to preserve their characteristic flora often encouraging a richer species diversity "lowland semi-natural biotopes are often limited" (Benstead *et al,* 1999) having seen a rapid decline due to a legacy of insensitive land-use changes such as land drainage, flood defence, agricultural intensification , and neglect Europe has witnessed large scale ecological loss and decline in wet grasslands particularly in the past 60 years mostly due to these factors (Joyce and Wade, 1998; Rural Economy and Land Use Programme, 2010).

"Land drainage/flood defence" can include; modification of natural hydrology (i.e. isolation, rapid evacuation of winter floods, maintenance of drainage channels). Changes in agricultural practices commonly include; intensive grazing and conversion to arable use, re-seeding, increases in land drainage and fertiliser use, change from hay cutting to silage, neglect and cessation of management (RSPB *et al,* 1997). "Local habitat and biological diversity of streams and rivers are strongly influenced by landform and land use within the surrounding valley at multiple scales. However, empirical associations between land use and stream response only varyingly succeed in implicating pathways of influence" (Alan, 2004). The hydrology is semi-natural for many lowland river catchments with flow dynamics having been modified through construction of dams, weirs, sluices and other hard structures including straighten courses, levees and urbanisation of floodplains increasing frequency and decreasing duration of lag periods (Davie, 2008).

In the UK, policy and environmental regulation between the 1930s and 1970s focussed predominantly on increasing agricultural production in order to attain greater national self sufficiency, subsequently leading to the drainage of many rural floodplains. Since the 1980's, the rise of environmental objectives and conservation of water resources has exercised greater influence over the way land is managed leading away from the previous dominance of management led decision making, for the priority use of floodplains for agricultural production and flood risk management. This has resulted in more "'joined up' approach which includes using agricultural land to contribute to the management of flood risk alongside other purposes, whether farming, biodiversity or recreation" (Rural Economy and Land Use Programme, 2010). Changes in policies and market conditions have created an inclination towards less intensive land management and the creation of restoration schemes.

Berg (2008) investigated "the response of coastal wet grassland plant communities to abandonment and management practices" including grazing, cutting and soil disturbance in western Estonia using a monitoring plot experiment where "composition and abundance were monitored using species and functional groups". The results for abandoned areas indicated a greater abundance of "litter cover, little bare ground, and the encroachment of taller competitive strategist species" such as *Phragmites Australis* (a similar conclusion to a study by Burnside *et al,* 2007*)*. In disturbance experiments effects appeared dependent "on the type of community (species rich or species poor) and the intensity of disturbance" (grazing, regular cutting or intense soil disturbance) for instance, species-rich tall grassland communities displaying greater stability "than species-poor lower shore grassland community when cutting was re-instated". Furthermore, in the wetter plant communities that were managed there was a greater shift in the cover of dominant species and it appeared that re-installation of management contributed to existing disturbance levels related to hydrology, by favouring species with more stress tolerance such as *Agrostis stolonifera* and *Juncus gerardii* at the expense of those less flood tolerant such as *Festuca rubra* (Berg, 2008).

Burnside *et al* (2007), used classification of vegetation and plant indicators to assess grazing abandonment in Estonian coastal wetlands. Using "nine study sites with varying management histories comprising an area of 287ha, a total of 198 quadrats were taken from 43 distinct vegetative patches in five of the sites". Using TWINSPAN analysis to identify community type and constructing a phytosociological key for character taxa, a vegetation classification in a GIS based context was applied "to classify all the study sites, using a ground survey technique and 1:2000 scale air photos" (Burnside *et al,* 2007). Results showed "coastal wet grasslands were most extensive in grazed sites", or sites that had been received more intensive grazing. Abandoned sites showed a decline in coastal wet grassland plant communities of particular conservation value with significantly greater abundance of Phragmites australis stands, scrub and tall grasslands. Furthermore all plant community types displayed "significant edaphic differences", with particularly high pH and conductivity and low soil moisture "for open pioneer patches in comparison to other vegetation types". They conclude the study demonstrates the importance of grazing as a factor "influencing coastal wetland plant communities", but that environmental variables such as topography also affect vegetation distribution (Burnside *et al,* 2007).

2.5 Legislation

It is often the case that UK national legislation and policy is heavily influenced and shaped by international legislation as UK foreign policy strives for the UK's inclusion as an active and leading member of the global community (i.e. The United Nations, The European Union,). The United Kingdom is a contracting party to a number of intergovernmental treaties (Conventions) and as a member state of the European Union is also obliged to adhere to European Directive legislations which have acted to raise the profile, awareness and support for the implementation of effective environmental actions aimed primarily at conservation of biodiversity through protection and/or restoration of individual species and habitats (Bennet, 2004; Rosenqvist *et al,* 2007; Seto and Fragkias, 2007; CBD, 2010b; Morand, 2010). Conventions have played a key role in imparting guidance and supplying the framework to many Directives in which member state national authorities must implement and adapt into their own national legislation in order to achieve certain set end results by a predefined time (European Commission, 2010a), though the means by which they integrate a directive is at a members own discretion.

"Traditionally, habitat conservation was thought to follow automatically the protection of individual species, and the implementation of species protection programmes has resulted in many practical management schemes for improving or restoring functions at the regional, national and international level" (Joyce and Wade, 1998). Biological Conventions internationally important in contributing towards legislative protection for lowland wet grassland (both directly and indirectly) include Ramsar 1971 (RAMSAR, 2010), the Bern Convention 1979 (Europa, 2006) and the UN Convention on Biological Diversity 1992 (CBD, 2010a). Key European Directives to a large extent stemming from such Conventions include; the Birds Directive and the Habitats Directive which are now recognised by the European

Commission (2010b) as forming the “cornerstone of Europe's nature conservation policy”. Important UK national conservation legislation and policy influenced and shaped by these directives are mostly under the umbrella of the Wildlife and Countryside Act 1981 with various subsequent amendments of key important including Wildlife and Countryside (Amendment) Act 1985 and act 1991, Countryside and Rights of Way (CRoW) Act 2000 (in England and Wales), Wildlife and Countryside Act 1981(England and Wales) (Amendment) Regulations 2004, and the Natural Environment and Rural Communities Act 2006 (in England and Wales) (European Commission, 2010b).

Ramsar is the convention on **‘**Wetlands of International Importance’, signed in 1971 ratified by the UK in 1976, it “provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources” (Ramsar, 2010). It currently has 160 contracting parties and identifies “1,896 sites” in its ‘List of Wetlands of International Importance’ totalling a surface area of “185,467,509 hectares” as designated Ramsar sites (Ramsar, 2010). One of the key criteria for the designation of Ramsar sites was “especially those acting as waterfowl habitat to internationally significant numbers of water birds (Ramsar, 2010). Lowland wet grasslands though not equal to a wetland ecosystem, they do however form a significant component of them and are recognised as providing significant habitat for wading, breeding and migratory birds (Joyce and Wade, 1998).

The Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats) came into force in 1982 and its principal aims are to ensure conservation and protection of wild flora and fauna and their habitats (listed in appendices 1 and 2 of the Convention (Europa, 2006)), to enhance “cooperation between contracting parties, and to regulate the exploitation of those species listed in appendix 3" (JNCC, 2010c). Particular emphasis was placed on the need to protect those habitats and species recognised as endangered or vulnerable, including migratory species. All contracting countries are required to take action to; promote and encourage national policies (including regard in planning and development), education and dissemination of general information related to the conservation and need for conservation of wild floral and faunal species and their habitats. Furthermore co-ordinating research and efforts along with a sharing of information, experience and expertise, to enhance effectiveness of measures (Council of Europe, 2010).

As a result of these measures, legal obligations were imposed on all contracting parties for the protection of over 500 wild floral species and over 1000 wild fauna species (JNCC, 2010d). Joyce and Wade (1998) drawing on work from Fernández-Galiano (1995) states that "despite the excellent scientific work of the expert groups, a number of shortcoming can be observed (Fernández-Galiano, 1995) including; legal form of proposals and suggestions are relatively weak, a lack of precision in "passages concerning the legal protection of threatened natural habitats", agricultural, forestry or fishery policies are unaffected by the legislation ("of particular significance to lowland wet grasslands") and lacking specification for conservation approaches to endangered natural habitats (Joyce and Wade, 1998). The response of the European governments in meeting its obligation to the Bern convention resulted in the establishment of the Birds Directive 79/409/EEC, and contributed to the EU Habitats Directive 92/43/EEC and Convention on Biological Diversity (CBD).

The United Nations (UN) Convention on Biological Diversity (CBD) signed in Rio de Janeiro 1992 (CBD, 2010; DEFRA, 2007) similar to the Bern Convention, but seen as an upgrade, it is wider in political dimensions and scope providing greater reference to; “genetic material, ex situ conservation, processes for identification of problems and monitoring of biological diversity, environmental impact assessment, control over genetically modified organisms, conservation incentives, domesticated or cultivated species” (Council of Europe, 1993 in Joyce and Wade, 1998). The CBD also requires contracting parties to develop a national biodiversity action plan (BAP) aimed at those species known to be vulnerable or in danger of extinction.

A follow on from the Birds Directive (Joyce and Wade, 1998) and incorporating some its features was Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, otherwise known as the ‘Habitats Directive’ adopted in 1992. It is the key instrument “by which the European Union meets its obligations under the Bern Convention” (JNCC, 2010d). The primary aim of the Habitats Directive is to promote the maintenance/protection and restoration of natural habitats and wild species recognised as of high conservation value for Europe, through introduction of robust protective management measures for these habitats and species taking account of economic, social and cultural requirements including regional and local characteristics (JNCC, 2010d).

It established a network of protected sites called NATURA 2000 (also fore filling community obligations under the UN Convention on Biological Diversity) and a strict system of species protection, together protecting “over 1000 animal and plant species and over 200 so called habitat types” (European Commission, 2010b) of which lowland wet grasslands is included. This Natura 2000 network of sites includes SPAs established under the Birds Directive and Special Areas of Conservation (SACs) for other rare and vulnerable species and habitats to provide increased protection and management. “All EU Member States are required to manage and implement Natura 2000” (NATURA, 2010) and must take appropriate steps under article 6.2 of the Habitats Directive to avoid significant disturbance of species and deterioration of habitat for which the site has been designated and furthermore “it is not permissible to wait until deterioration or disturbance has occurred before taking action” (Williams *et al,* 2005). It is important to note Natura 2000 is not a strict system of nature reserves, even though it does certainly include nature reserves, the majority of the land is privately owned with emphasis placed on future management being sustainable both ecologically and economically.

In the UK, there are a range of protective designations for sites including lowland wet grassland habitats. Sites of special scientific importance (SSSI’s), originally established under the National Parks and Access to the Countryside Act 1949 (OPSI, 2010) and superseded by the Wildlife and Countryside Act 1981, are building blocks of nature conservation in the UK. They include National Nature Reserves (NNRs) or Local Nature Reserves (LNRs), Ramsar sites (established under the Ramsar Convention), Special Protection Areas (SPAs) under the Birds Directive and Special Areas of Conservation (SACs) under the Habitats Directive. According to Natural England (2010) “There are over 4,000 Sites of Special Scientific Interest (SSSIs) in England, covering around 7% of the country's land area. More than 70% of these sites, (by area) are internationally important for their wildlife”.

The Wildlife and Countryside Act 1981 along with subsequent amendments is the primary legislation in the UK which protects flora, fauna and habitats of concern (Evans, 1997). It consolidates and amends existing national legislation and implements the Convention on the Conservation of European Wildlife and Natural Habitats 1982 (Bern Convention) and Council Directive 79/409/EEC on the conservation of wild birds (Birds Directive) (recently replaced by Directive 2009/147/EC). According to the JNCC (2010e) some of the most recent amendments are the "Countryside and Rights of Way (CRoW) Act 2000 (in England and Wales), the Nature Conservation (Scotland) Act 2004 (in Scotland) and the Natural Environment and Rural Communities Act 2006 (in England and Wales)". In response to the Convention on Biological Diversity held in Rio 1992, the UK in 1994 became the first country to produce a national biodiversity action plan (BAP) (Defra, 2007) and lowland wet grassland is once such BAP priority habitat.

According to Joyce and Wade (1998) "substantial improvements at the legal and institutional level" came with the approval of the European Community Council Directive on the Conservation of Natural Habitats of Wild Fauna and Flora (92/43/EEC) (Habitats Directive) (building on the 1979 European Council Directive on the Conservation of Wild Birds (79/409/EEC) (Birds Directive)) under the NATURA 2000 initiative and the adoption of the United Nations (UN) Convention on Biological Diversity (CBD) signed in Rio de Janeiro 1992 (CBD, 2010; DEFRA, 2007).

The Convention on Biological Diversity (CBD) held at the United Nations Earth Summit in Rio 1992 (CBD, 2010) aims at protecting and conserving the Earth's biological diversity (flora, fauna and their habitats). The Habitats Directive is more specifically aimed at protecting the European Union's biodiversity through designation of sites of European importance for listed habitats and species subsequently labelled Special Areas of Conservation (SAC). These SAC's are to be maintained at, or restored to, favourable conservation status. Still there is a lack of complete and reliable information which is a key obstacle to the implementation of legislation.

However overall, “the highly fragmented and disintegrated patchwork of protected sites and management agreements” has largely “failed to stop or reverse the negative trends of habitat loss and species decline”. The EU habitats directives and the convention on biological diversity have provided a framework for which implementation of strategies and policies can be updated especially the cooperation and sharing of research information internationally enables positive feedback on the legislative and policy development system.

Illyés *et al* (2009) cites how finding “effective conservation” and “ecologically cost-effective management regimes” that “maintain the ecological functionality and biodiversity of a community” present a major challenge to management of semi-natural grasslands. Muller and Brandl (2009) emphasise implementation of effective management can only be achieved “if data are available on assemblage-environment relationships”. Furthermore, the importance of the need to understand relationships inherent within wet grasslands is emphasised by the need to accommodate the implications of climate change (Rural Economy and Land Use Programme, 2010; Thompson *et al,* 2009) within management regimes allowing adjustment for future effects of changing temperature and hydrology (e.g. intensity and duration and flooding). In England, “winters getting warmer and wetter, while summers become hotter and drier” (EA, 2009) and “even the most optimistic predictions show us locked into at least 50 years of unstable climate (Natural England, 2009). Hydrology will change (Thompson *et al,* 2009; Demuth *et al,* 2006; Knight *et al,* 2009) and wet grassland community composition will change in response to the effects of raised water levels as demonstrated in Toogood *et al* (2008) and Toogood and Joyce (2009).

3 Site Description

The Knepp Castle Estate (some 3500 acres/1400 hectares) is located in West Sussex England, UK adjacent to the A24 and near to the town of Horsham (figure 3-1 and 3-2).Here, the estate owner Charlie Burrell has embarked on an ambitious re-wilding project known as the 'Knepp Wildland Project'. Having previously been an estate principally devoted to traditional arable and dairy farming, the focus has been shifted entirely through a series of regeneration and restoration projects aimed predominately at nature conservation and low intensive grazing assisted by entry into Defra's Countryside Stewardship Scheme (Greenaway, (2006), and restoration of elements of the historic landscape which originated as a medieval deer park (Knepp, 2010).

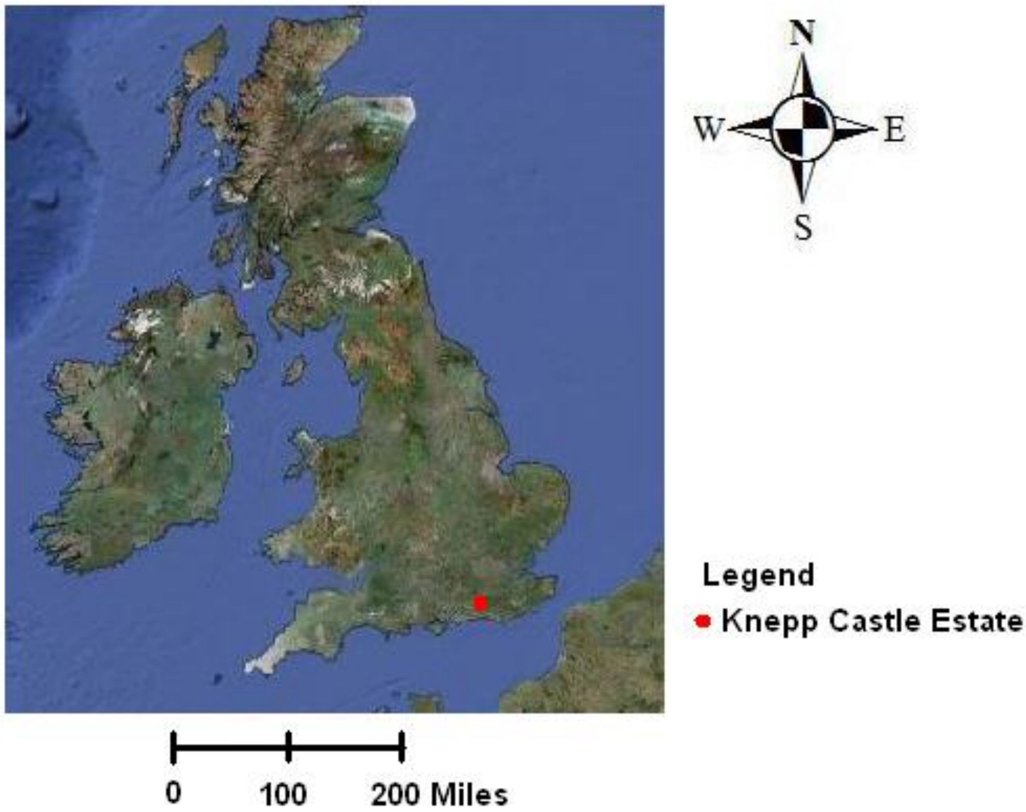

Figure 3-1: UK scale Knepp Castle Estate location map.

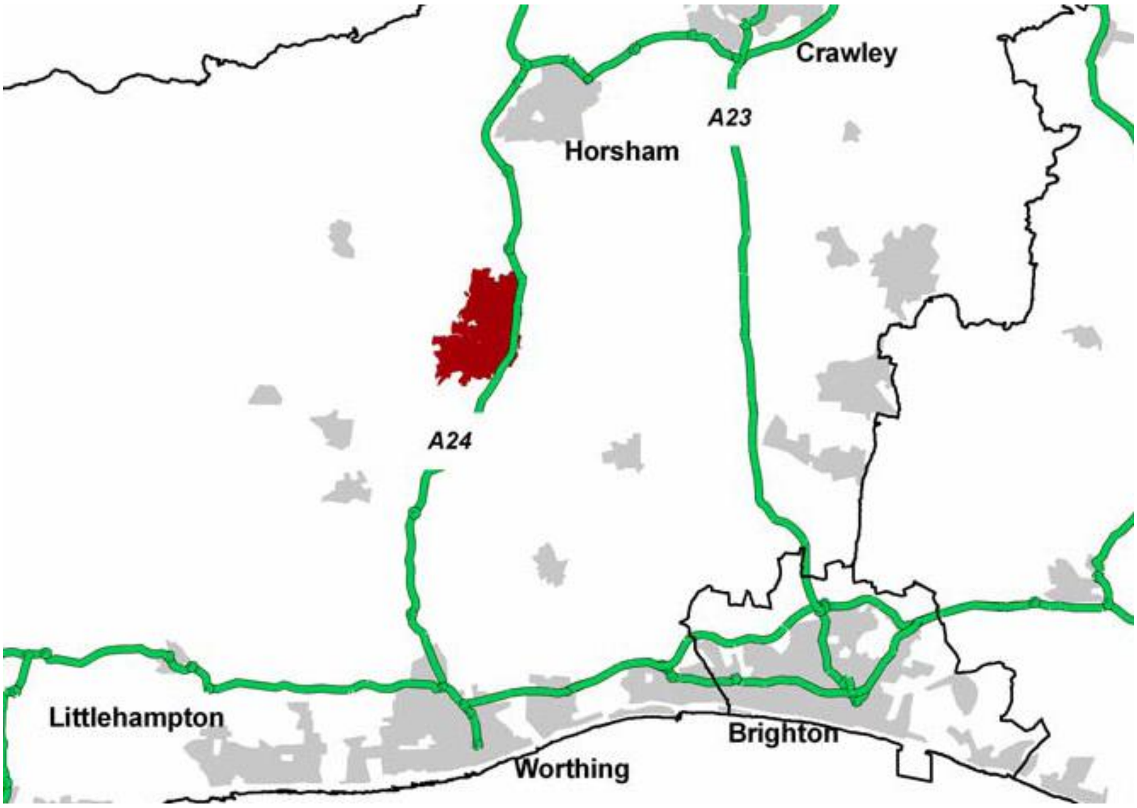

Figure 3-2: Location of Knepp Castle Estate, East Sussex UK (Knepp, 2010).

The focus of this study is the floodplain grassland surrounding one such project known as 'The River Adur Restoration Project' (plate 1) established in 2004 with project participants including the Environmental Agency (EA), Natural England, DEFRA, English Heritage, Sussex Wildlife Trust and the Knepp Castle Estate (RRC, 2010; SORP, 2010). It seeks to allow a 2.2km stretch of the River Adur (a "lowland clay catchment river") (Janes *et al*, 2006) to return to its natural meanders after three centuries of being directed into an artificially canalled over sized channel restoring the natural floodplain system and is anticipated to greatly increased species richness of both flora and fauna (Knepp, 2010; Janes *et al,* 2006). A river restoration pre-feasibility study (Janes *et al,* 2006) concluded restoration was feasible, and a ecological baseline survey (Greenaway, 2006) was undertaken to create a bench mark of ecology allowing analysis of any changes to be made in future studies via comparison

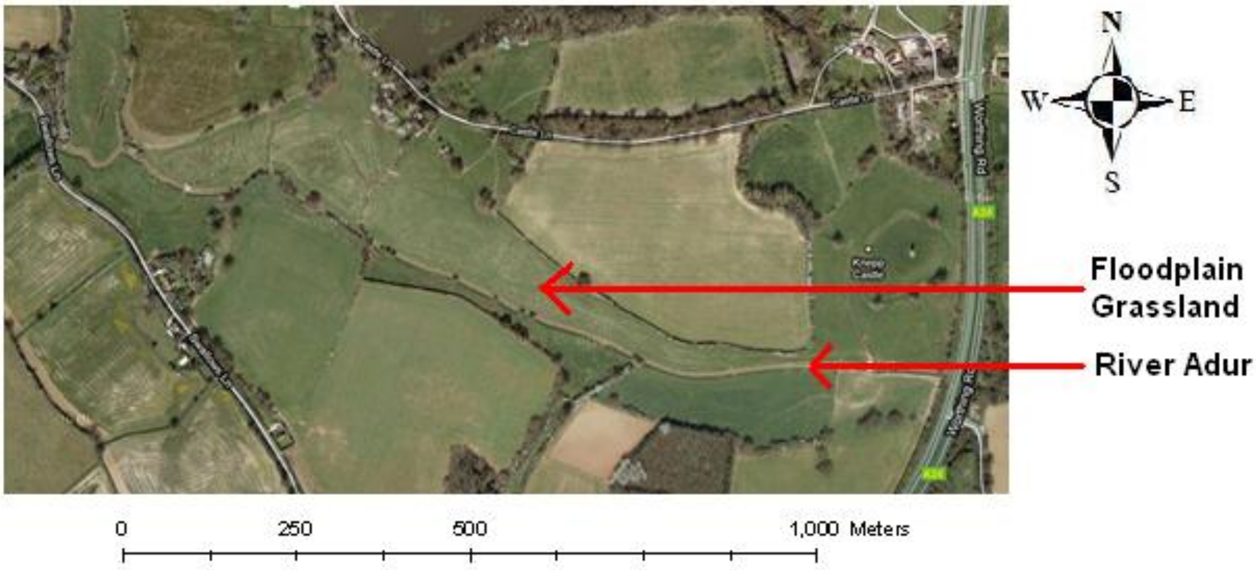

Figure 3-3: Map showing location of floodplain grassland study site adjacent to River Adur on the Knepp Castle Estate.

Plate 1: The River Adur floodplain study site, Knepp Castle Estate.

Forming part of the wider ‘Knepp Wildland Project’ the floodplain was also taken out of arable and commercial grassland, and now forms part of the deer park. Greenaway (2006) states that in summer 2005 (pers.comm. Jason Emrich) the deer park contained an “estimate of around 550 animals” which consisted of approximately 500 fallow deer, “6- 10 ponies, 16 cattle with 13 calves and 10 sows”. According to Janes *et al* (2006) the current river channel is overlarge for the flows and size of catchment that is due to past modification including the construction of weirs and drainage channels to the floodplain (Knepp, 2010) with the existing river bed profile runs between 2 to 2.5 meters below the floodplain profile (Janes *et al,* 2006) which is known to flood in winter and early spring (SFRA, 2008; Knepp, 2010).

4 Methodology

4.1 Data Requirement Summary

Primary Data:

- Vegetation (Source: Quadrat field survey).
- Micro-topography (Source: D-GPS survey).
- Soil Moisture (Source: Transect field survey using soil moisture meter survey and D-GPS).
- Soil pH (Source: Field survey and subsequent lab analysis).

Analytical Methods:

- Collation of vegetation data for species diversity, frequency and abundance.
- Collation of micro-topography, soil moisture and soil pH data into GIS.
- Descriptive Statistics.
- Exploratory Spatial Data Analysis (ESDA).
- Regression Analyses.

4.2 Objective 1: Vegetation Survey

The use of quadrats (also known as plots) in sampling vegetation is a common method allowing measurement of individual species frequency, density, cover or biomass. The size of the quadrat used varies based on the type of plant species/community under investigation. Vegetation consisting of smaller plants, at greater density or greater species diversity should require smaller quadrats and subsequently larger species (i.e. trees) larger quadrats. A degree of consistency in quadrat size and type allows greater comparative power between studies of similar vegetation (Rodwell, 1998). Table 4-1 displays commonly used quadrat sizes used for vegetation sampling according to community type (Sutherland, 2006).

Plant community	Quadrat size
Bryophyte, lichen and algal	0.01-0.25 m²
Grasslands, tall herb, short shrub and aquatic-macrophyte	0.25-16 m²
Tall shrub	25-100 m²
Trees in woods and forests	400-2500 m²

Table 4-1: Quadrat sizes used for vegetation sampling (Sutherland, 2006).

Five visually clear distinctions (zonations) were made between plant communities and variations in elevation during an initial walk through of the River Adur floodplain grassland site, Knepp Castle Estate, West Sussex England. Areas of vegetation zonation from the river moving away north over the floodplain were as follows; 'lower bank zone' (LB) representing the lower margins of the river bank; 'middle bank zone' (MB) representing the upper river margins; 'top bank zone' (TB) the natural levee (where over topping might occur), 'Middle floodplain' (MF) was a wide relatively gently sloping/elongated depression where pooling might occur following a flood event; and 'Upper floodplain'(UF) was the area furthest north before a man made hedgerow and trees ended the grassland floodplain.

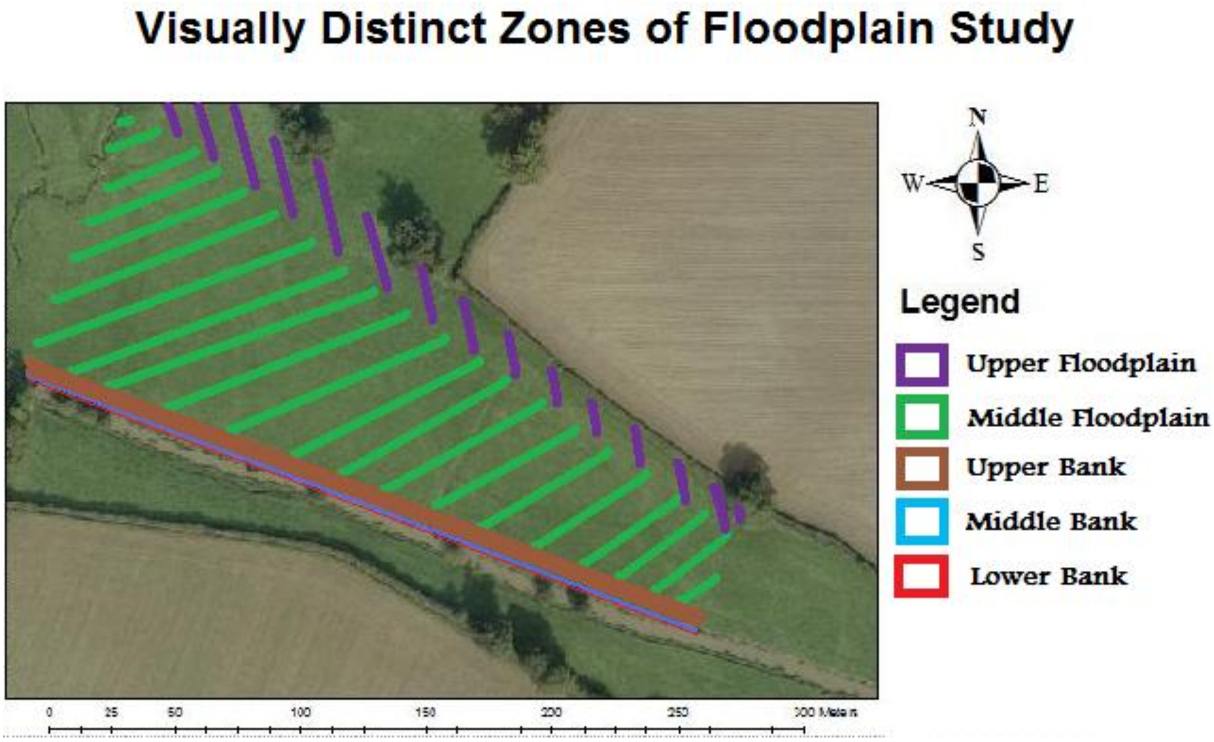

Figure 4-1: Approximation of the five visually distinct zones investigated in this study.

Plant species, species area coverage (percent), including litter and bare ground were recorded in 1m x 1m quadrats in-line with other research studies on these types of communities (Toogood and Joyce, 2009) (appendix 1). Hubbard's (1992) grass identification and Rose's (2006) wild flower key books were utilised for identification and confirmation of plant species. The sampling approach was of a stratified random design; stratified by the decision to place 10 quadrats in each of the 5 visually distinct zones, and random by placing the quadrats at random intervals along each of the sections (appendices 2, 3, 4, 5, 6, and 7). Cover was assessed by eye, a recognised approach, defined "as a vertical projection on to the ground of all the live, above-ground parts of the plants in the quadrat" (Rodwell, 1998).

The choice of sample size, in this case the size of the quadrat and the number of quadrats, is very important for we wanted to document a true representation of species abundance/frequency and richness in the study site. This needs to be based on species area relationships ("the number of species in areas of different size irrespective of the identity of the species within the areas"). Following a sample effort, a species accumulation curve was applied to recorded data to test if the accumulation rate of new species over the sampled area was a sample effort with good representation (Ugland *et al,* 2003).

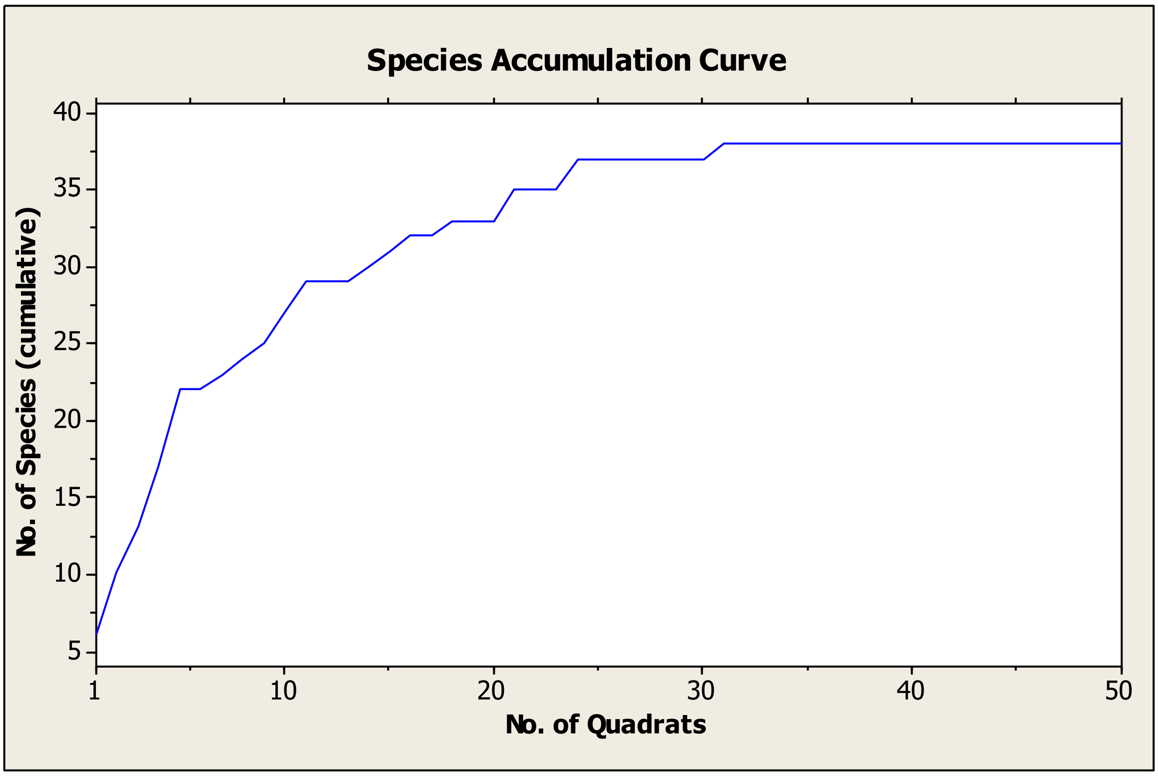

Figure 4-2: Sampling effort curve of vegetation quadrat survey.

4.3 Objective 2: Micro-topographical measurements in quadrats

A constellation of navigation satellites and control systems forms the global positioning system (GPS). Two main global navigation satellite systems (GNSS) exist, the American NAVSTAR system and the Russian GLONASS system" (Heywood *et al,* 2002). The American system consists of 24 operational satellites, an "optimal number of 21 satellites with 3 operational spares" in distinct high altitude Earth orbits of approximately 12,000 miles (20,000km). Inclined towards the "equator at 55°" with each satellite completing an orbit of the Earth every 12hrs, this "system is designed to ensure at least four satellites are visible at least 15° above the horizon at any given time" allowing specially designed GPS receivers to determine its location anywhere in the world (NOAA, 2007; Heywood *et al,* 2002; Longley *et al,* 2005) (figure 4-3).

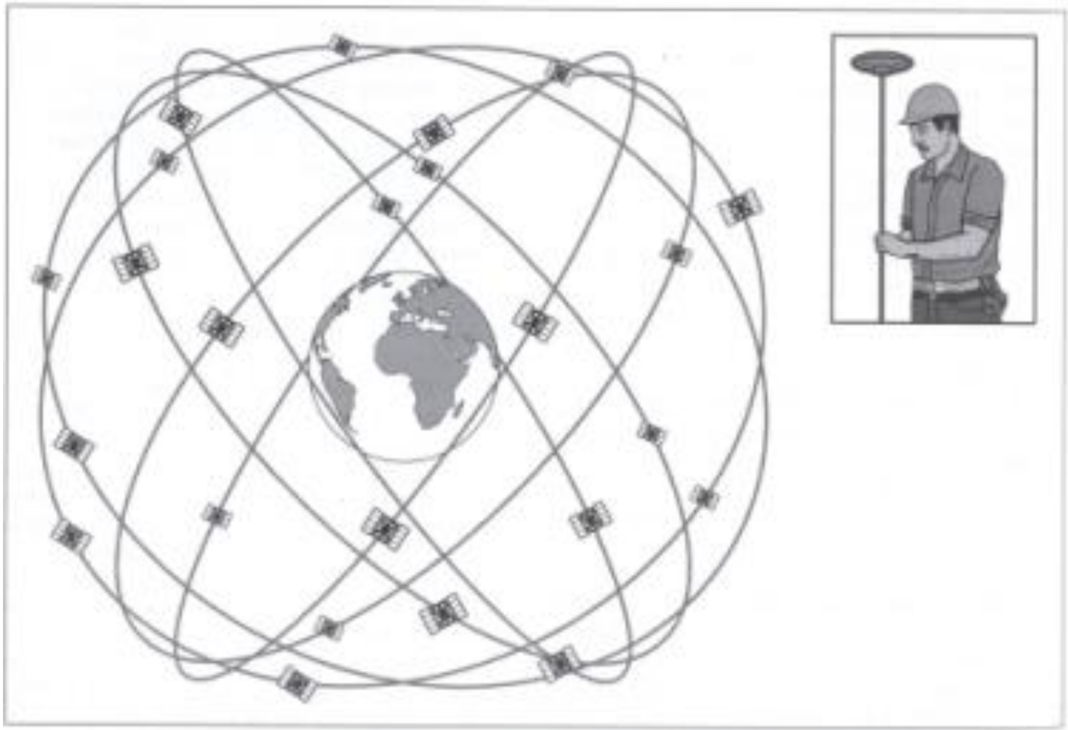

Figure 4-3: GPS constellation of satellites.

Two low power radio signal transmissions known as ‘L1’ and ‘L2’ from each satellite provides three crucial pieces of information; a pseudorandom code (a unique identifier pertaining to each satellite), satellite ephemeris data (satellite location data at any time) and almanac data concerning satellite status and current date and time maintained by onboard atomic clocks (NOAA, 2007; Leica Geosystems, 2007).

A process known as ‘trilateration’ (the measurement of distances between points forming horizontal triangles) is used to determine ground position from GPS based on visible distance to satellites (Montgomery and Schuch, 1993). This distance is calculated by taking the signal travel time (the difference between satellite transmission and receiver reception time) and multiplying by the speed of light. Providing a receiver can pick up and process signals from three satellites it can “determine a two dimensional position on the Earth (i.e. longitude and latitude)” (x and y), however an additional fourth satellite is required in order to establish the third dimension (height) (z value) (NOAA, 2007; Heywood *et al,* 2002) using a reference ellipsoid and subsequent calculation to the geoid (Natural Resources Canada, 2009).

The reference ellipsoid (*EGM96)* is the computational model (EUROCONTROL and IFEN, 1998) representing “a mathematical reference surface that approximates the shape and size of the geoid model which represents “the equipotential (gravity) surface that best approximates mean sea level”. The ellipsoid model is stored in the GPS because the geoid contains too much information to be stored in GPS itself. Therefore the elevation obtained directly from the GPS is the ellipsoid height which is an approximation of actual height because there is no account for gravitational effects. A reference ellipsoid therefore requires correction using the geoid before true elevation above sea level (orthometric height) can be calculated (Czerniak and Reilly, 1998; Natural Resources Canada, 2009) (figure 4-4 and 4-5).

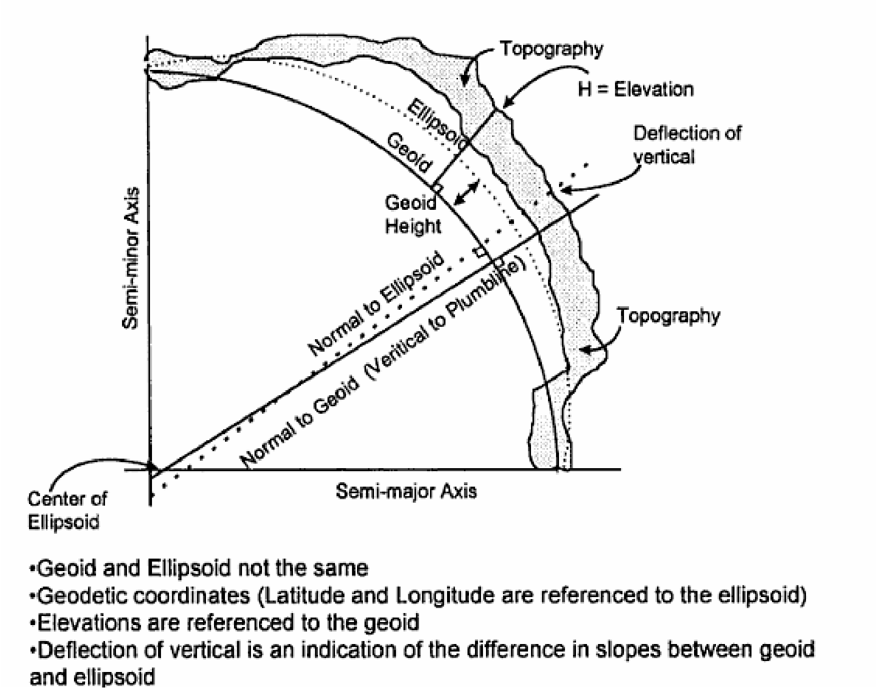

Figure 4-4: Relation of the three measurement surfaces (Czerniak and Reilly, 1998).

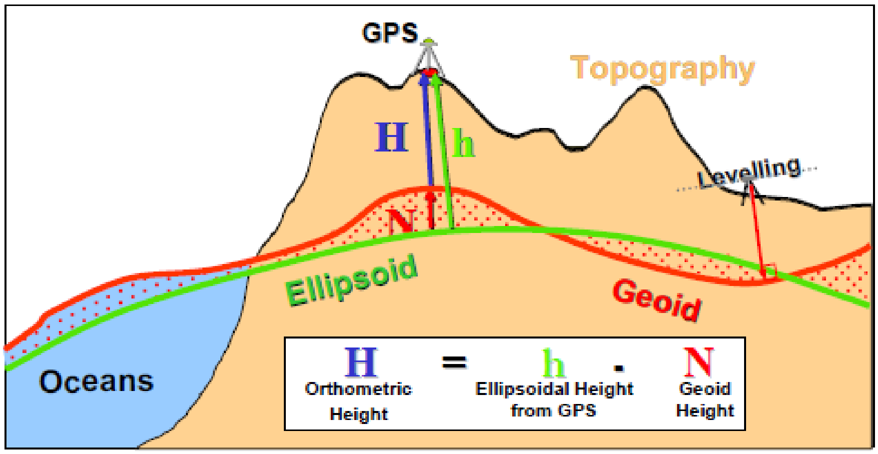

Figure 4-5: Orthometric height, ellipsoidal height and geoid height (Natural Resources Canada, 2009).

A differential global positioning system (D-GPS) represents an enhancement to global positioning systems (GPS) which utilise a network of fixed ground based reference stations to transmit the difference between geographical positions indicated by satellites and the known fixed referenced positions (Longley *et al,* 2005). The difference between measured satellite pseudoranges and actual pseudoranges are broadcast by these base stations allowing receivers to correct their own pseudoranges by the same amount either through radio or telephone signals or by post processing data (Leica Geosystems, 2007). These correction signals combined with utilisation of more satellites act to greatly improve both positional and elevational accuracies obtained with D-GPS in comparison to standard GPS units.

D-GPS enables rapid and very precise collection of positions however there are sources of error. These include ionospheric (signal delays proportional to the total electron content), atmospheric degradation, ephemeris errors, multipath/cycle slips, issues of quality in receiver software and hardware, minor atomic clock errors and obstructions to line of sight for satellite signals such as buildings/trees (NOAA, 2007; Heywood *et al,* 2002).

Elevation and positional data were recorded using a real time kinetic Leica differential global positioning system (D-GPS) 1200 series rover unit with post processing via Rinex files downloaded using Leica Geo Office software (Leica Geosystems, 2007) to adjust elipital for orthometric height. The design approach was stratified random with 20 position/elevation points recorded within each quadrat randomly and placed into GIS ArcView 9.3 using the local map system of the British National Grid (OSGB36) (Greaves, 2001) to allow subsequent investigation of the relationship between micro-topography, vegetation and soil pH in-line with studies by Burnside *et al* (2007) and Ward *et al* (Unpublished).

The Leica D-GPS 1200 series utilised in this method possesses a global navigation satellite system measurement engine which supports both GPS and GLONASS (SmartCheck+) and high level real time kinetic technology that allows for fast satellite acquisition, high accuracy centimetre measurements keeping the user informed of accuracy errors which are stored allowing later correction using post processing. General error of 20mm vertically and 10mm horizontally can be expected for post processed data with Leica Geo Office software (Leica Geosystems, 2007) correcting elliptical in relation to geoid height for orthometric height producing highly accurate elevation data.

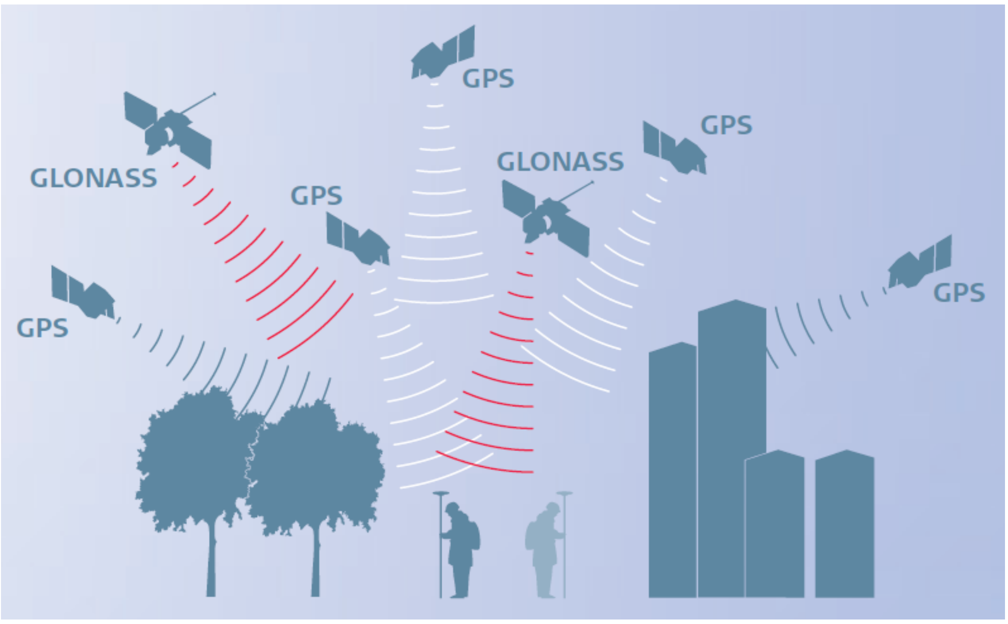

Figure 4-6: GPS and GLONASS satellites enabling higher centimetre accuracy (Leica Geosystems, 2007).

A key limitation that arose from this method was created when it was realised during post processing the data through Leica Geo Office software was that Leica only provides the correction files for a period of 1 month. Since the data was all post processed together shortly after the completion of the last quadrat survey, this 1 month limit had been exceeded for the top bank zone therefore the micro-topographical data (position and height) was uncorrected for this zone. An example of one quadrat taken from the GIS for top bank shows the effect this can have with distance between points (i.e. 1.77 meters) in comparison to a middle bank quadrat (figure 4-7). This was therefore taken as a consideration in later analysis.

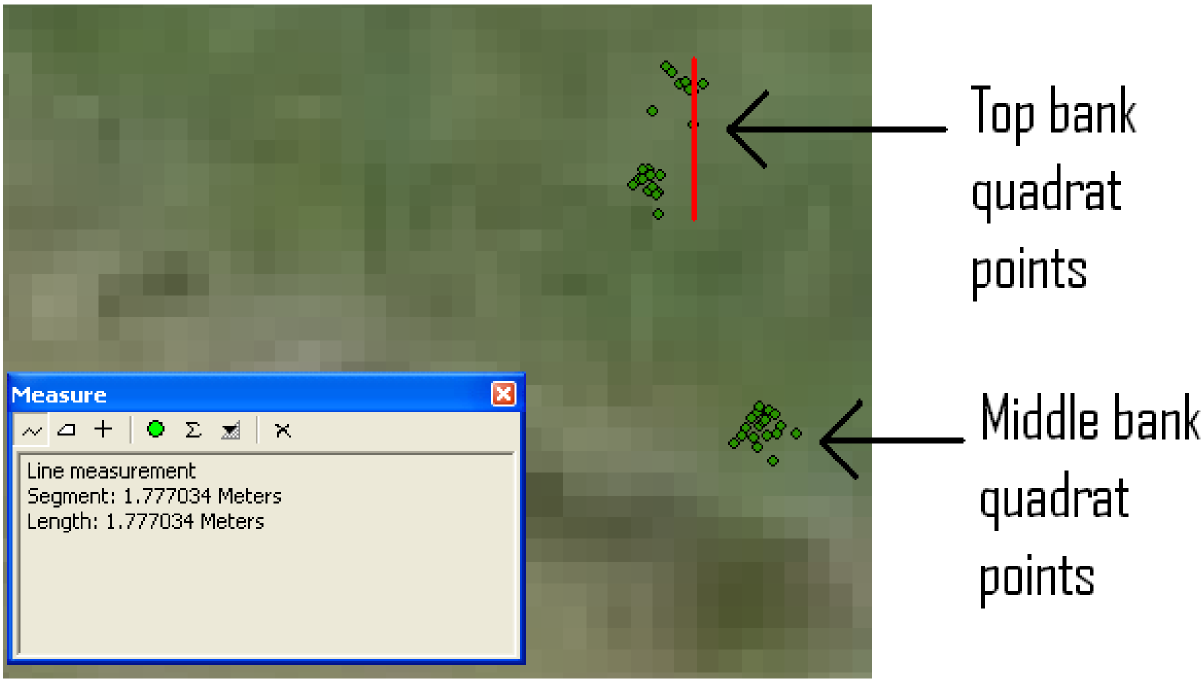

Figure 4-7: Example of top bank zone D-GPS points that weren't post processed (corrected). Note how the middle bank points that were post processed appear more compact and quadrat shaped.

4.4 Objective 3: Record soil pH within each quadrat.

A stratified sample design was used which involved adequate soil samples (approximately 300 grams) taken from the centre of each quadrat following completion of both vegetation and micro-topographical surveys. Laboratory analysis was utilised in determination of the pH value of the fifty soil samples involving use of an electrometric method known as 1 in 5 super saturated solution testing for pH using a calibrated electric pH meter that according to Head (2006) is recognised as the as a highly accurate method with associated error between 0.05 and 0.02 pH units.

On arrival in the laboratory, suitably durable 500ml glass beakers were weighed using a 2 point pre-calibrated scale (accurate to within 0.01 gram) as deemed appropriate (Head, 2006) and the weight recorded. Approximately 100 grams of each individual soil sample were added to ensure spare capacity should contamination/error occur. Between samples the scales were cleaned of debris with a brush and zeroed to ensure best accuracy.

All fifty samples were labelled placed on a tray and air dried in an oven as standard procedure, first at 35°C for 48hrs and then at 105-110°C for 24hrs with the weight recorded between stages (Head, 2006). This was to keep chemical reactions from changing soil composition characteristics and represented at 35°C the plant available moisture and then total moisture at 105°C. If all samples had been taken on the same day for even better a shorter period, this might have been used as supplementary data to the study, but was not due to the lack of comparably due to the 40 day gap between survey start and finish.

In turn, 50 ml of distilled water was added to glass beakers and weighed before 10 gram of soil was added in addition from each master batch. The soil samples were left submerged in this distilled water for 48 hrs and stored in a dark environment before testing soil pH. The operational principle behind super saturated testing for pH is that the solution to be tested is considered as an electrolyte of a voltaic cell. Of the two electrodes on the pH probe, one electrode called “the reference electrode, remains at a constant voltage with respect to the solution and is unaffected by changes of pH. The voltage of the other electrode is affected by the conductivity, and indirectly by the pH, of the test solution, allowing the complex relationship between pH and voltage can be determined” (Head, 2006) upon initial calibration of the electric pH probe to solutions of known pH which ensure accuracy and compensates for any temperature effects.

The stages of calibration were as follows;

1. Using distilled water electrodes were decontaminated.
2. Electrodes were immersed in buffer solution samples of known pH 4.0, 7.0 and 10.0 respectively with digitally displayed millivolts recorded in each buffer solution sample.
3. Millivolts readings were related to the pH solutions 4.0, 7.0 and 10.0 by plotting of a calibration graph and linked with a fitted line (figure 4-8) (Note; this should be and was straight – inferring the instrument is working correctly).
4. This acted as a working scale of the relationship between millivolts and pH enabling measurement in all 50 super saturated solutions with cross contamination prevented by decontamination of probe between samples.

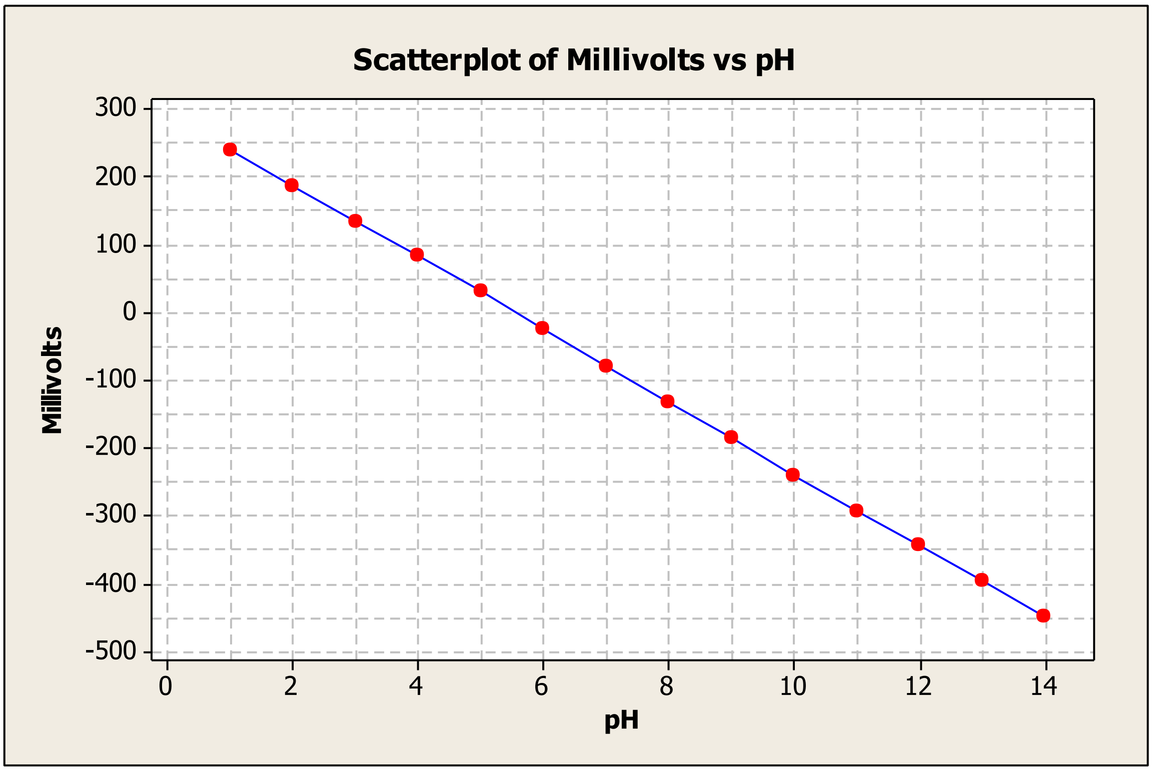

Figure 4-8: Electric pH probe calibration line plot.

4.5 Objective 4: Record Micro-topography and soil moisture using transects of the floodplain.

Transect surveys have a wide range of applications in ecological studies and a number of different types are recognised as appropriately suited methods, however like all methods it depends on what the aims of the investigation are. According to Sutherland (2006) transects are "commonly used to survey changes in vegetation along an environmental gradient" (line-intercept method) and in surveying highly mobile fauna such as birds/butterflies. Moving at a suitable pace along the set line recording species observed directly in front and at a set distance from the line (usually based on size and mobility of fauna in determining observers ability to accurately identify), for example a butterfly line transect might be set at five meters. Often surveyors will record the measured/estimated distance from the animal to the observer when first spotted to the transect line and the angle so that the perpendicular distance may be calculated (Sutherland, 2006).

Types of transect include; line and point transects. Line and point transects are predominantly stratified methods with an observer moving along a largely predetermined route through the study area only randomised by randomly placing where the line starts and variance in the point at which the observer stops or due to impractical obstructions (i.e. a tree or river) (Sutherland, 2006).

In this study we utilised a line transect survey design approach for we wanted to investigate the relationship between micro-topography and moisture along gradients through the study area and use the data collected to create a digital terrain model in ArcView GIS. Micro-topography was recorded using the Leica D-GPS with post processing of data and moisture was measured using a moisture probe which involved pushing a three prong probe into the ground and taking the subsequent digital reading (appendix 8). Five transect lines were used in the three zones; one in the ‘Top Bank zone’, three in the ‘Middle Floodplain zone’ and one in the Upper Floodplain (appendix 9). This was due to the ‘middle floodplain zone’ being wide, whereas top bank and upper floodplain were viewed as narrow strips. Lower bank and middle bank zone were excluded due to limitations emplaced by GPS surveying around/beneath trees, the health and safety concerns associated with the potential danger of falling in the river exacerbated by steep slope and uneven ground and expensive equipment D-DPS equipment (£50,000) (Neil Burnside, pers.comm.).

The use of this method allowed rapid data collection which is appropriate to soil moisture because soil moisture is a highly variable component which is known to vary on the day scale if not by the hour depending on weather conditions and soil structure. Therefore, originally it was thought soil moisture could measured with each quadrat as well, but on realisation of this limitation, measurements on different days in some cases weeks apart would be of limited insight value. The main disadvantage of the utilised approach was that both soil micro-topography and moisture do not follow linear patterns, they are highly variable (Miller *et al,* 1994; Krebs, 2001) and vertical line transects as well as many more points would have enabled a greater representation of the study area in regard to these factors.

4.6 Analysis

Vegetation data collected in the survey were collated into Microsoft Excel 97-2003. They were arranged so that we had quadrat code (Q_code), D-GPS points, species number and species names running horizontally as row headings. Species number was used as a measure of species diversity and ground cover as a measure of abundance. Species number was counted and subsequently added to the GIS. For each zone frequency of occurrence was recorded and the ground cover percentages were summed and converted to a percentage of abundance in each zone (i.e. *Alopecurus pratensis* Lower bank zone 3/1000*100 = 0.3%). At the bottom of these rows, total percentages of the entire survey were calculated (i.e. 200/5000*100 = 4%). Those species with the highest frequencies and percentages were coloured to make them stand out and examined in relation to their frequency and abundance in all other zones to identify whether they were good indicator species.

Q_code	d-gps	Species Number	Per quadrat cumulative	Agrostis stolonifera	Alopecurus pratensis	Bromus sp.	Cardamine pratensis	Cirsium sp. Thistle	Creeping Yellow Cress	Dactylis glomerata	Festuca arundinacea	Festuca ovina	Festu rubra
Lower Bank 1	696_715	6	6									5	
2	736_755	6	10										
3	776_795	8	13					8				5	
4	816_835	9	17				4	3				4	
5	856_875	13	22		3			2		8		12	
6	896_915	6	22										
7	936_955	6	23										
8	976_995	7	24										
9	1016_1035	4	25										
10	1056_1075	9	27							5			
Frequency /10	N/A	N/A	N/A	0	1	0	1	3	0	2	0	4	
SUM	N/A	N/A	N/A		3		4	13		13		26	
Percentage	N/A	N/A	N/A	0	0.3	0	0.4	1.3	0	1.3	0	2.6	
Middle Bank 1	676_695	16	29		2		2	6	3	12		9	
2	716_735	9	29		4			8		6		15	
3	756_775	14	29		6			6		12		15	
4	796_815	13	30		3				20	15		10	
5	836_855	13	31	26	4					6		8	
6	876_895	13	32		4		3	4		12		20	
7	916_935	9	32		2					3		5	
8	956_975	14	33		5					10		12	
9	996_1015	16	33		8		1			10			
10	1036_1055	17	33		8		1	3		10		18	
Frequency /10	N/A	N/A	N/A	1	10	0	4	5	2	10	0	9	
SUM	N/A	N/A	N/A	26	46	0	7	27	23	96	0	112	
% of zone quadr	N/A	N/A	N/A	2.6	4.6	0	0.7	2.7	2.3	9.6	0	11.2	
Top Bank 1	1_20	9	33			64	8				10		
2	22_41	2	33		40	47							

Figure 4-9: An extract from the vegetation survey Excel worksheet.

ESRI's ArcView Geographical Information System (GIS) 9.3 software was utilised in this study, giving the data both a visual and digital spatial dimension. The geographical spatially referenced (D-GPS) data was digitized into ArcMap using the British National Grid co-ordinates system and a pre-referenced aerial photograph overlain. All the data positional data collected with the D-GPS in both quadrats and transects were stored following post processing and added in a single shapefile (figure 4-10).

Figure 4-10: Post processed D-GPS data set with pre-referenced aerial photograph.

All field results (vegetation, pH and moisture) were entered into an excel spread sheet in the correct layout to GIS databases with attribute headings horizontal. Since the identification numbers unique to each D-GPS point taken were recorded (appendices 1 and 2) it allowed for the data to be joined (matched up). This required entry of short heading, no spaces between any letters or words and no headings starting with a number and subsequent conversion to CSV Comma Delimited file (figure 4-11) before being joined to the data based on the ID field unique to each position taken.

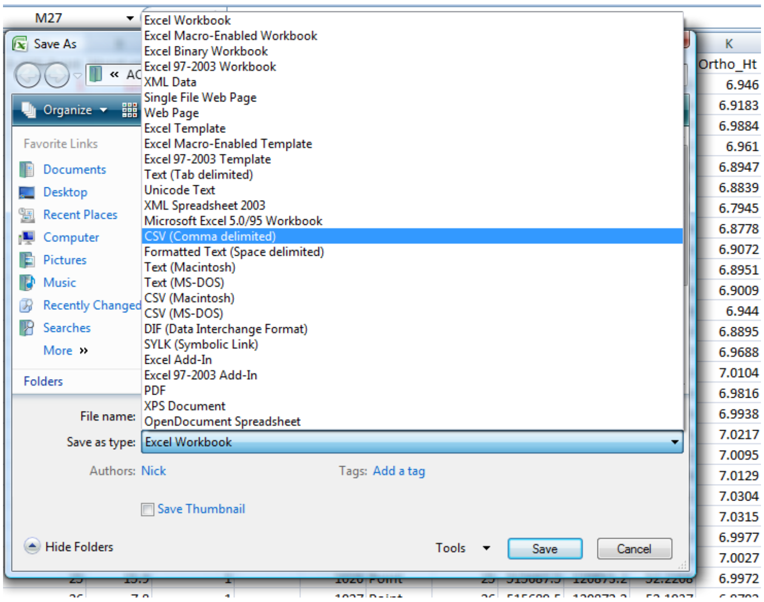

Figure 4-11: Saving an excel spreadsheet in CSV (comma delimited) format.

Upon entry into the GIS, the data was sorted to separate quadrat and transect data, and then subsequently the groups within these surveys (zone quadrats/transects 1, 2 and 3). This involved the 'select by attribute' function (figure 4-12) which allows using Boolean operators. These Boolean operators are part of the standard database query language adopted by virtually all mainstream databases in interrogating databases called SQL (structured or standard query language) to select those records of interest (Longley *et al,* 2005). In the example below we wanted to extract the quadrat data and since we knew the data was recorded under GPS_ID's 1 to 1000, we used GPS_ID>=1 AND <=1000.

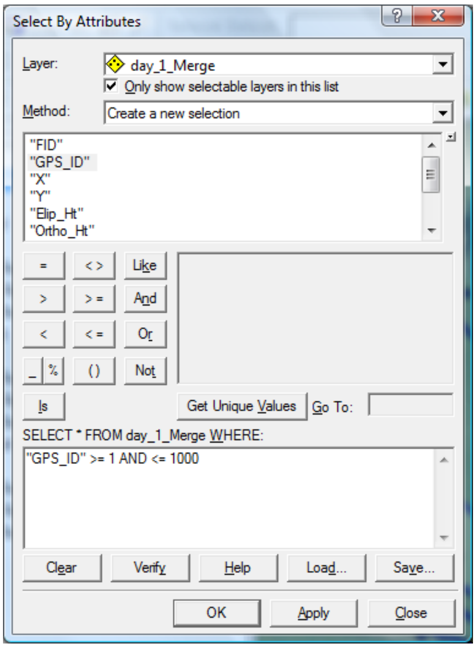

Figure 4-12: Extracting quadrat data from all D-GPS data using attribute query.

Once the corresponding records of interest are highlighted in the attribute table, ArcMap allows for the creation of a new layer using 'create layer from selected features' (figure 4-13). Once this has been done and all the data are present for further analysis.

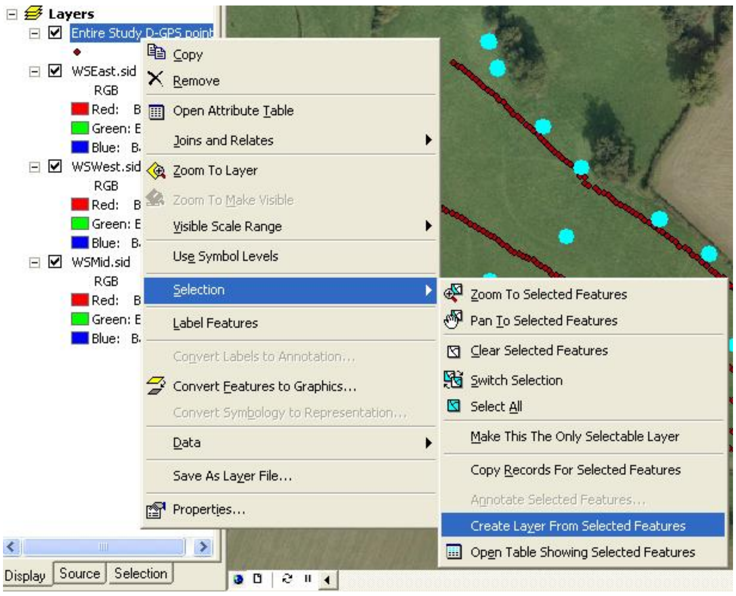

Figure 4-13: Using 'create layer from selected features' in ArcMap.

Descriptive statistics were utilised in the describing the data using the mean or median (depending on distribution – parametric/non parametric), minimum, maximum and standard deviation. There are a number of methods for extracting these statistics and these were all used at some point. These include; 'Symbology' function in layer properties (figure 4-14) through 'Quantities' > 'Classify' which gave us all the descriptive statistics used in the project (count, minimum maximum, mean, median, standard deviation) with exception of the range; Statistics from the attribute table using 'Statistics' (figure 4-15 and 4-16) which gave us the same statistics excluding the median; and also through exporting data to Minitab 16 statistical software package. It was dependent on convenience to the task at hand. These were also used at times to cross reference the data to ensure we had exported or created a layer containing all the correct data.

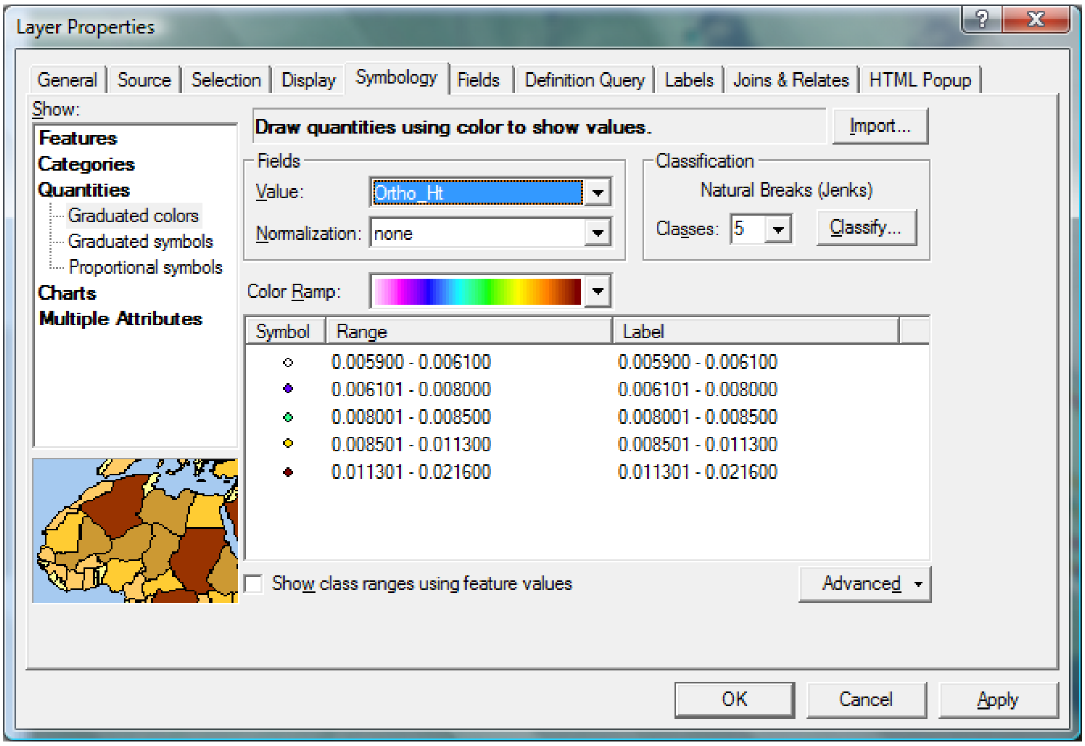

Figure 4-14: Layer properties > symbology > Quantities > Value (i.e. Orthometric Height) > Classify.

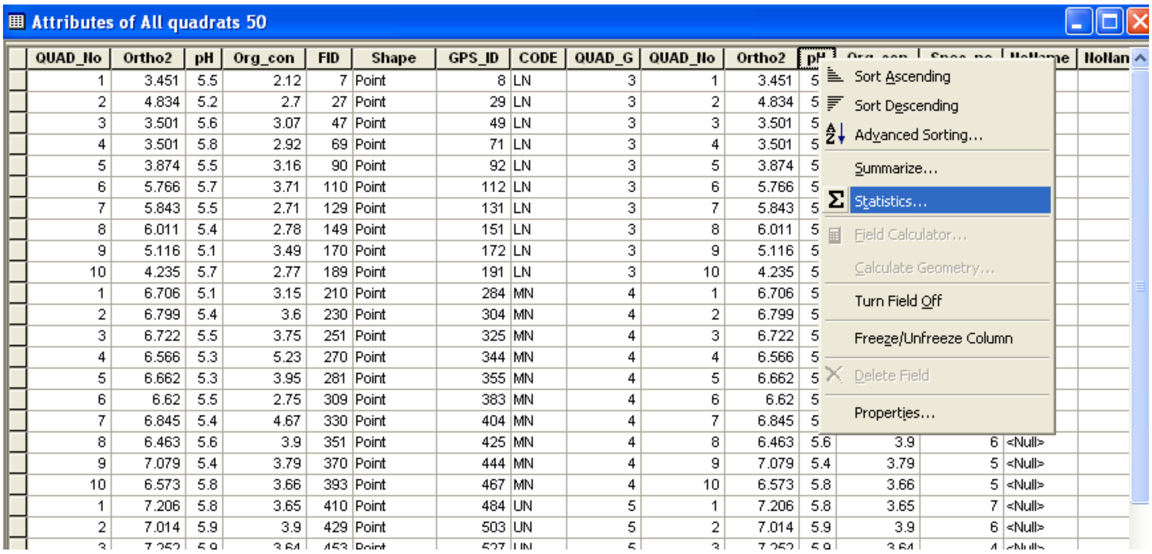

Figure 4-15: Using the 'statistics' function from attribute tables in the GIS.

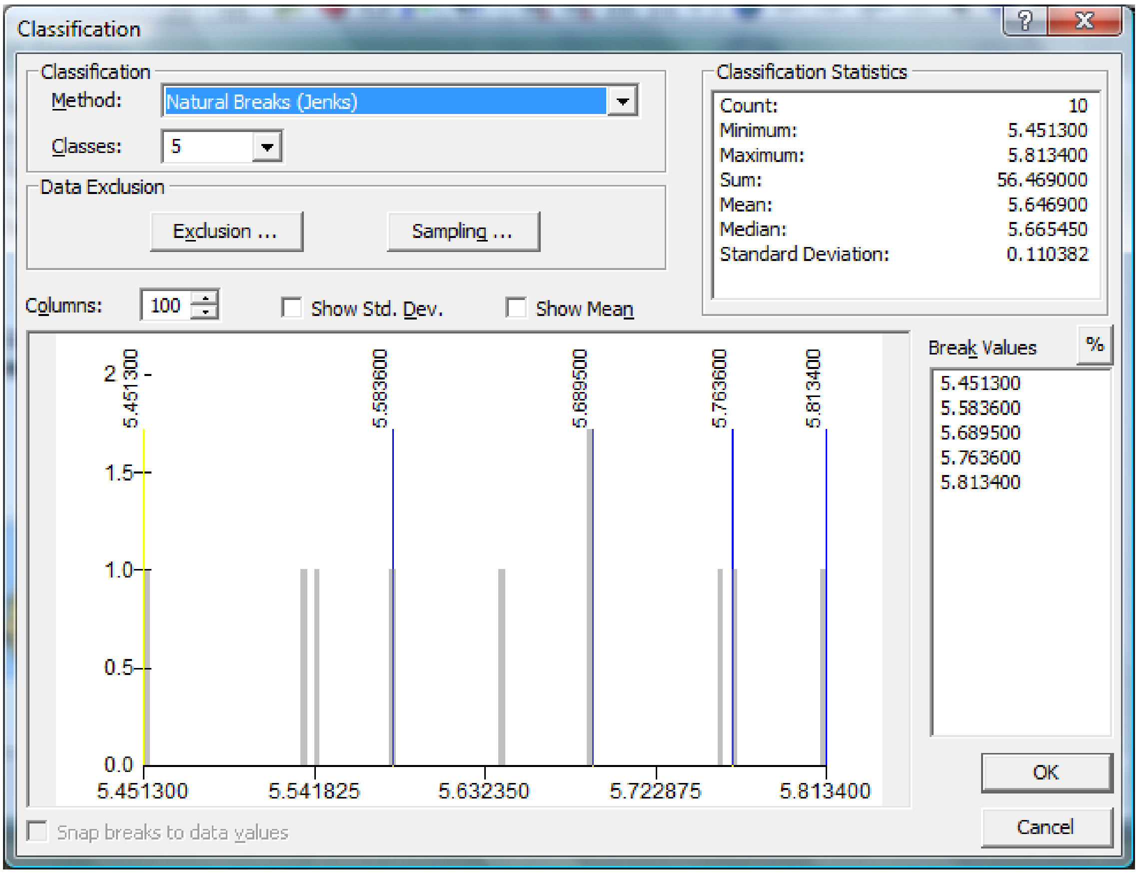

Figure 4-16: Symbology Classify method of extracting descriptive Statistics.

Exploratory Spatial Data Analysis (ESDA) from the 'Geostatistical Analyst' extension was used to construct histograms (also giving the descriptive statistics including interquartile range), normal QQ plots and in investigation of spatial trends in species number, micro-topography, soil pH and transect (micro-topography and soil moisture) data. This allowed us to investigate the distribution (parametric/non- parametric) of the data and in particular select outliers which are then shown as highlighted points in visually in the map. Although trend analysis was used in this project, the results did not highlight trends that were not already displayed in the data.

Minitab 15 statistical software was used to construct boxplots and regression analysis (simple and multiple). Boxplots were used to summarise and present data, it makes no assumptions of distribution. The box represents the lower and upper quartiles (middle 50% of the data) with a divided line at the median value. The vertical lines represent the largest and smallest values within 1.5 inter-quartile ranges. The star symbols are outliers identified as not normally distributed. This makes boxplots particularly useful when comparing two or more sets of sample data. Both simple and multiple linear regression analysis was used to explore relationships between variables of micro-topography, soil pH and species diversity. One variable has to be designated as a response and one or more predictor variables are required. It produces a P-Value which if less than 0.05 indicates a relationship of significance at a 95% confidence interval and a coefficient of determination (R^2) and R^2 adjusted. The R^2 adjusted is statistically more powerful therefore this was used in all regression test results.

5.0 Results

5.1 Vegetation

A total of 35 species were recorded across all five study zones (appendix 3) including 10 graminoids (grasses) all from the Poaceae family, 21 herbs, 1 wetland species and 2 woody species with 1 species unidentified. The majority of plants were identified to the species level, but some only as far as Genus and 1 to family level (see appendix 10).

Testing the vegetation data (species number) for normality (appendix 11 and 12) revealed middle bank, top bank and middle floodplain were parametric (normal) in distribution (kurtosis <3), but lower bank, upper floodplain and all quadrat data were non-parametrically (not normally) distributed (kurtosis >3). Therefore the following descriptive statistics of species richness extracted from the GIS (table 5-1) for each zone subsequently uses the mean for middle bank, top bank and middle floodplain, but the median for lower bank and upper floodplain as statistically appropriate to representation. Further statistical testing of two samples of parametric and non-parametric distribution should subsequently use a non-parametric test.

Table 5-1 and figure 5-1 display species richness recorded in the vegetation quadrats for all zones. The middle bank clearly supports the greatest species richness with mean species 13.4, followed by upper floodplain median 7, lower bank median 6.5, middle floodplain mean 5.4 and top bank mean 4.8 containing the lowest species richness. Between zones species richness was on average most variable in middle bank with standard deviation 2.7, followed by lower bank 2.503, top bank 2.044, upper floodplain 1.826 and middle floodplain

1.174. The median species in all quadrats and thus representing a sample of the floodplain as a whole was 6.5.

Species No.	Count	Min	Max	Range	Mean	Median	S.D
All Quadrats	50	2	17	15	7.6	6.5	3.698
Lower Bank	10	4	13	9	7.4	6.5	2.503
Middle Bank	10	9	17	8	13.4	13.5	2.716
Top Bank	10	2	9	7	4.8	5.0	2.044
Middle Floodplain	10	4	7	3	5.4	5.5	1.174
Upper Floodplain	10	4	11	7	7.0	7.0	1.826

Table 5-1: Descriptive Statistics of vegetative species recorded in quadrat survey.

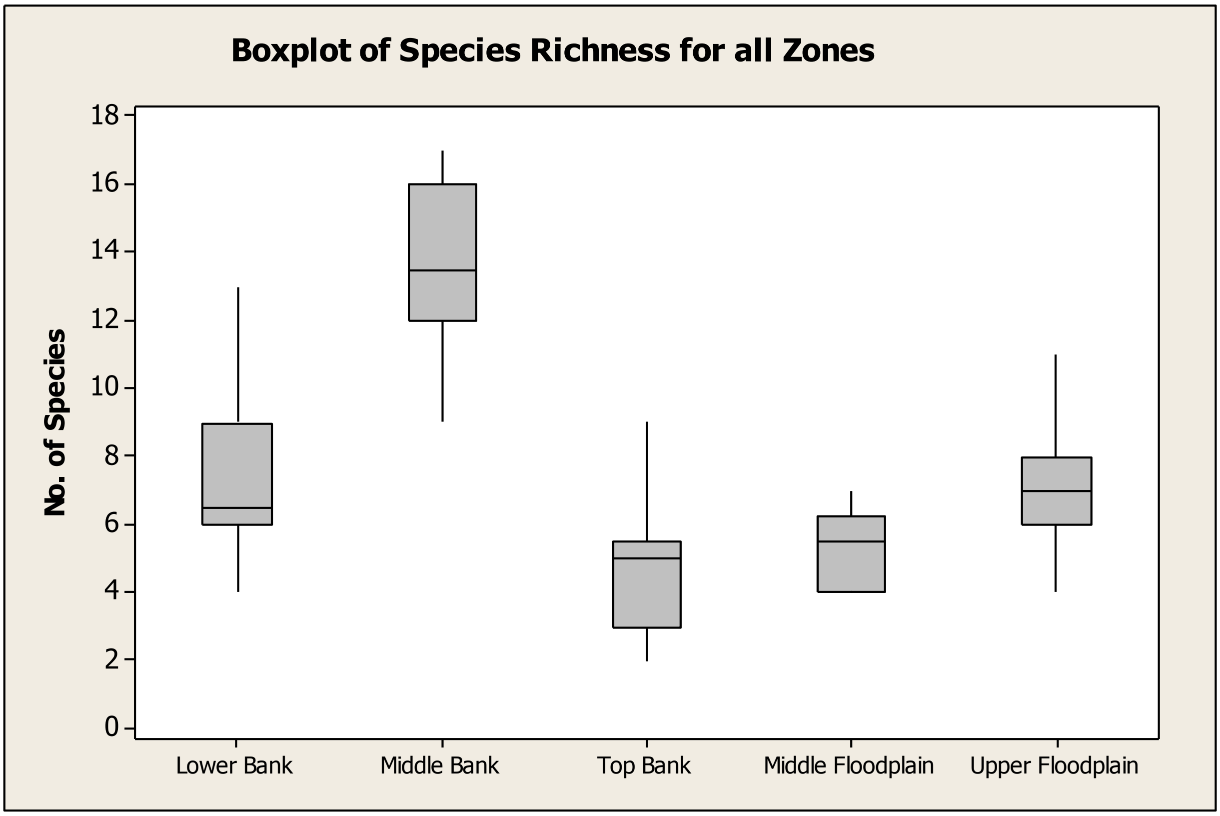

Figure 5-1: Boxplot of species richness recorded in each zone.

The top five vegetation of greatest abundance over all 50 quadrats were identified in order as *Festuca ovina* 14.3 %, Bromus sp. 10.8%, *Phragmites australis* 10.2%, *Festuca arundinacea* 9.2% and *Alopecurus pratensis* 5.2% (figure 5-2). Bare ground was also significant representing 9.3% of ground cover, of which 46.4% occurred in the middle bank zone (totalling 20.2% of ground cover in the middle bank zone) (figure 5-3). Ground cover by litter was 5.9% of the surveyed area with the biggest contribution coming from the middle floodplain zone (figure 5-4).

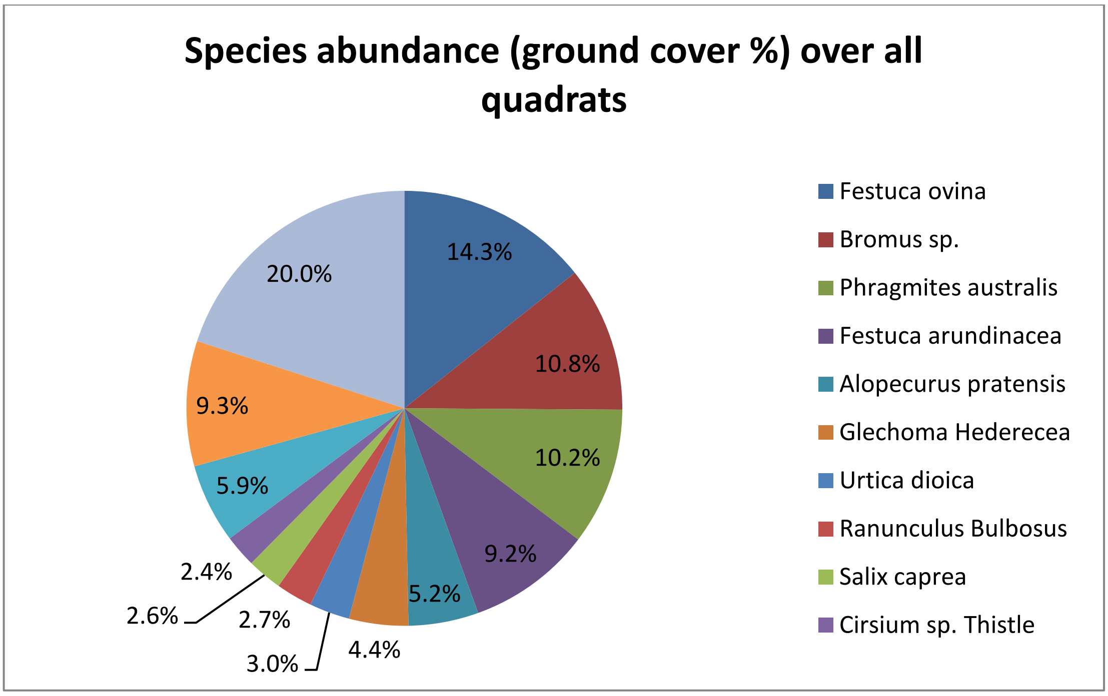

Figure 5-2: Ground cover % as a measure of abundance in all quadrats with top 10 species, litter and bare ground.

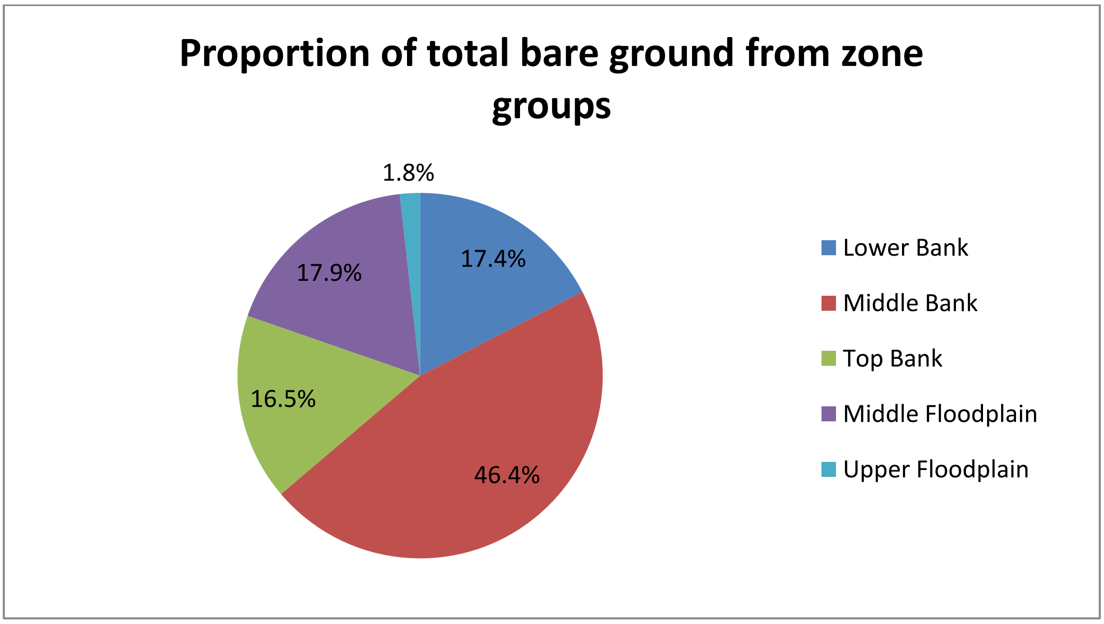

Figure 5-3: Bare ground recorded over quadrat groups (zones).

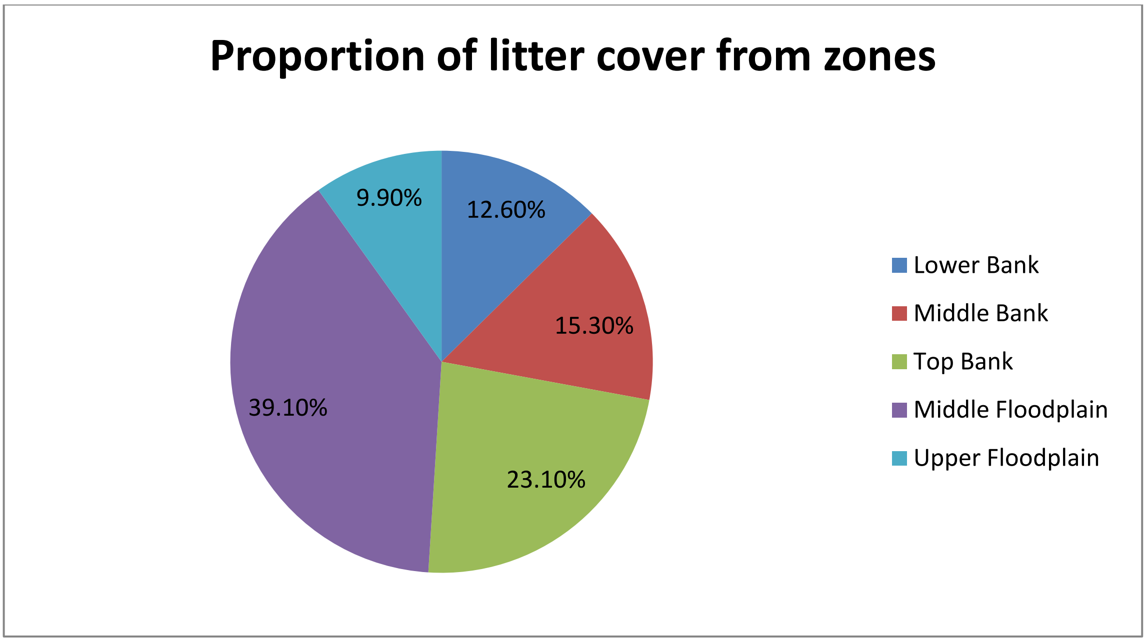

Figure 5-4: Litter cover recorded over quadrat groups (zones).

A number indicator species for different zones were identified based on both frequency of occurrence and abundance. These were *Phragmites australis* and *Salix Caprea* in the lower bank zone, *Dactylis glomerata* for the middle bank zone, Bromus sp. for top bank zone, *Festuca arundinacea* and *Glechoma Hederecea* for middle floodplain zone, and *Festuca ovina* and *Trifolium repens* for the upper bank zone.

Lower bank was typically characterised by an abundance of *Phragmites australis* which occurred in all 10 quadrats (frequency 10/10) and on average accounted for 47.5% of cover for the entire zones quadrats. The middle bank also contained *phragmites australis*, but at a lower frequency 6/10 and greatly reduced abundance 3.3%. *Salix caprea* was also of significantly greater abundance and frequency in the lower bank zone at 11.4% and frequency of occurrence 8/10. Although *Salix caprea* was present in middle bank, top bank and upper floodplain its frequency of occurrence/abundance was very low at 3/10, 4/10, 2/10, and 0.6, 0.4 and 0.5% respectively.

In the middle bank zone, *Festuca ovina* was the most abundant 11.2% and although occurring with high frequency 9/10, *Dactylis glomerata* was slightly more frequent 10/10 and only a little less in abundant 9.6%. *Festuca ovina* was overall the most abundant species throughout the entire floodplain survey at 14.3% (figure 5-2) and it appeared in all zones most notably as an indicator for the upper floodplain where it accounted for 47.5% cover and appeared with frequency 10/10 which accounted for 66% this 14.3% adundance over the entire floodplain. *Dactylis glomerata* however is most likely the better indicator of the middle bank zone, despite occurring in 4 zones. It constituted a small component of 3 other zones (lower bank 2/10 at 1.3%, top bank 2/10 at 1.5% and upper floodplain 2/10 at 0.2%) and was entirely absent from the middle floodplain zone.

The top bank zone contained an abundance of Bromus sp. at 46.9% and frequency 10/10 and was also the second most abundant species in the entire floodplain survey at 10.8% (figure 5-2). The top bank zone accounted for 87.2% of this 10.8% displaying abundance in this zone as having a high weighting/impact on the entire floodplains abundance results. Bromus sp. were entirely absent from the lower and middle bank zones, constituted a low frequency and abundance in the middle floodplain 2/10 and 0.3% and although at high frequency in the upper floodplain 9/10 only accounted for 6.6% of ground cover.

Festuca arundinacea was considered an indicator species of the middle floodplain appearing in 10/10 quadrats and at 39.1% represented the most abundant species for this zone. The only other zone it appeared in was the top bank zone with frequency 5/10, but only accounted for 7% cover (abundance). *Glechoma Hederecea* was also identified as an indicator species for the middle floodplain zone being the second most abundant 21.6% at frequency 10/10 and also only appearing in the upper floodplain zone, but at greatly reduced abundance 0.3% and frequency 2/10.

Since *Festuca ovina* was the most abundant (47.5%) and frequent (10/10) species in the upper floodplain, but also the most dominant species in the entire survey, *Trifolium repens* 8.5% is a better indicator for this zone as it was the second most abundant 8.5% (frequency 5/10), but appeared very little in any other zone. It appeared at frequency 1/10 and constituted only 0.2% of abundance in both lower bank and top bank and was absent from all others.

5.2 Micro-topography Recorded in Quadrats.

Testing the micro-topographical data for normality (appendices 13 to 18) revealed middle bank, top bank and middle floodplain were parametrically distributed, but the lower and upper floodplain were non-parametrically distributed. Therefore the following descriptive statistics of orthometric height extracted from the GIS (table 5-2 and represented visually in figure 5-5) for each zone use the mean for middle bank, top bank and middle floodplain and the median for lower bank and upper floodplain as statistically appropriate.

Top bank according to the mean 4.548m was the lowest in elevation, but this data was not post processed and is therefore not truly representative. After all if the top bank was of the lowest mean elevation, it would not be the top bank. The maximum value 6.787m seems a much more probable figure in reality based on what we observed visually (a raised ridge representing a levee). This will be discussed further in chapter 6. Taking this limitation into account, the order of elevation from lowest to highest was lower bank (median 5.642m), middle bank (mean 6.27m), then either top bank or middle floodplain (6.671) followed by upper floodplain. Based on the post processed data, the upper floodplain contained the greatest standard deviation in elevation, followed by the middle bank, lower bank and middle floodplain with the top bank not suitable for comment.

Orthometric Height (M)	Count	Min	Max	Range	Mean	Median	S.D
All Quadrats	1000	2.478	7.424	4.946	6.046	6.362	1.049
Lower Bank	200	5.380	6.452	1.072	5.645	5.642	0.159
Middle Bank	200	5.616	6.665	1.049	6.270	6.308	0.254
Top Bank	200	2.478	6.787	4.309	4.548	4.615	1.181
Middle Floodplain	201	6.402	6.883	0.481	6.671	6.679	0.113
Upper Floodplain	199	3.558	7.424	3.866	7.093	7.082	0.281

Table 5-2: Descriptive Statistics of micro-topography recorded in quadrat survey.

The upper floodplain contained 1 low value identified as an outlier (3.558m) (appendix 18 and figure 5-5) and the lower bank contains 5 outliers of high value (appendix 14 and figure 5-5) which are both visually displayed in appendix 19.

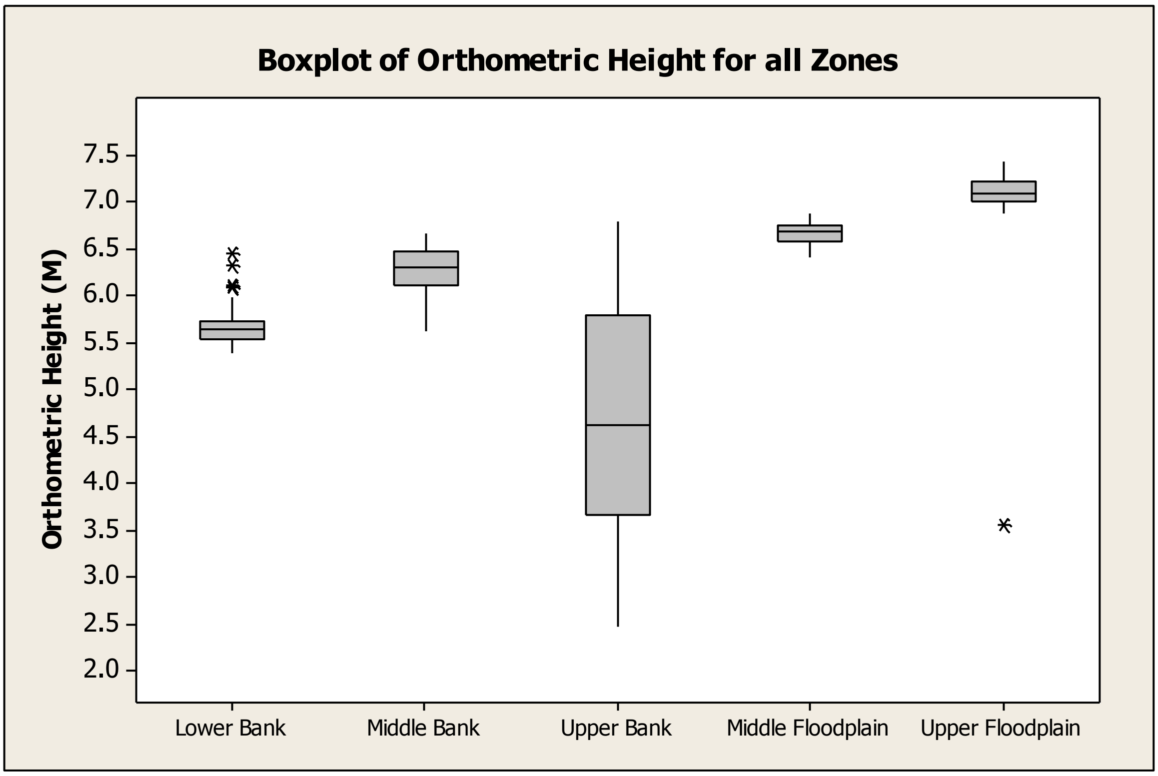

Figure 5-5: Boxplot of micro-topography data recorded in all zones.

5.3 Soil pH

Testing the distribution of the data grouped together (appendix 20) showed the data was parametric (normal) in distribution and individual zones (appendix 21, 22, 23, 24 and 25) were all parametrically distributed. Therefore the mean represents the entire data set and all zones as the best representation of the average.

Mean Soil pH for the floodplain was pH 5.77 and the pH range 4.9 to 6.6. Lower bank displayed the greatest mean pH 6.17 followed by middle bank pH 6.16, upper floodplain pH 5.61, top bank pH 5.5 and middle floodplain pH 5.43. Upper floodplain contained the greatest standard deviation 0.40 followed by lower bank 0.24, top bank 0.22, middle floodplain 0.19 and middle bank 0.13. The minimum soil pH was in upper floodplain pH 4.9 and the maximum in lower bank pH 6.6 (table 5-3).

PH	Count	Min	Max	Range	Mean	Median	S.D
All Quadrats	50	4.90	6.60	1.70	5.77	5.80	0.41
Lower Bank	10	5.80	6.60	0.80	6.17	6.10	0.24
Middle Bank	10	6.00	6.40	0.40	6.16	6.15	0.13
Top Bank	10	5.10	5.80	0.70	5.50	5.50	0.22
Middle Floodplain	10	5.10	5.80	0.70	5.43	5.40	0.19
Upper Floodplain	10	4.90	6.20	1.30	5.61	5.70	0.40

Table 5-3: Descriptive Statistics of soil pH recorded in quadrat survey.

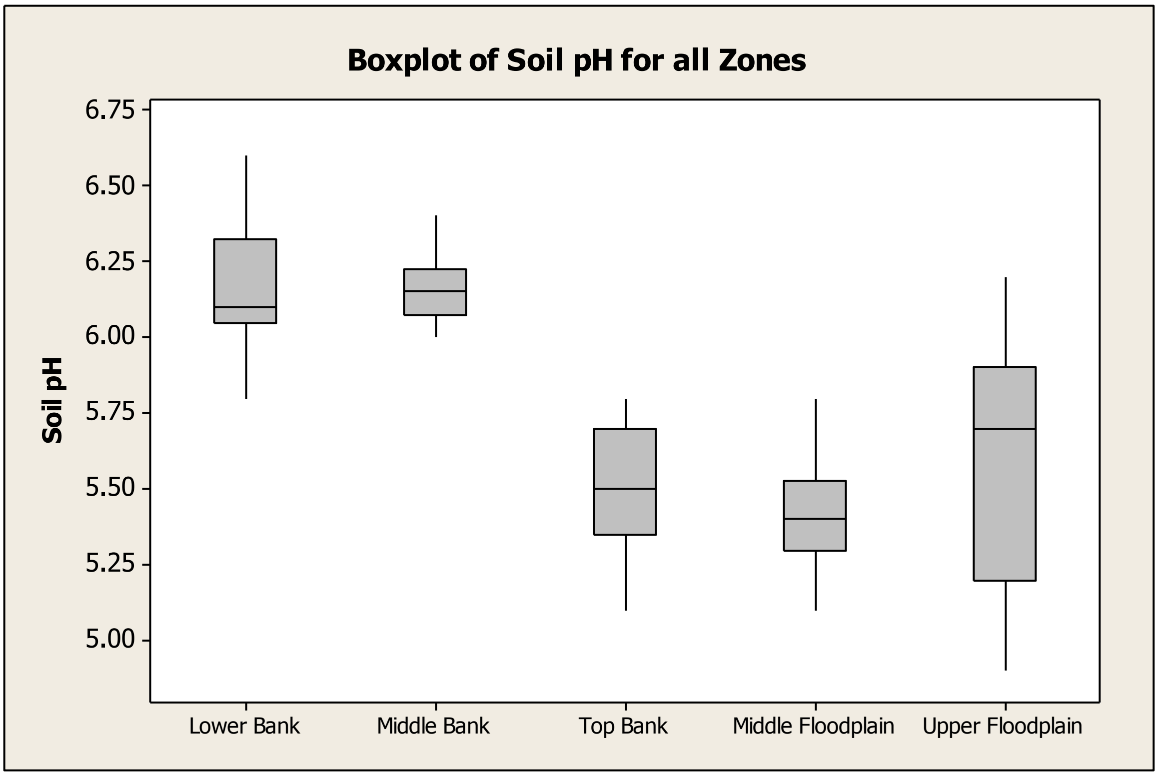

Figure 5-6: Boxplot of soil pH recorded in all zones.

Using figure 5-6 in tandem with table 5-3, and appendices 21, 22, 23, 24 and 25 no outlying pH values were present. Lower bank was normally distributed between 5.8 and 6.6 with lower quartile 6.1 and upper quartile 6.3 with slight right skew. Middle bank was normally distributed between 6 and 6.4 with lower quartile 6.1 and upper quartile 6.2 further demonstrating its narrow distribution. The top bank was normally distributed between 5.1 and 5.8 with lower quartile 5.4 and upper quartile 5.7 with slight right skew. The middle floodplain was normally distributed between 5.1 and 5.8 with lower quartile 5.3 and upper quartile 5.4 with slight right skew. The upper floodplain clearly shows the greatest range in the boxplot, normally distributed between 4.9 and 5.61 with lower quartile 5.2 and upper quartile 5.9.

5.4 Micro-topography, Soil pH and Species Richness.

Regression analysis carried out between mean orthometric height and species diversity for all quadrats revealed no relationship of significance (P= 0.364 >0.05 r^2 adjusted 0.0%) (figure 5-7). Top bank data was excluded and the data retested, but no relationship of significance (P=0.153 >0.05 and r^2 adjusted 2.8%) was established, although the P-value had decreased and the r^2 adjusted had increased (figure 5-8). The standard deviation taken for each quadrats 20 points was applied in regression analysis as a measure of micro-topographical heterogeneity. Using data from all quadrats regression revealed no relationship of significance (figure 5-9), but on exclusion of the top bank data a significant positive linear relationship was identified (P=0.000) with micro-topographical heterogeneity accounting for 14.8% of the variation in species richness (figure 5-10).

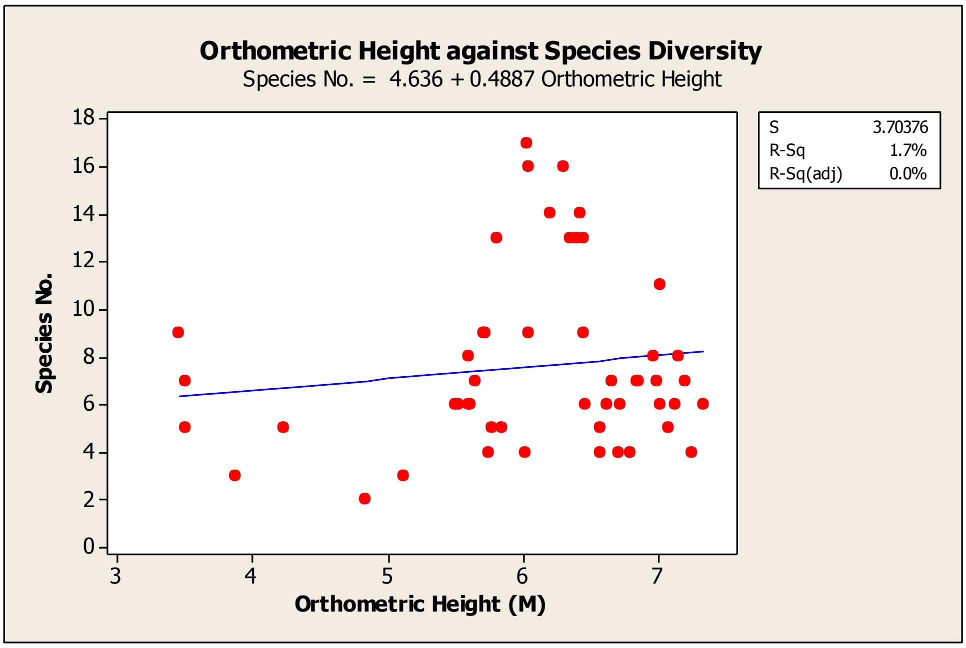

Figure 5-7: Scatter plot with regression of mean orthometric height against species number (P= 0.364 >0.05).

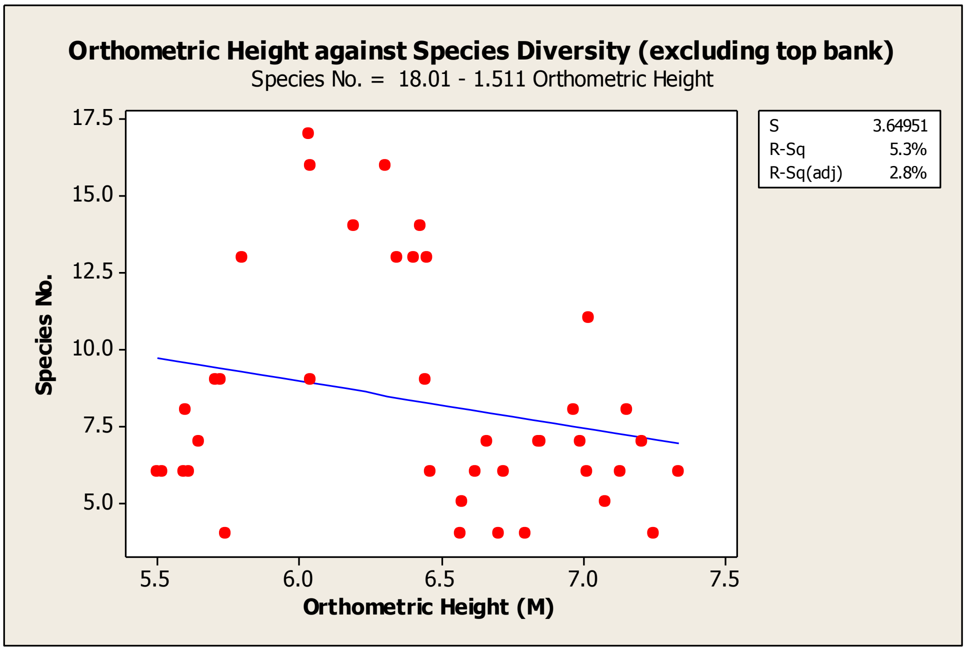

Figure 5-8: Scatter plot with regression of mean orthometric height against species number excluding top bank zone (P=0.153 >0.05).

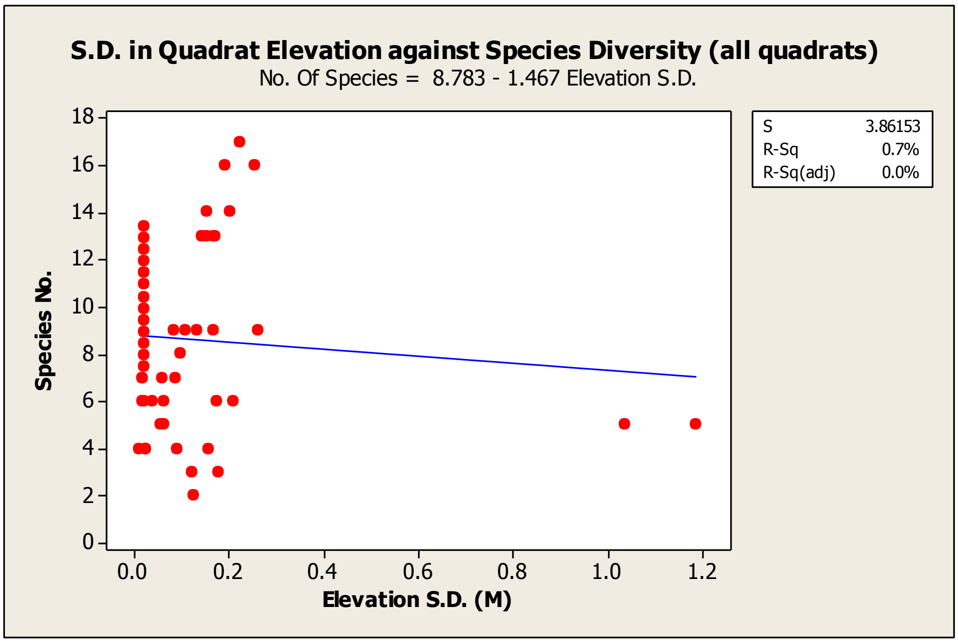

Figure 5-9: Scatter plot with regression of orthometric height standard deviation against species diversity in all quadrats (P= 0.568 >0.05)

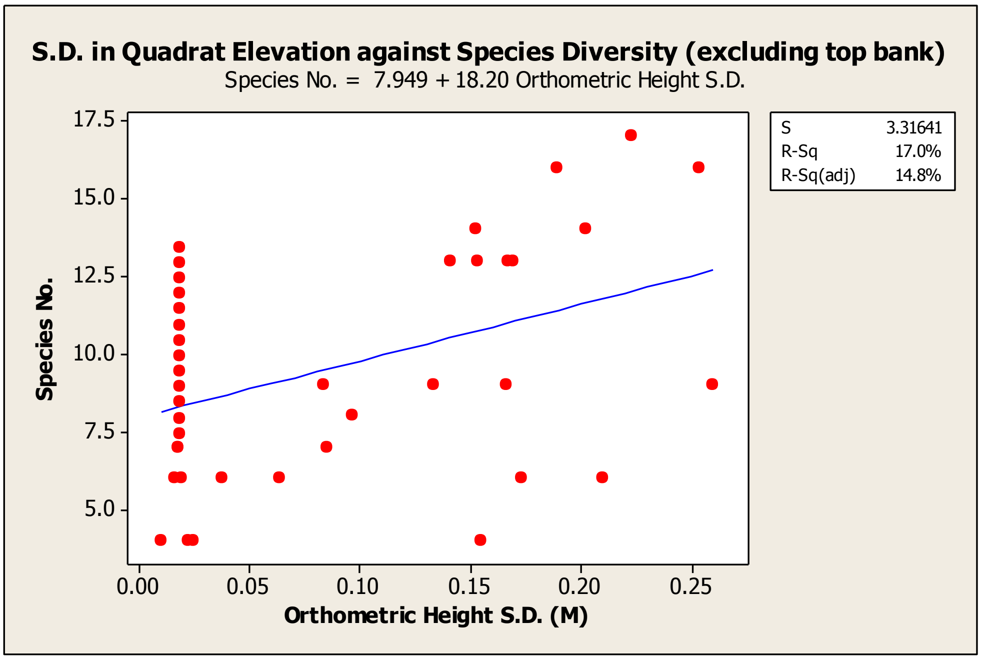

Figure5-10: Scatter plot with regression of orthometric height Standard deviation against species diversity in all quadrats excluding top bank (P=0.008 <0.05).

Regression between soil pH and species diversity revealed a very strong positive linear relationship (P= 0.000 <0.05) with soil pH accounting 34.3% (R^2 adjusted) of the variation in species diversity (figure 5-11). Regression between mean orthometric height and soil pH revealed no significant relationship (0.607 >0.05 R^2 adjusted 0.0%) (figure 5-12). Regression for mean othometric height and soil pH excluding top bank zone data also revealed no relationship of significance0.870 >0.05 R^2 adjusted 0.0%) (figure 5-13). Multiple regression for using species diversity as the response and soil pH and standard deviation of orthometric height (excluding top bank) revealed a significant relationship (P= 0.037 <0.05) and accounted for 15.9% (R^2 adjusted) of the variation in species diversity (note there is no graph available for multiple regression).

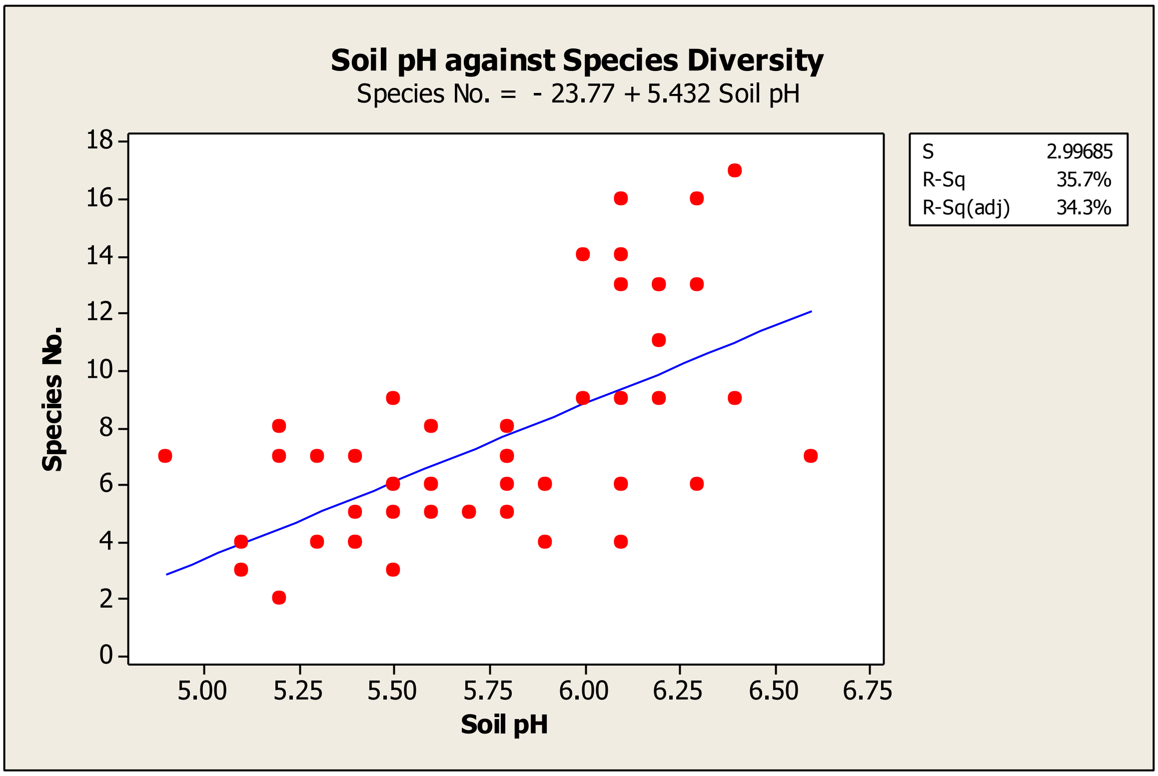

Figure 5-11: Scatter plot with regression of soil pH against species diversity reveals very positive significant relationship P=0.000 <0.05 (R^2 adjusted = 34.3%).

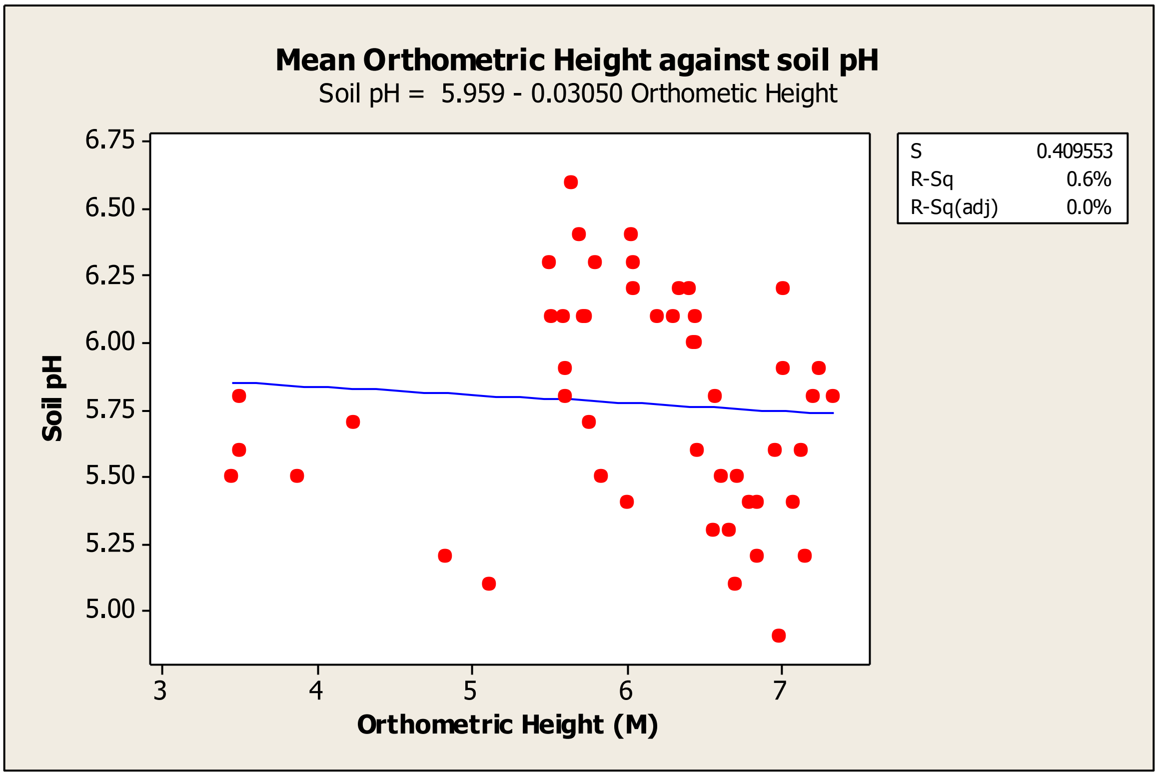

Figure 5-12: Scatter plot with regression of mean orthometric height against soil pH (0.607 >0.05).

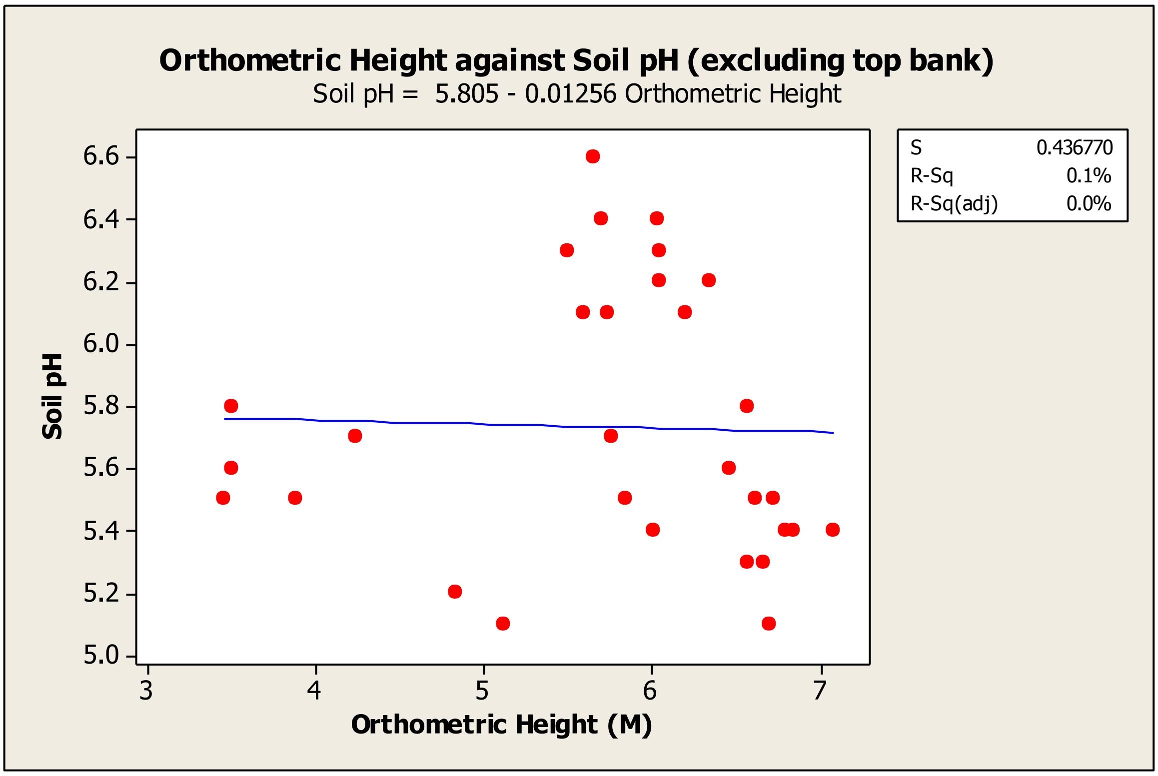

Figure 5-13: Scatter plot with regression of mean orthometric height against soil pH excluding top bank (0.870 >0.05).

5.5 Micro-topography and Soil Moisture Transect Survey.

Looking at appendices 26, 27, 28 and 29 all micro-topography and soil moisture data grouped and individually (transects 1, 2 and 3) show all the data collected are skewed by both high and low value outliers away from the line of best fit making their sample population distribution non parametric (not normal) in nature as further confirmed by the kurtosis values >3. Log transformation did not adjust their distributions significantly enough to allow for parametric testing. Based on this evidence statistically the median was used in the subsequent analysis as a better representation of all sample populations.

Table 5-4 and figure 5-14 display the data for elevation (m). The median values of elevation show upper floodplain (transect 3) as the most highly elevated at 7.331m, followed by top bank (transect 1) 6.775m and middle floodplain (transect 2) as lowest in elevation at 6.730m. The upper floodplain is displayed as having the largest elevation variation with a standard deviation (S.D.) of 0.553m, minimum of 5.055m and maximum value 8.859m; followed by top bank zone with standard deviation 0.171m, minimum 6.209m and maximum value 7.032m; and middle floodplain had the lowest variation 0.159, 6.156 and 7.047 respectively.

Elevation (Meters)	Count	Min	Max	Mean	Median	S.D.
All Transects	669	5.055	8.859	6.849	6.796	0.361
Transect 1 - Top Bank	129	6.209	7.032	6.775	6.800	0.171
Transect 2 - Middle Floodplain	417	6.157	7.047	6.730	6.765	0.159
Transect 3 - Upper Floodplain	123	5.055	8.859	7.331	7.421	0.553

Table 5-4: Summary table of descriptive statistics for elevation (m) recorded in transect survey.

Figure 5-14 used in tandem with table 5-4 and further supported by appendices 27, 28 and 29 shows upper bank elevation was normally distributed between 6.408 and 7.032m. There is little deviation from the median 6.8m with the lower and upper quartiles ranging from 6.694m to 6.890m further highlighting a slight right skew. There were 4 outliers of low elevation in transect 1. Transect 2 elevation was normally distributed between 6.408 and 7.047m. There is greater deviation from the median 6.8m than transect 1 with the lower and upper quartiles ranging from 6.641m to 6.843m supporting evidence of a slight right skew. Transect 2 contained the greatest number of outliers with a total of 17 low values. Transect 3 was normally distributed between 6.251m and 8.346m and displayed the greatest range of elevation values and the greatest deviation from the median 7.421m with lower and upper quartiles 6.929m and 7.616m respectively along with a pronounced right skew. 3 outliers were apparent, 1 low value (5.055m) and 2 high values (8.793 and 8.859m) (figure 5-14).

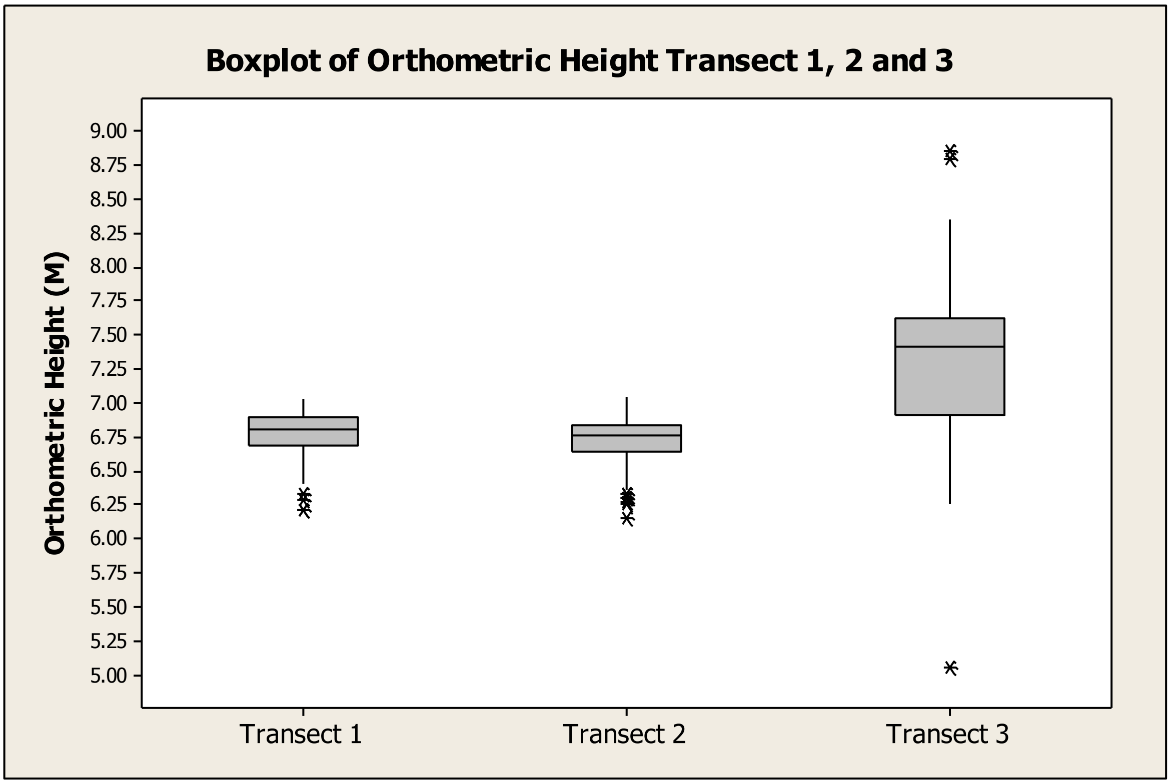

Figure 5-14: Box plot of orthometric height in transect survey.

Looking at the soil moisture data in table 5-5, figure 5-15 and appendices 30, 31, 32 and 33 the upper floodplain (transect 3) contained the greatest soil moisture with median 15.1%, followed by top bank zone (transect 1) 13.6% and subsequently middle floodplain (transect 2) with median 13.3%. Upper floodplain displayed the greatest variation in soil moisture content with standard deviation 4.2%, preceded by top bank zone 3.3% and middle floodplain zone 3.2%. The minimum and maximum values show upper floodplain contained the lowest moisture value at 3.9%, followed by middle floodplain 4.3% and top bank zone 7.6%, whereas middle floodplain had the highest moisture at 35.4%, upper floodplain 32.1% and top bank zone 24.9%.

Soil Moisture %	Count	Min	Max	Mean	Median	S.D
All Transects	669	3.9	35.4	13.9	13.5	3.5
Transect 1 - Top Bank	129	7.6	24.9	14.0	13.6	3.3
Transect 2 - Middle Floodplain	417	4.3	35.4	13.5	13.3	3.2
Transect 3 - Upper Floodplain	123	3.9	32.1	15.3	15.1	4.2

Table 5-5: Descriptive statistics of soil moisture recorded in transects.

Used in tandem figure 5-15, table 5-5 and appendices 31, 32 and 33 showed transect 1 (top bank) soil moisture was normally distributed between 7.6% and 21.4%. There is slight left skew illustrated by the lower and upper quartiles 11.7% and 15.93% in respect to the median 13.6% (skewness 0.525) and 2 outliers of high value (23 and 24.9%). Transect 2 (middle floodplain) showed normal distribution between 6.4% and 21.8% and slight left skew (skewness 1.077) with lower quartile 11.2% and upper quartile 15.4% with median 13.3%. 5 outliers were present with 1 low value and 4 high values, one of which was particularly high at 35.4%. Transect 3 was normally distributed between 6.1 and 24.3% with median 15.1% and lower quartile and upper quartile 12.4 and 17.68% respectively, and slight left skew. 3 outliers were present, 1 low and 2 high values.

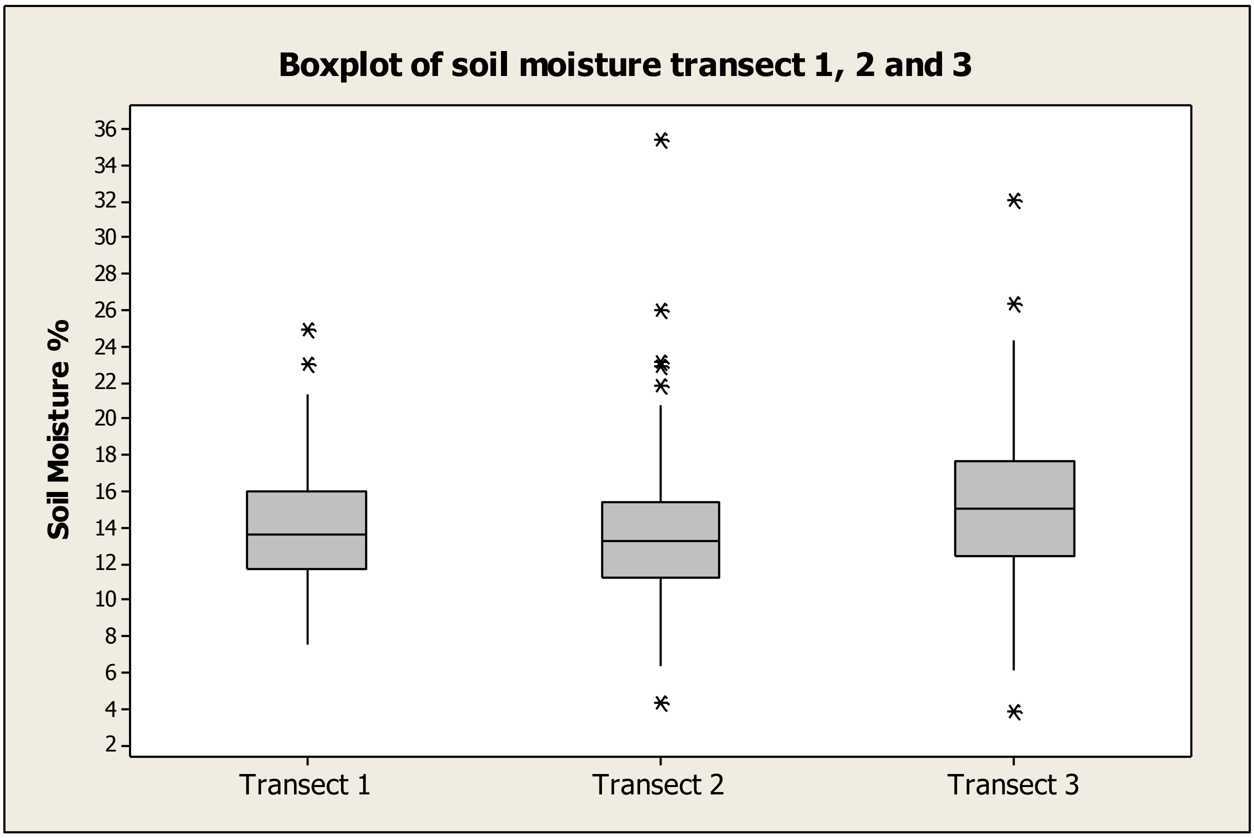

Figure 5-15: Box plot of soil moisture transect 1, 2 and 3.

Regression analysis between micro-topography and soil moisture recorded over all transects revealed no relationship of significance at the 95% confidence interval ($P= 0.228 >0.05$) with the coefficient of determination (R^2 adjusted) at 0.1% (figure 5-16). On further breakdown, regression on transect 1 (top bank) showed a weak positive relationship of significance at 95% confidence ($P= 0.042 <0.05$) with 2.5% (R^2 adjusted) of the variation in soil moisture explained by height (figure 5-17). Transect 2 displayed no relationship of significance ($P= 0.598 >0.05$) with 0.0% R^2 adjusted (figure 5-18) and transect 3 showed a significant negative relationship ($P=0.007 <0.05$) with soil moisture decreasing with height with 5.1% of its variation explained (figure 5-19).

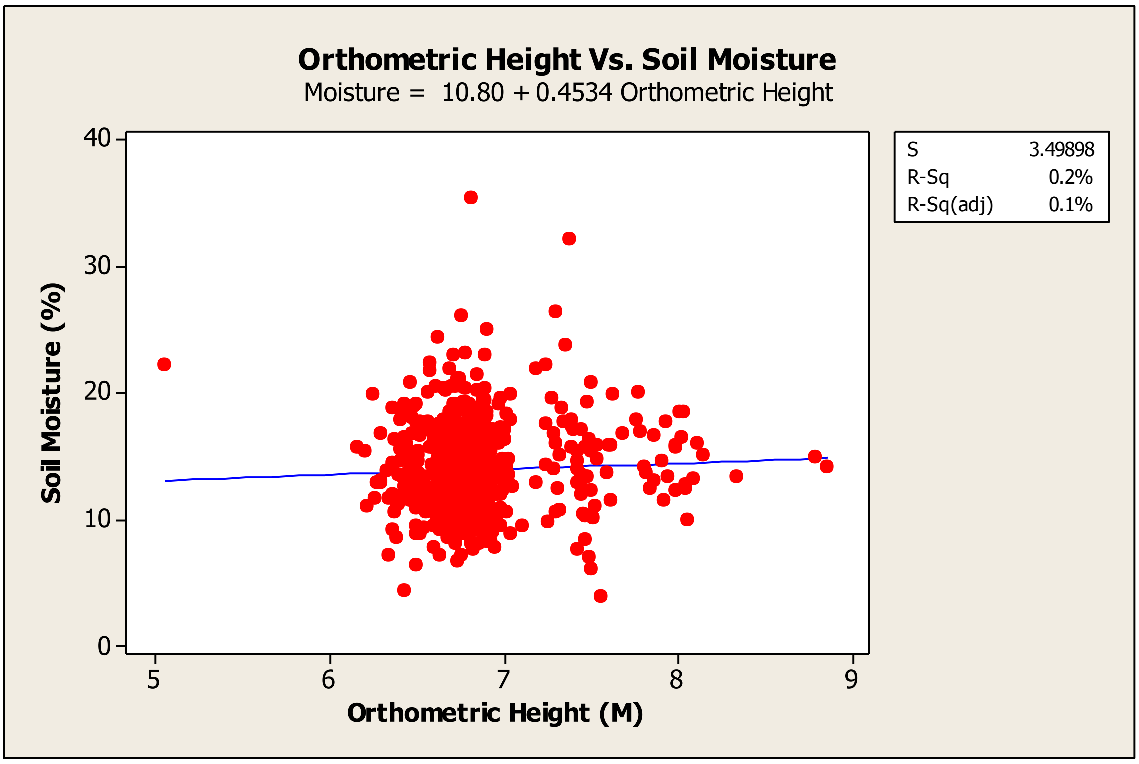

Figure 5-16: Scatter plot with regression of Orthometric Height against soil moisture from all transects (P= 0.228 >0.05).

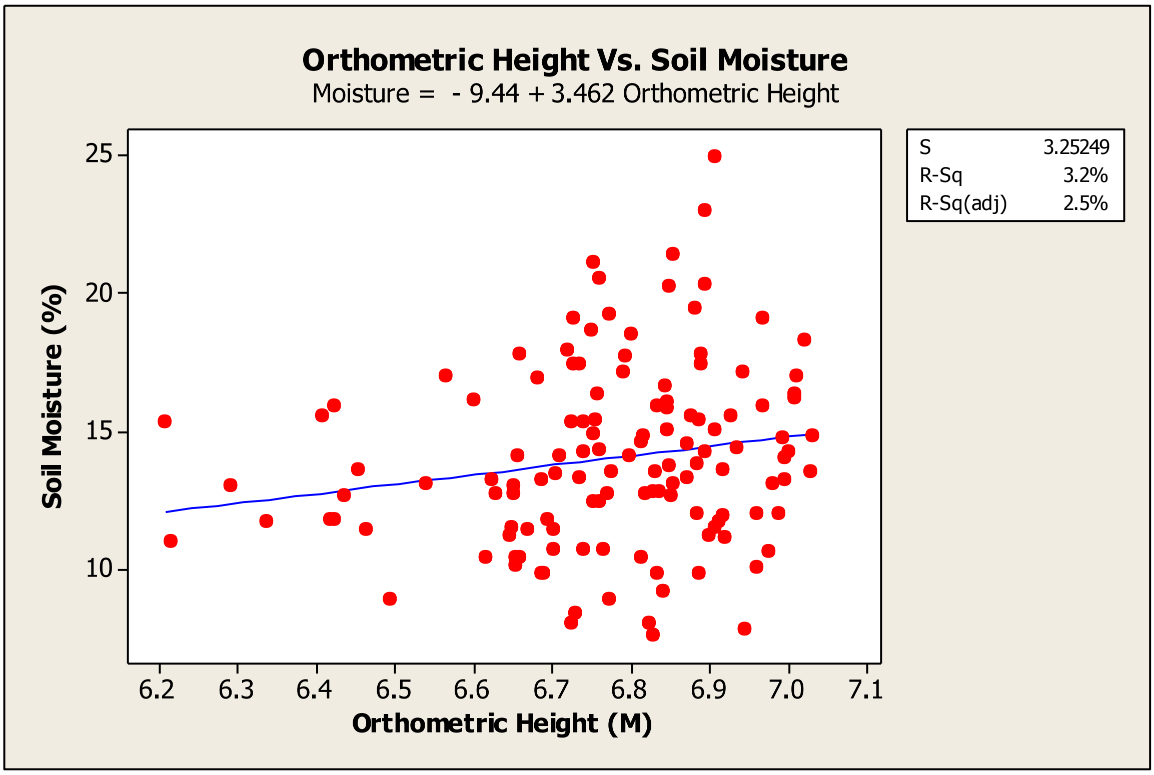

Figure 5-17: Scatter plot with regression of Orthometric Height against soil moisture in transect 1 (P= 0.042 <0.05).

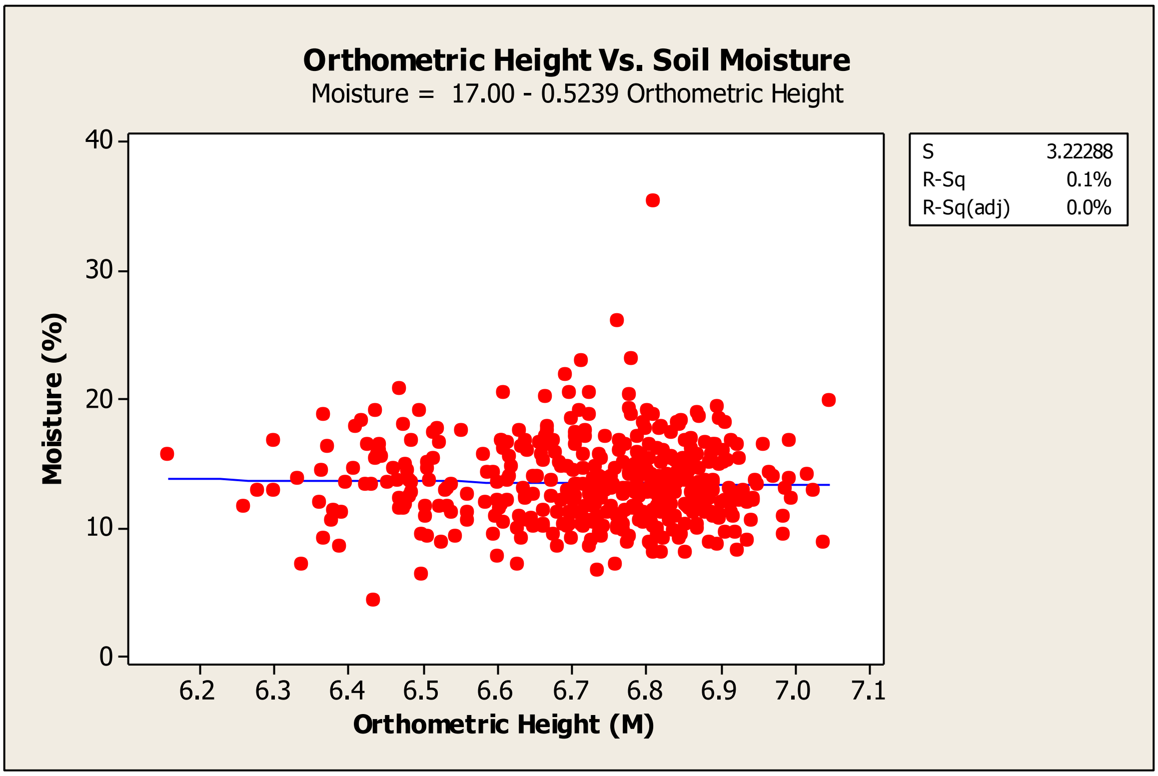

Figure 5-18: Scatter plot with regression of Orthometric Height against soil moisture in transect 2 (P= 0.598 >0.05).

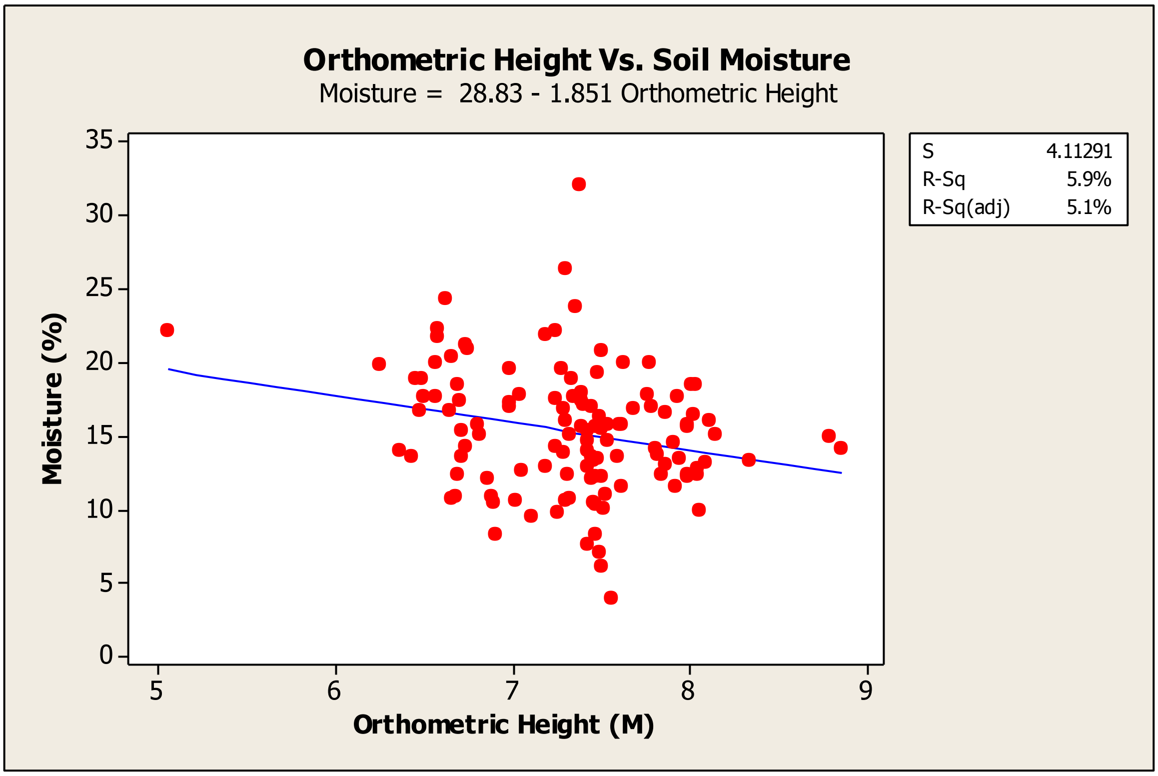

Figure 5-19: Scatter plot with regression of Orthometric Height against soil moisture in transect 3 (P=0.007 <0.05).

6.0 Discussion

6.1 Key Findings

Vegetation biodiversity of the floodplain totalled 35 species which included identification of 10 grasses of the Poaceae family (true-grasses), 21 herbs, 1 wetland specie(s) of the Juncaceae (rush family), 2 low growing woody species (appendix 10) and 1 unidentified species. The floodplain was dominated by an adundance of grass species; *Festuca ovina* 14.3%, Bromus sp. 10.8%, *Phragmites australis* 10.2%, *Festuca arundinacea* 9.2% and *Alopecurus pratensis* 5.2%. The vegetation along with pH data (median pH 5.8, range pH 4.9 to 6.6) suggest predominantly the habitat is neutral grassland containing mesotrophic (MG) NVC plant communities (Rodwell, 1998).

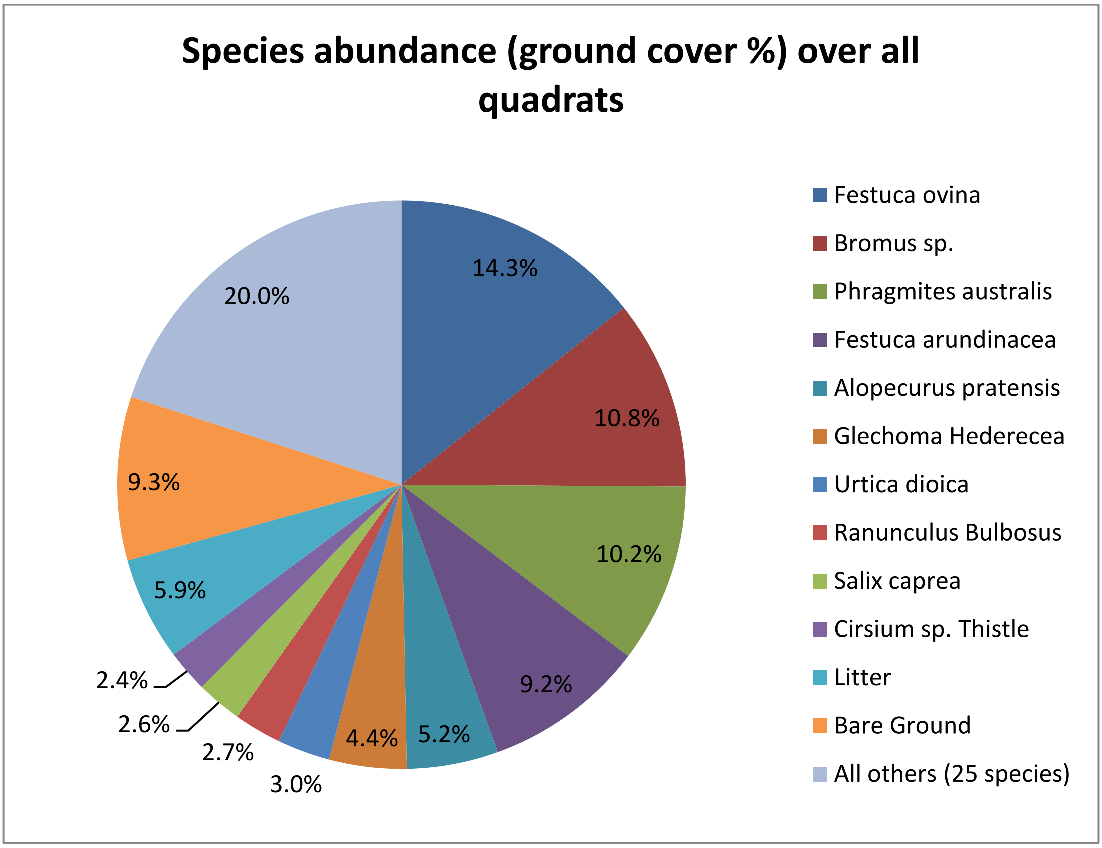

Figure 6-1: Top 10 abundant species over entire floodplain survey.

Species displaying zonation were as follows; *Phragmites australis* in the lower bank zone (median elevation), *Dactylis glomerata* in the middle bank zone, Bromus sp. for top bank zone, *Festuca arundinacea* and *Glechoma hederecea* for middle floodplain zone, and *Festuca ovina* and *Trifolium repens* for the upper bank zone.

Phragmites australis (common reed) was very clearly restricted to the lower bank zone (median elevation 5.642m) and middle bank zone with complete absence from all other zones (figure 6.2). A good indicator of these zones, though best for the lower bank zone displaying high frequency 10/10 and abundance 47.5%, however decreased frequency 6/10 and abundance 3.3% in the middle bank. This is most likely based on hydrology since it can withstand a constant water depth of up to 2 meters in still water, shallow water flows (approximately 25 to 60cm) and submergence events in sites liable to winter flooding. Another factor limiting its abundance in the middle bank is likely to be the slope angle since this species prefers flat or gently slanted ground (Grime *et al,* 1988) (plate 2).

Plate 2: Lower bank zone dominated by *Phragmites australis* (right), middle bank zone (centre) and top bank zone (left).

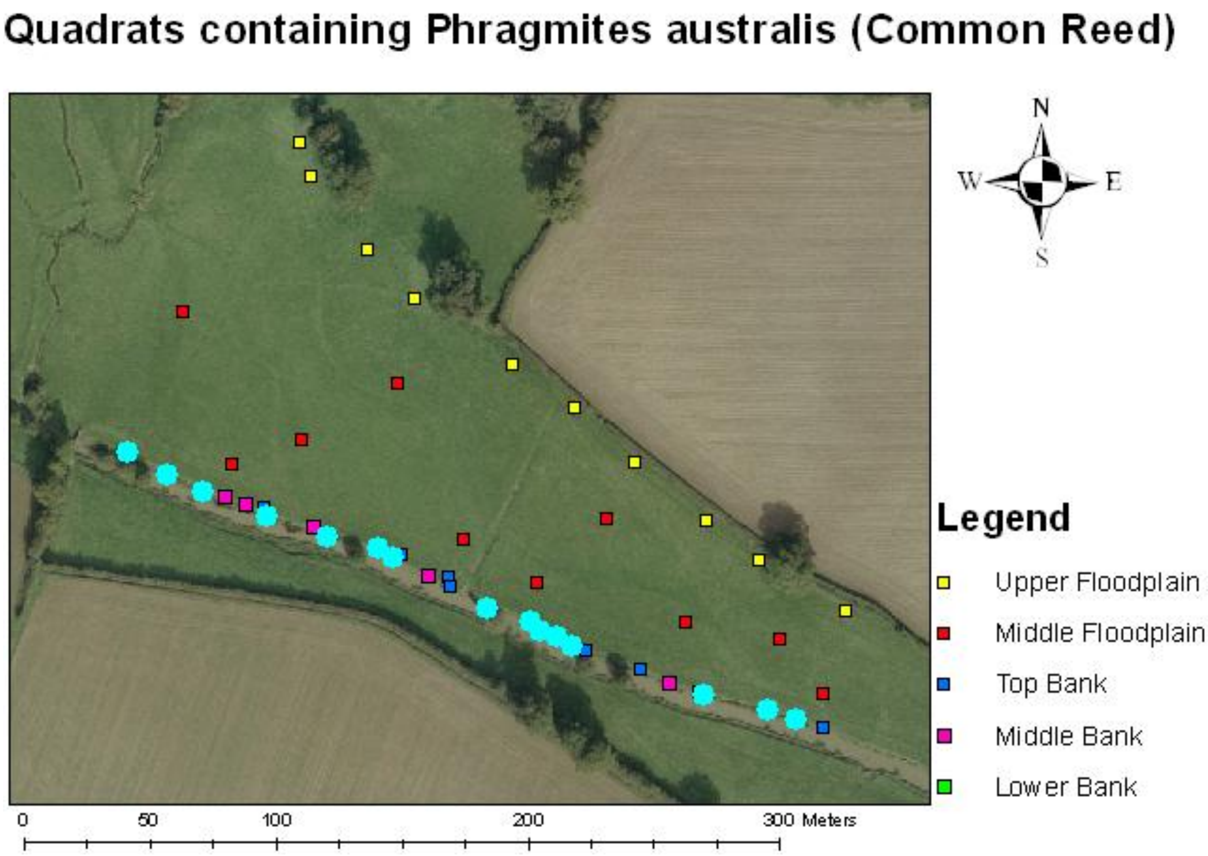

Figure 6-2: Quadrats containing *Phragmites australis* (Common Reed).

The middle bank zone (plate 3) (median elevation 6.308m) supported the greatest species diversity at mean species 13.4 and maximum species recorded was high at 17. The analysis revealed *Dactylis glomerata* (Cocksfoot) was considered to be the indicator species at frequency 10/10, abundance 9.6% although *Festuca ovina* (Sheep's Fescue) was more abundant 11.2% and with frequency 9/10, *Dactylis glomerata* had considerably lower abundance and frequency in all other zones occurring 2/10 in lower bank, top bank and upper floodplain at 1.3%, 5.5% and 0.2% abundance respectively (figure 6-3). *Dactylis glomerata* is most commonly associated with soils of pH range 5.0-8.0 (study site median pH 5.8, range pH 4.9 to 6.6) and moderately fertile mineral soil (RSPB *et al,* 1997). It occurs in moist soils and is tolerant of drought, but not prolonged flooding (RSPB *et al,* 1997) and as such is rather infrequent in wetland habitats. It can tolerate widely distributed slope angles with consistent bias towards south facing slopes and able to cope with medium bare soil exposures (Grime *et al,* 1988) (20.2% in middle bank). It could be that slope angle represented by micro-topographical standard deviation 0.25m in the middle bank zone is an important factor including dryer conditions created by an increased potential evaporation rate from this more exposed (bare) ground (Davie, 2008) which could be a key factor enabling to survival and competition in this zone.

Plate 3: Middle bank zone (centre) displayed the greatest species diversity (south facing with steep slope angle) and lower bank zone (left).

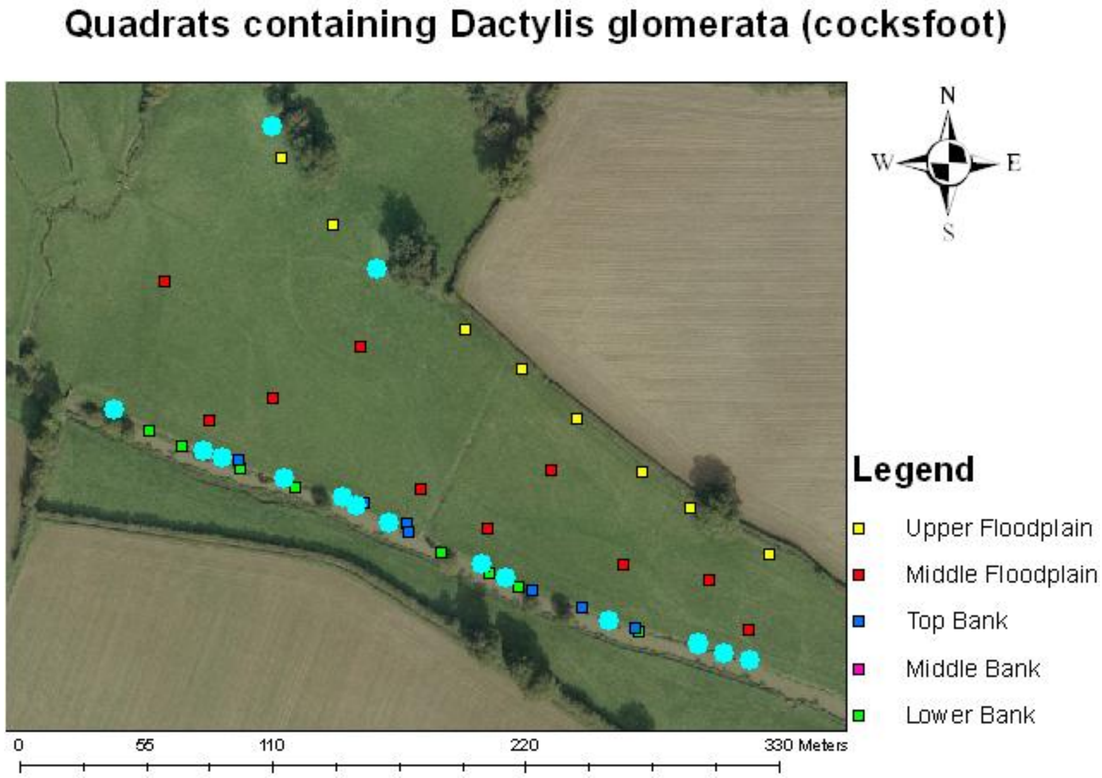

Figure 6-3: Quadrats containing Dactylis glomerata (Cocksfoot).

The top bank zone supported the lowest species richness at mean 5 species (plate 4). It is likely in a hydrological sense that this zone experiences the greatest extremes with dryness in summer and over topping during winter floods. It is difficult to assess this zone since the D-GPS quadrat points were uncorrected during post processing, but looking at the transect data as providing corrected elevation points on average its elevation is higher than the middle floodplain zone, but not always as demonstrated by the distribution of the data showing some points are higher than the middle bank zone whereas others are lower. This makes discussion of its elevation as an impact on hydrology difficult. We could look at points in transect 1 close to the quadrats, but not at the micro-topographical standard deviation since there would only be 1 point. It could be that top bank lacked micro-topographical heterogeneity that created this low species diversity or that Bromus specie(s) were so dominant (abundance 46.9%) that other species were out competed therefore excluded. Since identification was only to tribe level it is difficult to define physiological traits and hence the environmental conditions in relation to tolerance exhibited. Bromus specie(s) also occurred in middle bank (frequency 2/10 and abundance 0.3%) and upper floodplain (frequency 9/10 and abundance 6.6%) which may suggest a link between particularly top bank and upper floodplain (figure 6-4).

Plate 4: Top bank (right) and middle floodplain (left).

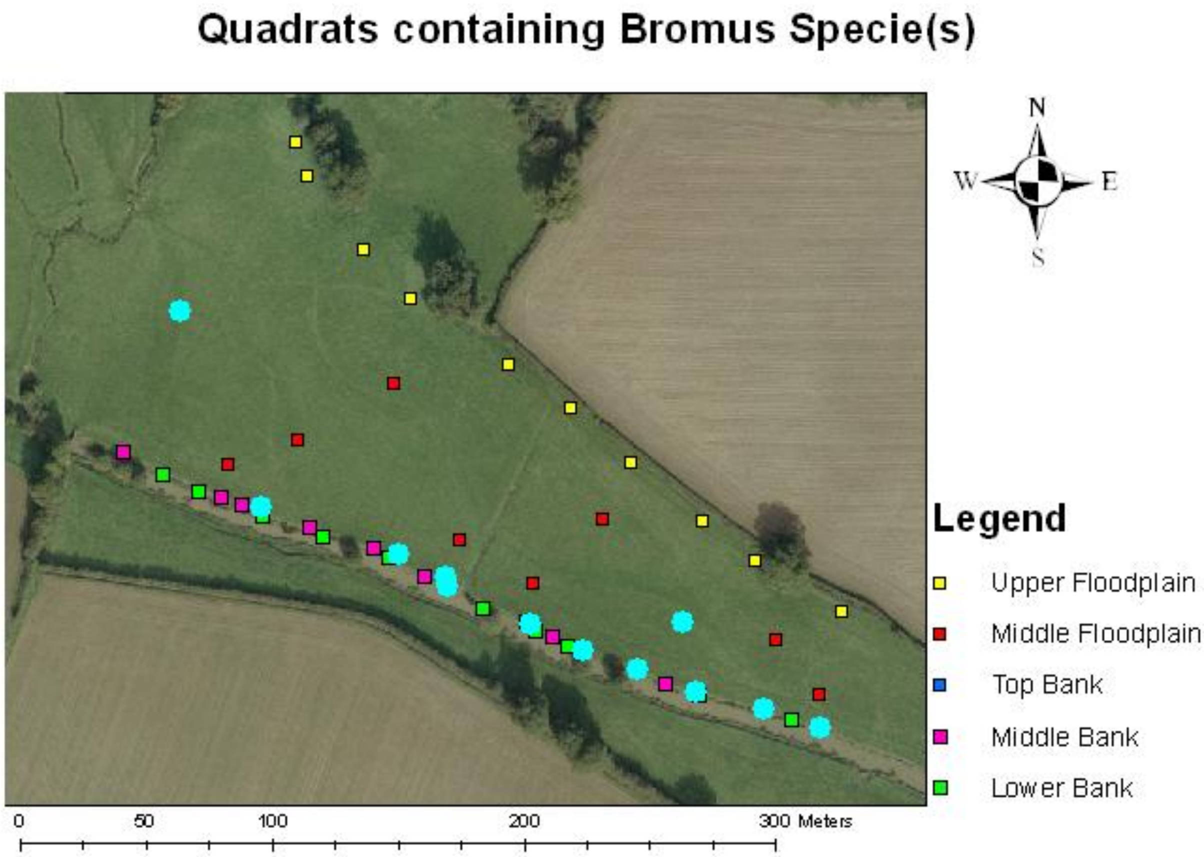

Figure 6-4: Quadrats containing Bromus specie(s).

Two species were identified as being dominant in the middle floodplain zone (plate 5) (median elevation 6.679m). These were *Festuca arundinacea* (Tall Fescue) frequency 10/10 and abundance 39.1% and *Glechoma hederecea* (Ground Ivy) frequency 10/10 and abundance 21.6%. *Festuca arundinacea* also occurred in top bank (frequency 5/10 and abundance 7%), but was entirely absent from the other zones. *Glechoma hederecea* was present with frequency 2/10 and low abundance 0.3% in the upper floodplain zone. This lower frequency and abundance in the appearance of *Glechoma hederecea* makes it the better indicator in the middle bank zone. According to Grime *et al* (1988) it is typically "a plant of shaded habitats" that is frequent in river banks, but absent from aquatic habitats which has a wide ranging slope capacity occurring on occasionally moist soils and most frequent and abundant in soils ranging from pH 5.5 to 7.5. RSPB *et al* (1997) further states Glechoma hederecea is particularly widespread in moist to damp sites, but is intolerant to flooding. The middle floodplain zone was not a shaded habitat, is a distant from the river bank although likely to experience flooding occasionally. The pH of the floodplain (median pH 5.8, range pH 4.9 to 6.6) and this zone (range pH 5.1 to 5.8) therefore is suitable for this species, but does not explain its zonation in the middle floodplain. It is likely that environmental variables not investigated in the site (i.e. nitrogen) and other physiological traits (i.e. competitive strategy) play a significant role in determination of this zonation (figure 6-5).

Plate 5: Middle floodplain zone.

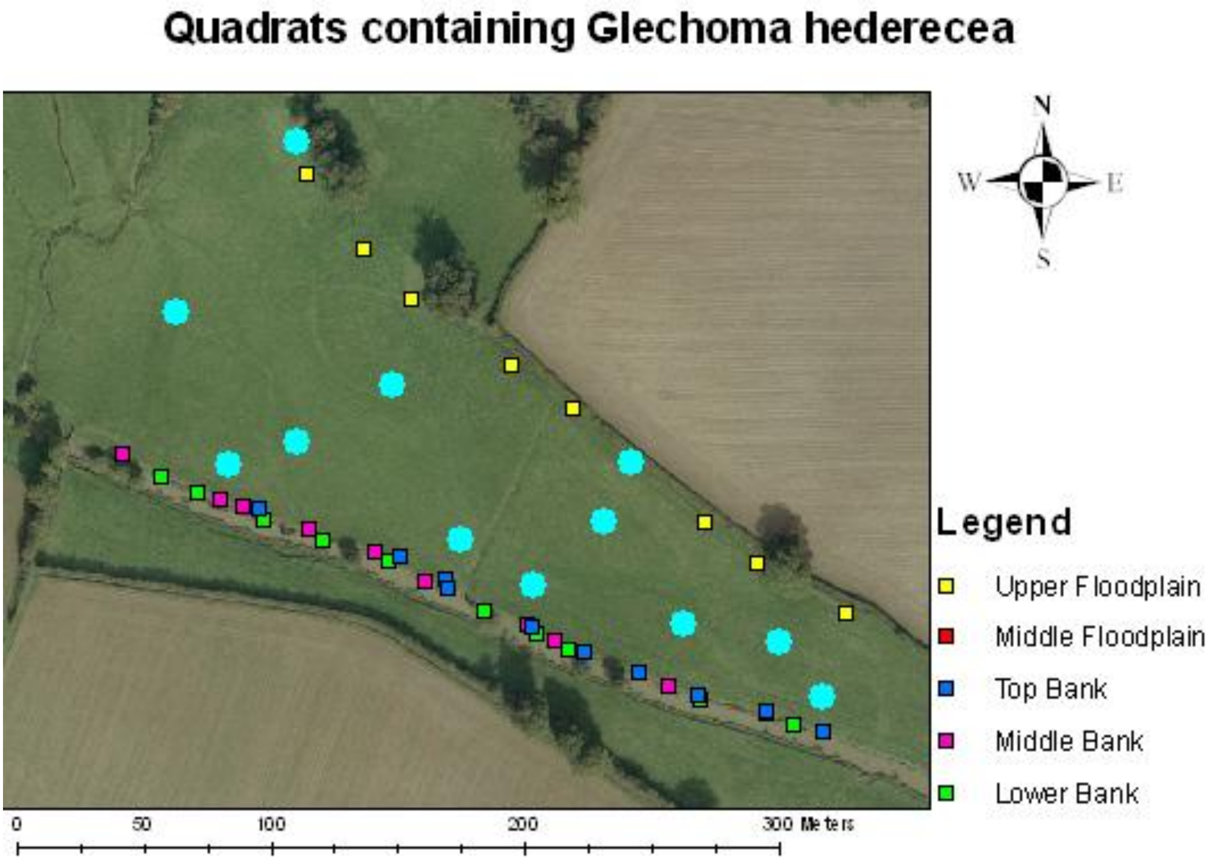

Figure 6-5: Quadrats containing Glechoma hederecea.

Festuca ovina (Sheep's Fescue) displayed a physiological capacity to establish in all zones (figure 6-6), but not always in great abundance. It displayed clear dominance in the upper floodplain with greatest abundance 47.5% and frequency 10/10 and also constituted the second most abundant species in the middle bank zone (11.2%), however displaying a decreased abundance in lower bank, top bank and middle floodplain. This species is rather ubiquitous being present in a wide variety of habitats across Britain and Europe due to its stress tolerant and competitive characteristics. It is "frequent and abundant over the full range of soil pH" (declining slightly over pH 5.0-7.5), able to cope with wide ranging slope angles both south and north facing, wide ranging bare soil capacity although noted as most frequent and abundant at low exposures and also shows a preference to moist ground and occasionally on tussocks in wetlands (Grime *et al,* 1988). Soil pH across the site appears to be of little limitation to *Festuca ovina's* abundance (range pH 4.9 to 6.6). Interestingly both middle bank and upper floodplain possessed the greater slope angles (micro-topographical standard deviation 0.25m and 0.281m) and upper bank according to the transect data contained greater soil moisture. It is perhaps likely middle bank experiences good soil moisture at certain times of the year when the river is swollen due to its proximity especially at the lower elevations in this zone. It is also likely that the runoff from the slope backing upper floodplain zone (plate 6) also acts in increasing moisture content due to runoff and seepage. These factors could contribute to an environmental gradient which enhances the competitive ability of *Festuca ovina* which have resulted enabling dominance in both of these zones.

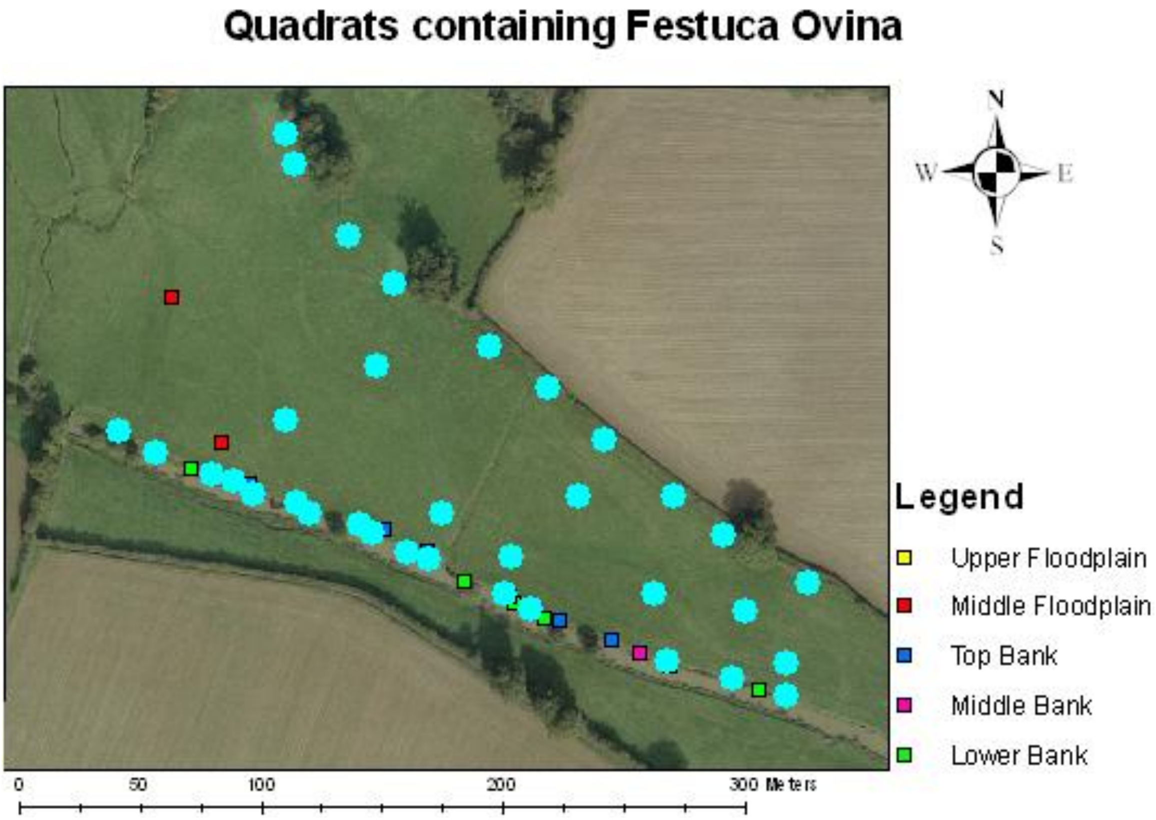

Figure 6-6: Quadrats containing Festuca Ovina.

Plate 6: Upper floodplain zone running horizontally to bottom of sloping valley side.

Trifolium repens (figure 6-7) was the second most dominant species in the upper floodplain zone (median elevation 7.082) accounting for 8.5% abundance at a frequency of 5/10. Unlike Festuca ovina, it occurs at very low abundance 0.2% and frequency 1/10 in two other zones (lower bank and top bank). We consider this species, although much lower in abundance than Festuca ovina, as most likely a better indicator of the upper floodplain zone based on this clearer zonation. According to Grime *et al* (1988), it is a wide ranging species which occurs with greatest abundance in moist fertile habitats, and commonly found in meadows and pastures, but also occurring in wetlands with a broad pH range from 5.0 to 8.0.

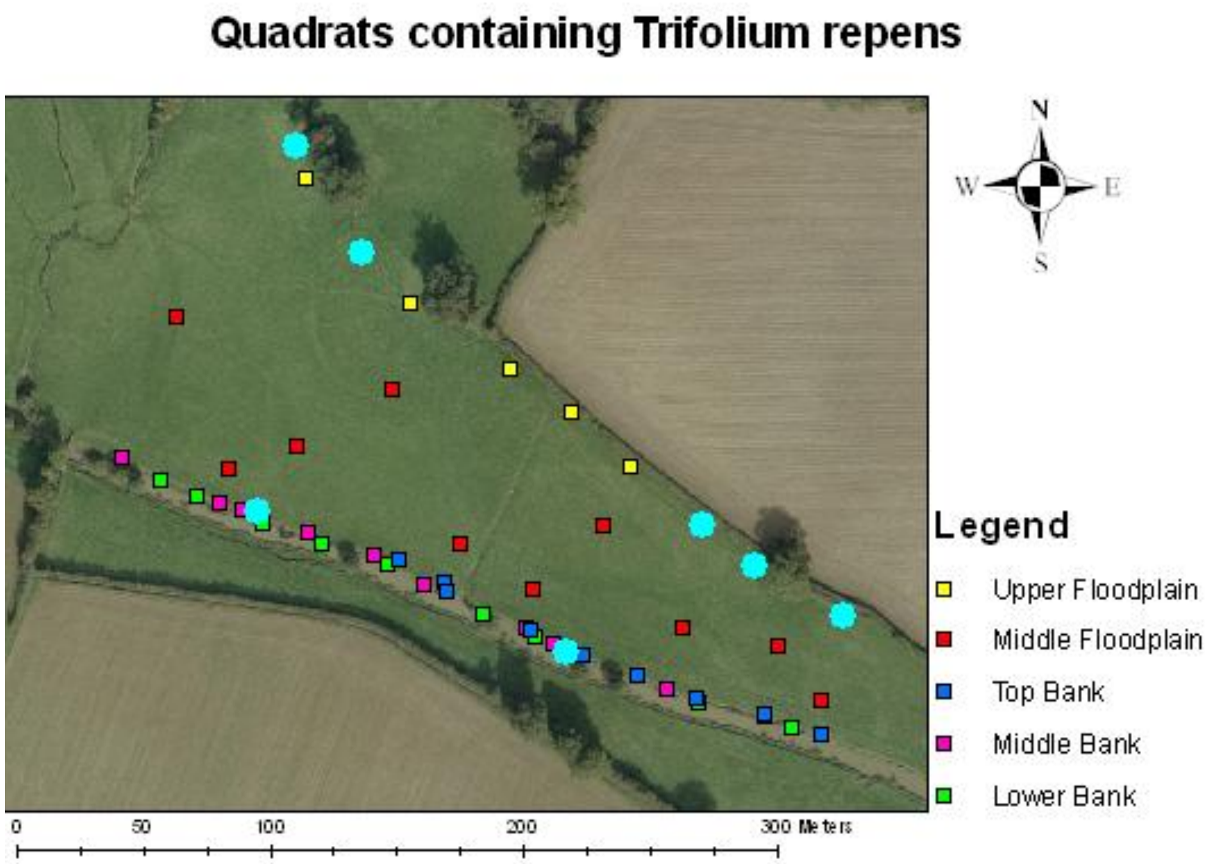

Figure 6-7: Quadrats containing Trifolium repens.

The results showed a number of species displayed clear zonation to both topographical and micro-topographical elevational gradients that were either across one or more zones, therefore evidencing that elevation is to an extent an indicator of vegetation in this system in-line with conclusions drawn in many other studies (Zedler and Zedler, 1969; Wong, 1974; Vivian-Smith, 1997; Bruland and Richardson, 2005; Martin *et al,* 2007; Moser *et al,* 2007; Ward *et al,* Unpublished). It is was thought this zonation across one or more zones was due to the zones being only representative approximations of topographical elevations, therefore variations in elevation within these zones, variations in environmental gradient edaphic factors, and biotic factors including species interactions (Krebs, 2001; Tansley, 2003) and grazing known to be important (Burnside et al, 2007; Berg, 2008), but not investigated in this study may account to a degree this cross over between zones.

The vegetation recorded (based on their different physiological tolerances) (Duffey *et al,* 1974; Grime *et al,* 1988; Krebs, 2001; Tansley, 2003; Crawley, 2000; Jackson and Colmer, 2005**;** Voesenek *et al*, 2004) established in (Grime *et al,* 1998; RSPB *et al,* 1997; Benstead *et al,* 1999) were indicative of environmental gradient variations , but this alone cannot provide conclusive quantifiable evidence of these environmental gradient factors, but hydrology is expected to be a key variable and to an extent a function of elevation (Day *et al,* 1988; Sluis and Tandarich, 2004; Setter *et al,* 1997; Banach et al, 2009; Lenssen and Kroon, 2005; Van Eck *et al,* 2006; Mommer et al, 2006). Soil pH was shown to be an important environmental gradient factor, established with a significant relationship (P = 0.000) to species richness with those areas of greater more neutral pH (i.e. the middle bank zone) containing greatest species richness.

Soil pH and micro-topographical heterogeneity (measured as the standard deviation between micro-topographical points) showed a significant relationship to species diversity (figure 6.8 and 6.9). Soil pH explained 34.3% and micro-topography heterogeneity 14.8% of the variation in species diversity. Micro-topography was also shown to play a role in soil moisture with regression between micro-topography and soil moisture in transect 1 and 3 displaying a significant relationship (figure 6.10 and 6.11) whereas transect 2 did not. An investigation of the soil type, structure, porosity and particle size would be appropriate. However, the main hydrological factor is likely to be the river flooding in winter. But in summer periods soil characteristics influencing soil moisture could play a more important role.

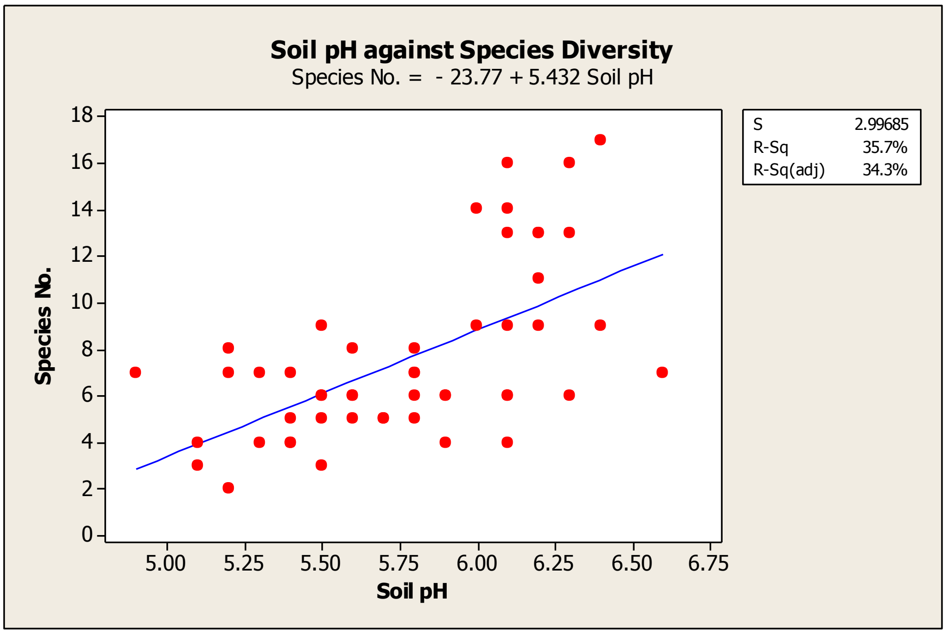

Figure 6-8: Scatter plot with regression of soil pH against species diversity reveals very positive significant relationship P=0.000 <0.05 (R^2 adjusted = 34.3%).

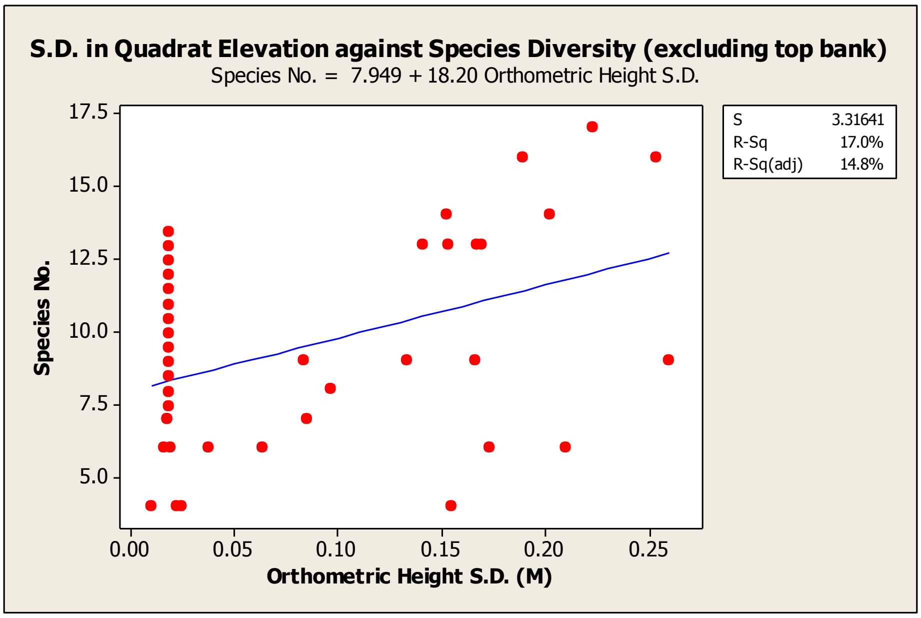

Figure 6-9: Scatter plot with regression of orthometric height standard deviation against species diversity in all quadrats excluding top bank (P=0.008 <0.05).

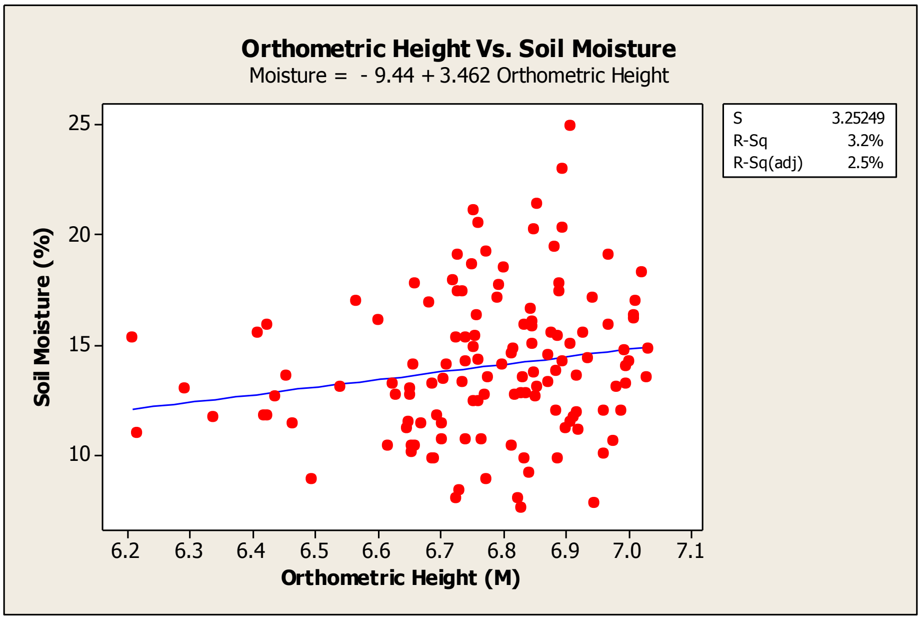

Figure 6-10: Scatter plot with regression of Orthometric Height against soil moisture in transect 1 (P= 0.042 <0.05).

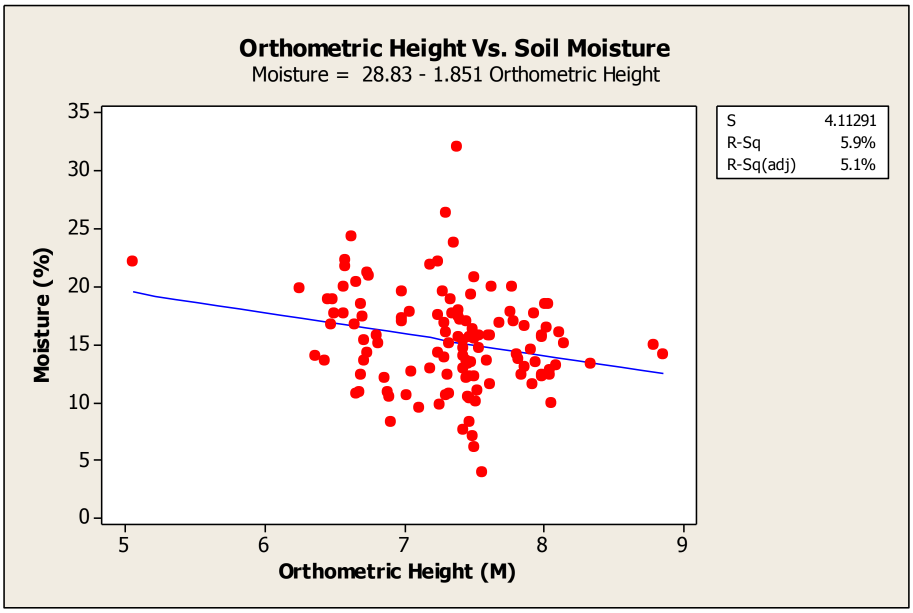

Figure 6-11: Scatter plot with regression of Orthometric Height against soil moisture in transect 3 (P=0.007 <0.05).

There are clearly many factors that we could consider in causing this zonation, further complicated by the different physiological responses exhibited by species to a changing environmental gradient. This study shows that species with more stress tolerant traits dominate the lower elevational positions (i.e. *Phragmites australis* in the lower bank) whereas the high elevations (greater elevation hence less frequently flooded) such as the upper floodplain are characterised with a greater abundance of less tolerant species *(i.e. Glechoma hederacea).* Flooding is most likely the dominant factor in this floodplain system in-line with the findings of many studies (Day *et al,* 1988; Sluis and Tandarich, 2004; Setter *et al*, 1997; Banach *et al,* 2009; Lenssen and Kroon, 2005; Van Eck *et al,* 2006; Mommer *et al,* 2006).

6.2 Limitations to Study

The surveys took place between 12th May and 9th June 2010, they accounted for a snap shot of vegetation and edaphic factors within this season only therefore not accounting for seasonal variation. Furthermore, the survey was limited to a confined section of the floodplain, therefore based on species area relationships established in ecology (MacArthur and Wilson (2001) it represents a sub sample of the floodplain. This is unavoidable in all studies and the sample effort is always a function of resource availability. A greater number of samples, sample approach choice and design are always likely to limit the scope of a project. Elevational zones could have been grouped based on pre-surveyed microtopography, and then sampled for vegetation using 2x2 meters quadrats in-line with the National Vegetation Classification system (Rodwell, 1998) with a greater number of replicates and subsequent edaphic variables.

The main disadvantage of the utilised approach in the transect survey was that both soil micro-topography and moisture do not follow linear patterns, they are highly variable (Miller *et al,* 1994; Krebs, 2001) therefore the transect survey could have been better designed with vertical transect lines crossing the horizontal ones to form a randomised grid of points. This would have allowed for development in the study in creating a miniature digital terrain model of the floodplain which could have been used to analyse and predict vegetation occurrences based upon any elevational relationships further identified with this technique. Micro-topographical outliers in the transect survey indicated an interesting feature in the floodplain which a better designed approach would have highlighted further. Transect 1 contained 4 low value outliers and transect 2 had 17 (also low value). When selected there appear to display on the aerial photography what is presumed to be 2 remnant river channels in close proximity to each other (figure 6-12).

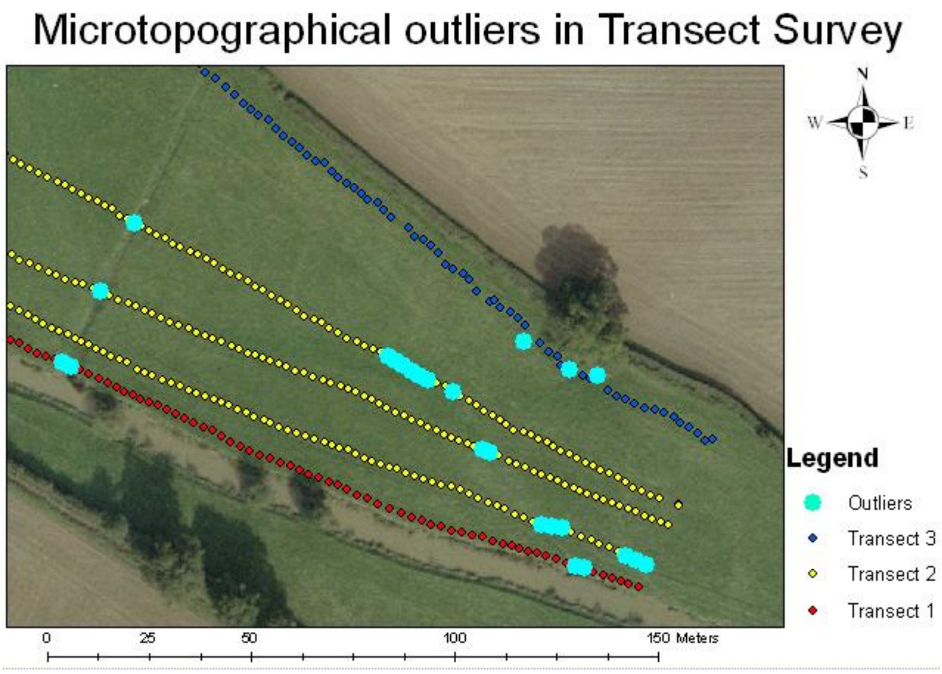

Figure 6-12: Identified elevation outliers of micro-topographical transect survey (outliers in right hand corner diagonally up and left appear to represent a remnant river channel.

The scope of the project was limited by resource availability, many other edaphic factors known to exert a degree of influence on species with susceptible traits could have been sampled (i.e. nitrogen, potassium, total soil moisture, particle analysis) and also the effect of grazing. A degree of technical error were present in the study centred round the lack of foresight in the unavailability of rinex correction files after a period of 1 month for post processing the position and elevation points taken in the top bank zone. This introduced a reduction in accurate sample data in the assessment of micro-topography heterogeneity in relation to species diversity and soil pH. Furthermore, limitations associated with the D-GPS technique inferred slight error when taking points in proximity to tall dense trees. These were identified in the GIS as outliers and represented 4 point taken in transect 3 and an additional point in the upper floodplain zone quadrat.

Human error although considered to be small also exerted slight limitation into the data. In the quadrat survey 200 points were supposed to be taken per zone. Due to human error 201 points were taken in the middle floodplain zone and 199 in the upper floodplain though statistically this does not represent a great effect. Species identification is sometimes a difficult time consuming task and attention to details is critical in correct identification. There were four surveyor for vegetation and as observed during the study, there is often different percentages of abundance assessed by eye.

6.3 Recommendations for Further Study

"Laser altimetry, commonly called light detection and ranging (LiDAR), is a source of geospatial data that can provide fine-grained information about the 3-D structure of ecosystems across broad spatial extents" (Vierling et al, 2008). This involves aerial mapping whereby from a plane, a pulse of light is emitted and the precise time recorded. The reflection of that pulse from the surface is detected and again the precise time recorded. Then using the constant speed of light, the time difference between the emission and the reflection, this can be converted into a slant range distance (line of sight distance). This allows for the position (X, Y) and elevation (Z) coordinates of the reflective surface to be calculated with the very accurate position and orientation of the sensor provided by an airbourne GPS and inertial measurement system. Use of LiDAR data which is available from the 'Geomatics Group', a commercial department of the Environment Agency for the study site (Geomatics Group, 2010) would allow for a 3 dimensional surface of micro-topographical variation to be recorded for the floodplain. This is fine grained, and subsequent use of the intensity values associated with different reflective surfaces (i.e. different vegetation) could be used to develop a vegetation index associated with the intensity values recorded. If LiDAR were used in tandem with subsequent measurements of edaphic factors (i.e. nitrogen, potassium, soil moisture, organic matter content, magnesium, calcium, pH) positionally referenced using a D-GPS this could be used to further investigate spatial relationships/patterns within the floodplain and allow for greater investigative power using a GIS spatial analysis to develop a digital terrain model including spatial interpolation techniques such as Kriging, IDW allowing the development of an analytical surface for vegetation occurrence using a developed physiological key.

7.0 Conclusion

The methodological approach demonstrates the clear use and applicability of D-GPS and GIS technology in collection of large data sets and rapid assessment of open habitats. The use of D-GPS for the collection of elevational points demonstrates a quick and easy method for ground surveying compared to conventional spirit levelling techniques, saving both considerable time and money.

This study was successful in investigating all the research questions it aimed to answer and provides insight into the complex processes underlying vegetation presence and abundance. It contributes to the record of vegetative species present in the estates floodplain for the land owner. It establishes vegetation does occur along elevational gradients in the Knepp Estate floodplain grassland. Increased micro-topographical homogeneity did display a positive effect on increasing species richness and a more neutral pH was also shown to increase species diversity. Despite the relationship between micro-topography and soil pH showing no quantifiable relation, the vegetation recorded based on their physiological traits did indicated the presence of underlying environmental gradients causing zonation. Knowledge of these relationships could be of use to the proposed river restoration project in addressing its conservation and restoration of rich floral and faunal biodiversity, and in the context of the wider estate.

Further study of the floodplain is recommended in order to gain knowledge and monitor change in this system from intensive agricultural to re-wilding. Re-wilding could be an effective conservation management tool of biodiversity and have implications for management projects elsewhere. Biodiversity despite increasing international conservation legislation and management consideration is still recognised as globally and locally declining. Greater knowledge and investigation of the relationship between vegetation, microtopography and edaphic factors can only contribute to scientific knowledge and understanding in a changing world.

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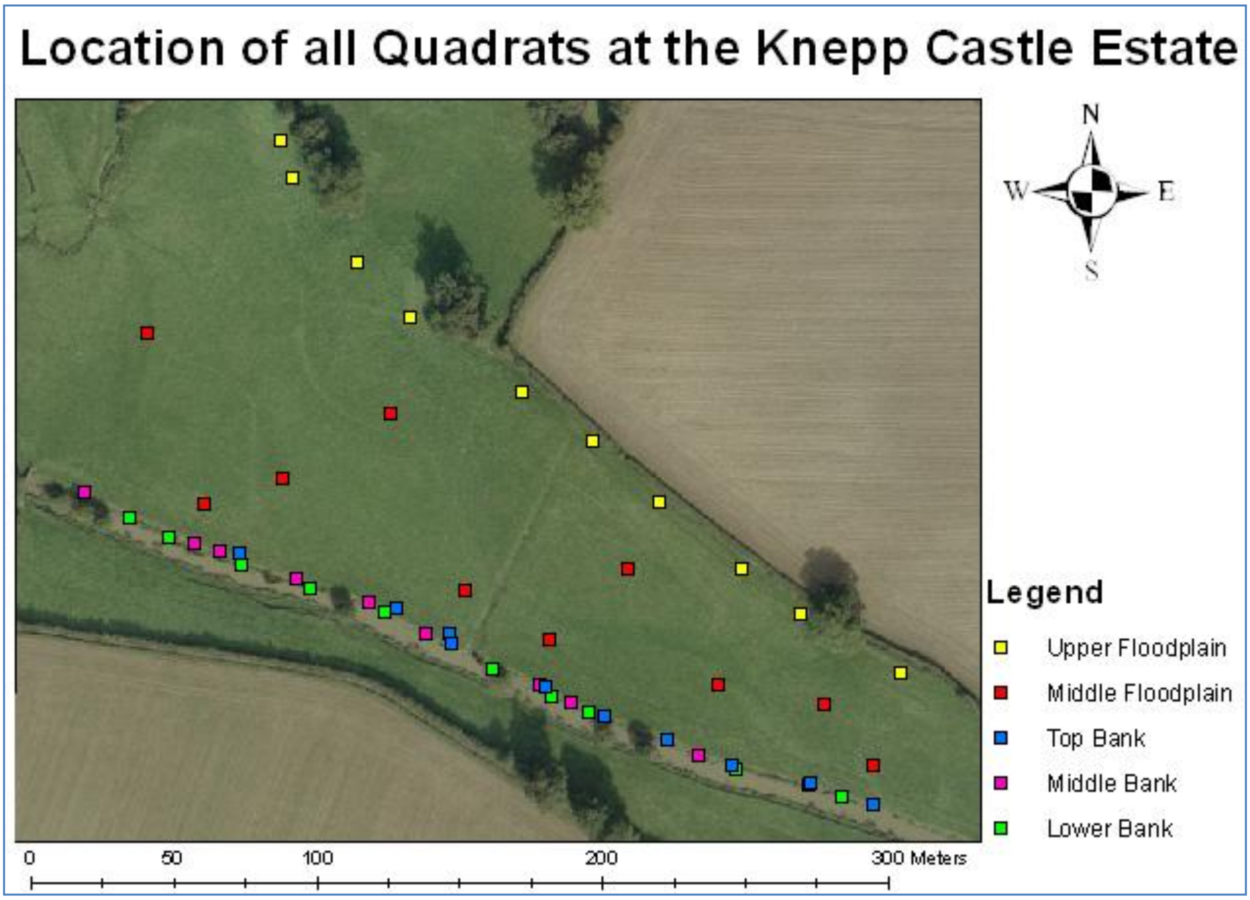
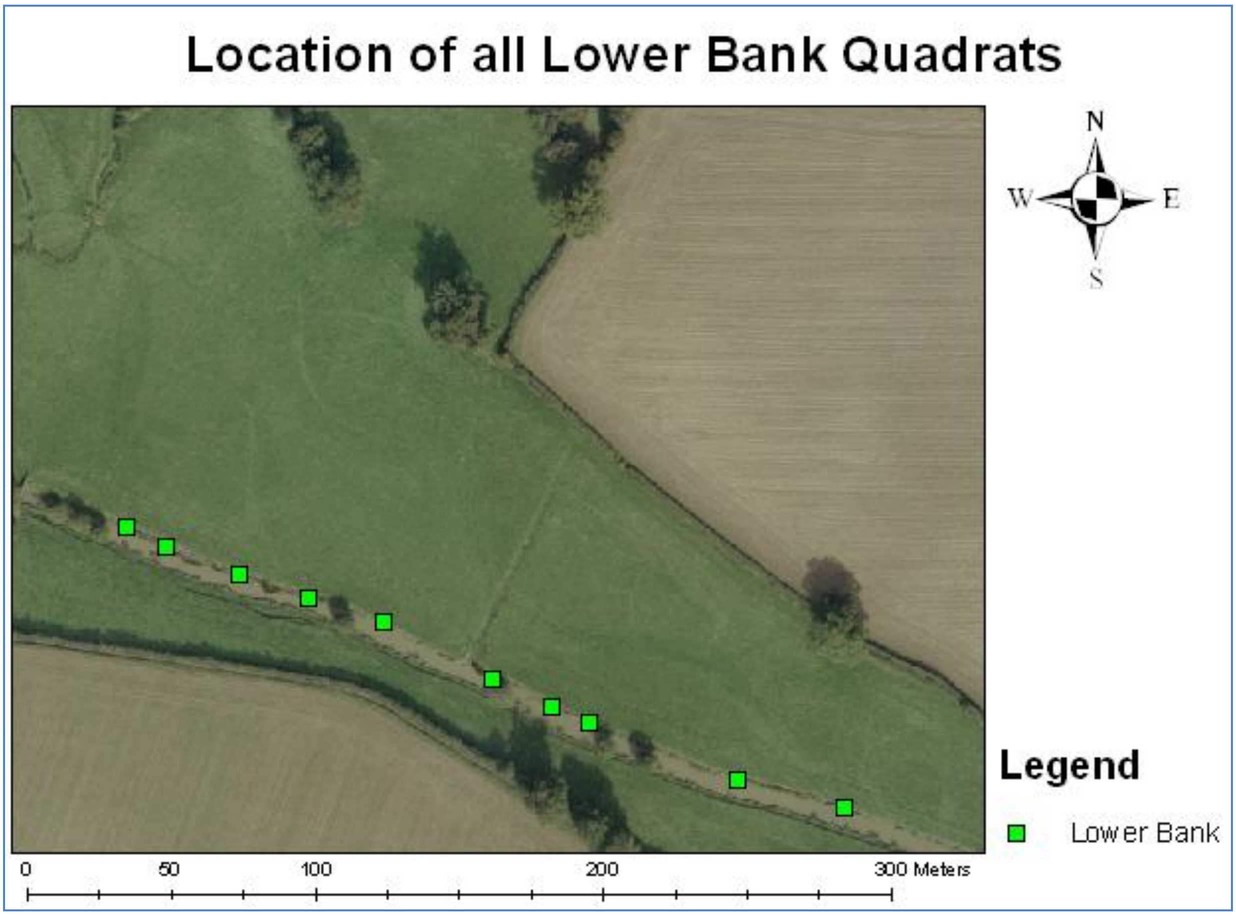
Appendix 1: Vegetation recording sheet example.

Date:	12/05/10		**Quadrat no.:**	1	
Recorders:	R. Ward, C.Sinclair, & N. Treble		**Habitat type:**	Top Bank	
DO NOT FORGET TO TAKE SOIL SAMPLES			D-GPS Points	1-20	
Latin name	**Present**	**% Cover**	**Latin name**	**Present**	**% Cover**
Agrostis stolonifera			*Plantago media*		
Alopecurus pratensis			*Ranunculus bulbosus*		
Bromus sp.	Y	65	*Taraxacum sp.*	Y	8
Dactylis glomerata			*Trifolium pratense*		
Festuca arundinacea			*Trifolium repens*		
Festuca rubra			*Hordeum secatimum*		
Phragmites australis			*Salix caprea*		
Poa subcaerulea			*Veronica serpulfolio*		
Cirsium sp.	Y	8	*serpyllifolia*		
Bromus erustus			*Glechoma hederecea*		
Festuca ovina	Y	10	*Pilosella Sp.*		
Sanguisorba minor	Y	1	*Thymus*		
Urtica dioica	Y	2	*Leantodon hispidus*	Y	3
Ranunculous bulbosus	Y	1	*Bromus erectus*		
Rumex obtusifolius	Y	2	*Cirsium acaule*		
Horsetail			*Leucantemmim vulgare*		
Leueanthumum			*Taraxacum officinale*		
Polygala vulgaris					
Cardamine pratensis					
			Bare		0
			Litter		0
			Unidentified		0
Total: 100%					

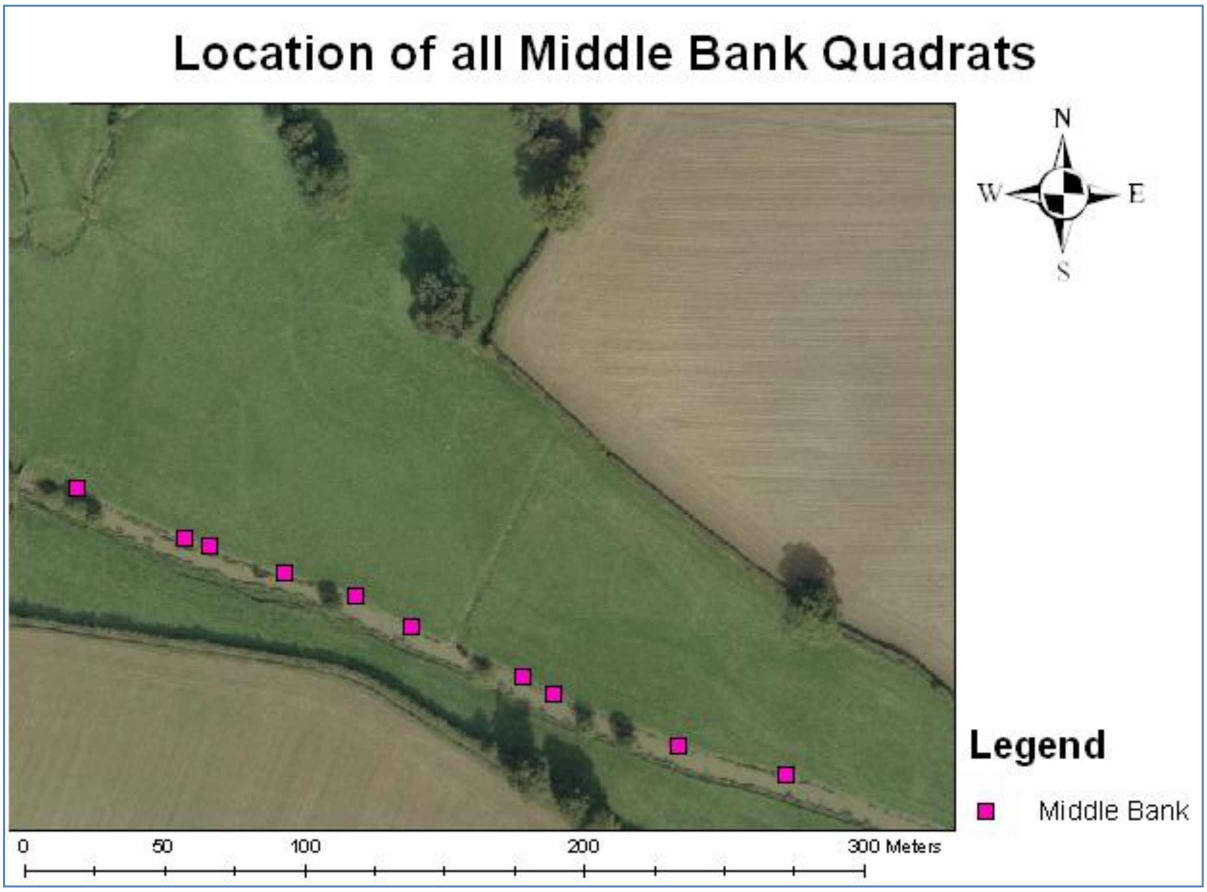
Appendix 2: The location of all quadrats undertaken during the vegetation survey of the study site.



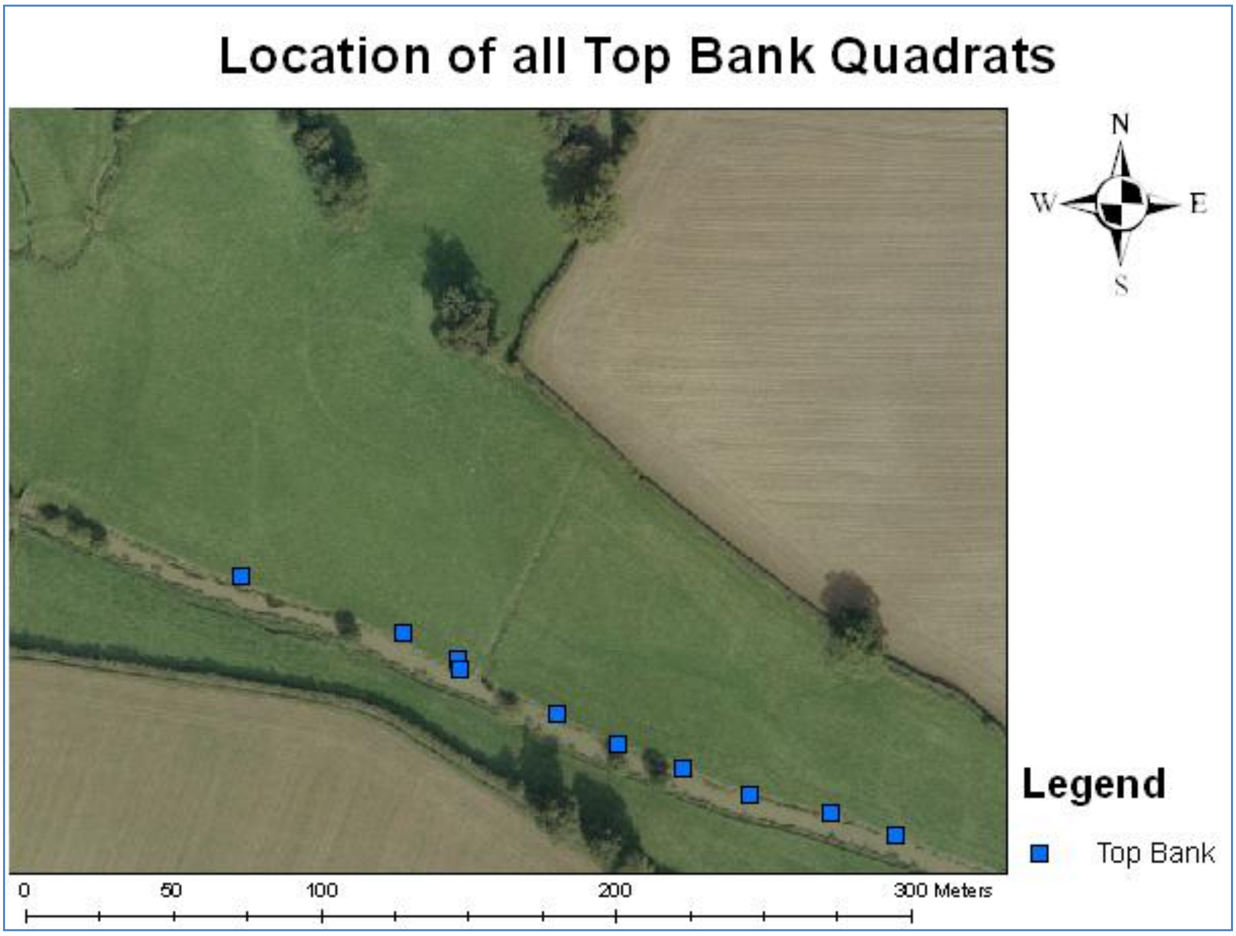
Appendix 3: Location of all lower bank zone quadrats undertaken during the vegetation survey of the study site.



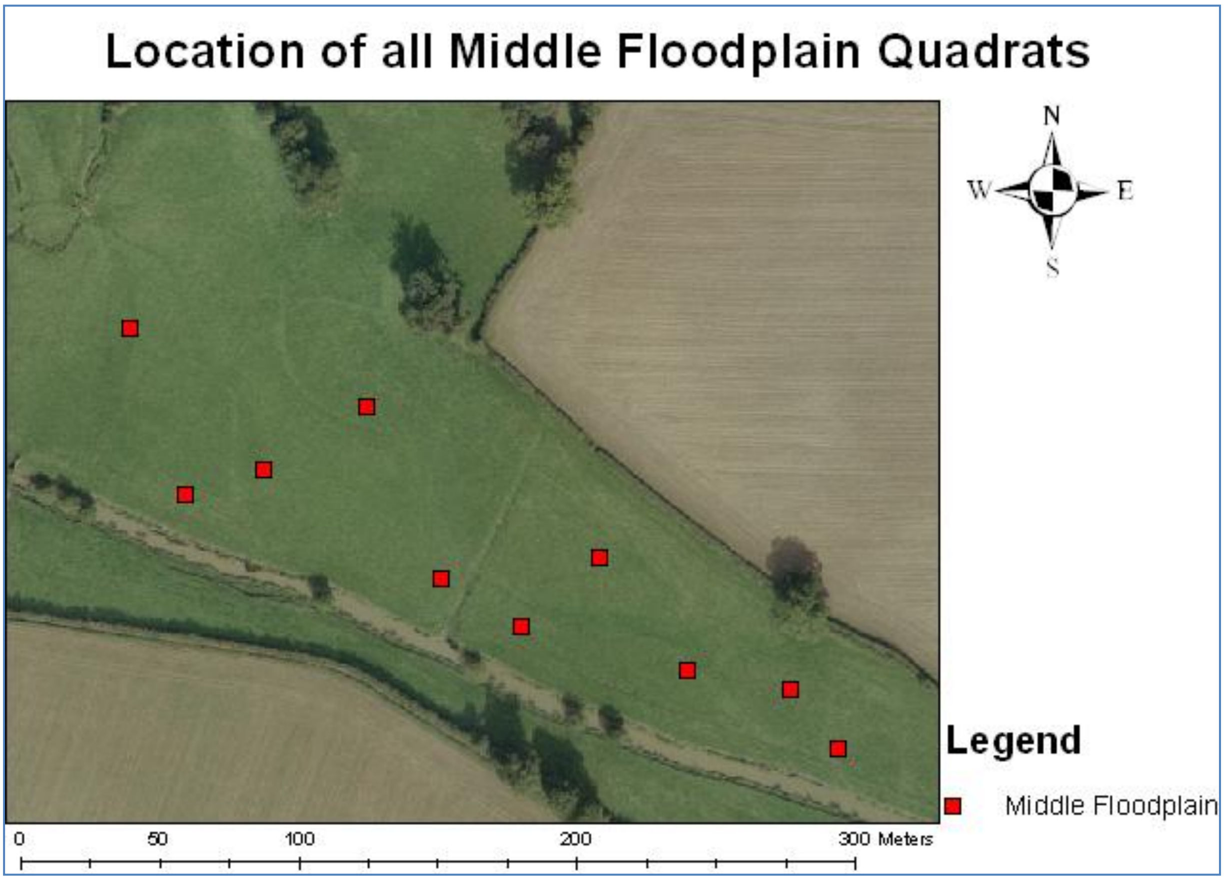
Appendix 4: Location of all middle bank zone quadrats undertaken during the vegetation survey of the study site.



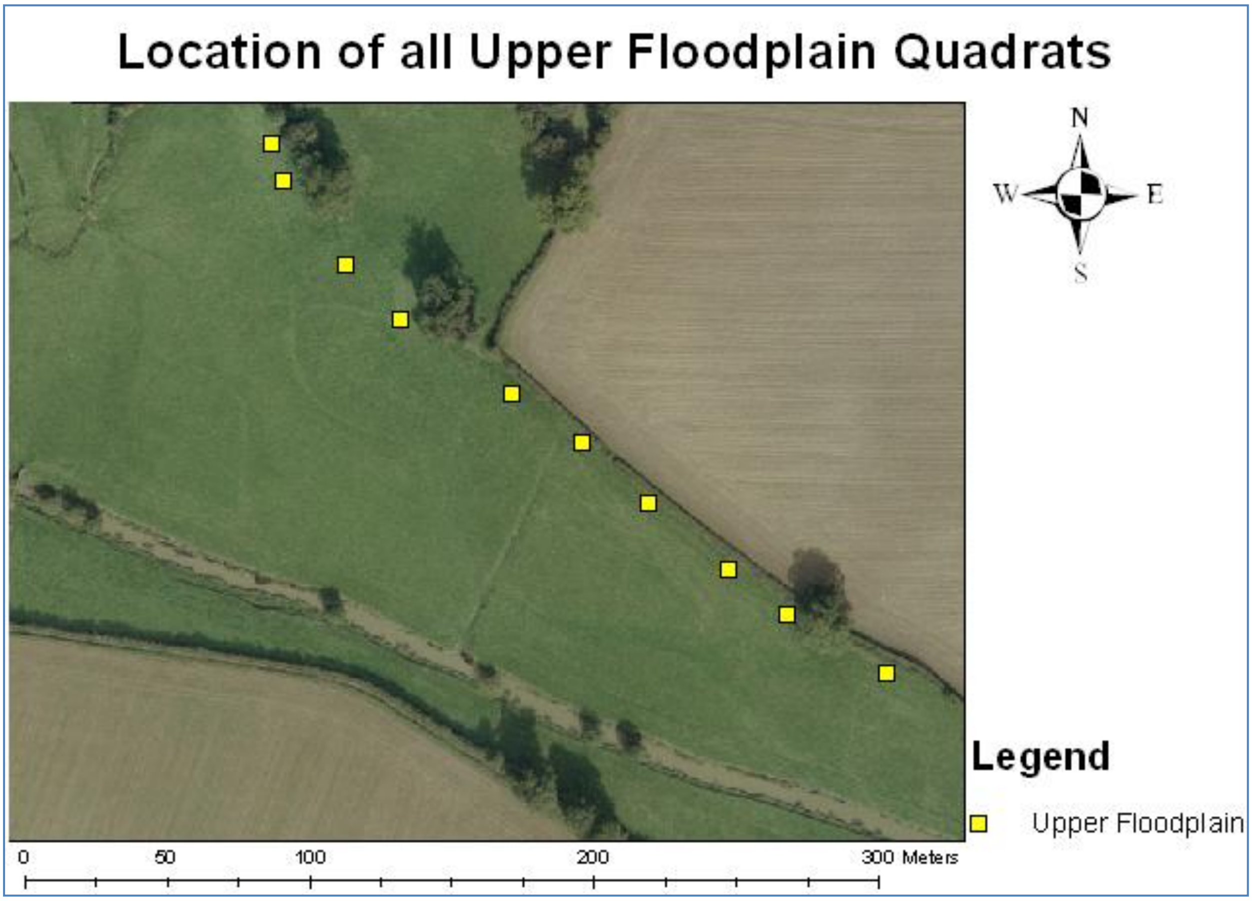
Appendix 5: Location of all top bank zone quadrats undertaken during the vegetation survey of the study site.



Appendix 6: Location of all middle floodplain zone quadrats undertaken during the vegetation survey of the study site.



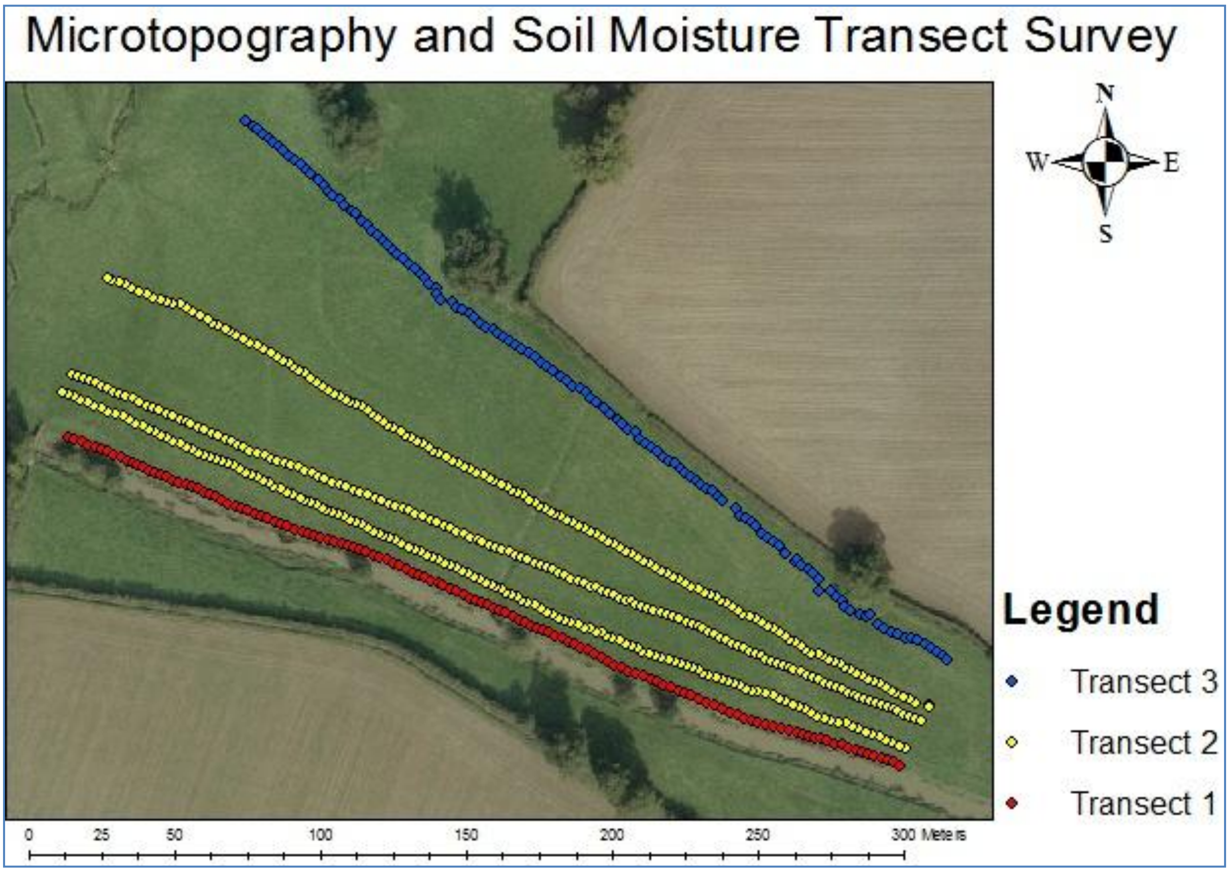
Appendix 7: Location of all upper floodplain zone quadrats undertaken during the vegetation survey of the study site.



Appendix 8: Transect survey recording sheet example.

Date:	23/06/10.				Transect no: 1		
Recorders:	Michael Dilley & Nick Treble						
D-GPS	**Moisture %**	**D-GPS**	**Moisture %**	**D-GPS**	**Moisture %**	**D-GPS**	**Moisture %**
1		31		61		91	
2		32		62		92	
3		33		63		93	
4		34		64		94	
5		35		65		95	
6		36		66		96	
7		37		67		97	
8		38		68		98	
9		39		69		99	
10		40		70		100	
11		41		71		101	
12		42		72		102	
13		43		73		103	
14		44		74		104	
15		45		75		105	
16		46		76		106	
17		47		77		107	
18		48		78		108	
19		49		79		109	
20		50		80		110	
21		51		81		111	
22		52		82		112	
23		53		83		113	
24		54		84		114	
25		55		85		115	
26		56		86		116	
27		57		87		117	
28		58		88		118	
29		59		89		119	
30		60		90		120	

Appendix 9: Location of all transects undertaken during the microtopography and soil moisture transect survey of the study site.



Appendix 10: Floodplain biodiversity.

Grass Species (Poaceae Family)

Agrostis stolonifera (Creeping bent)

Alopecurus pratensis (Meadow Foxtail)

Bromus species (Bromes)

Dactylis glomerata (Cocksfoot)

Festuca arundinacea (Tall fescue)

Festuca ovina (Sheep's Fescue)

Festuca rubra (Red fescue)

Hordeum Secalinum (Meadow Barley)

Phragmites australis (Common Reed)

Poa subcaerulea (Spreading Meadow-grass)

Herbs

Cardamine pratensis (Lady's Smock)

Equisetum (Horsetail)

Filipendula vulgaris (Dropwort)

Galium species

Glechoma hederacea (Ground Ivy)

Leantodon hispidus (Rough Hawbit)

Pilosella Species

Plantago media (Hoary Plantain)

Polygala vulgaris (Common Milkwort)

Ranunculus Bulbosus (Bulbosus Buttercup)

Cirsium Species (Thistle)

Rorippa sylvestris (Creeping Yellow Cress)

Rumex obtusifolius (Broad-leaved Dock)

Sanguisorba minor (Salad Burnet)

Scutellaria lateriflora (Skull Cap)

Taraxacum officinale (Common Dandelion)

Thymus (Thyme)

Trifolium pratense (Red Clover)

Trifolium repens (White Clover)

Urtica dioica (Stinging Nettle)

Veronica serpulfolio (Thyme leaf)

Wetland Species

Juncus (Juncaceae)

Woody Species

Salix caprea (Goat Willow)

Ivy vine plant (not further identified)

Appendix 11: ESDA histogram of species richness data recorded during the vegetation survey for lower bank (A), middle bank (B) and top bank (C) zones.

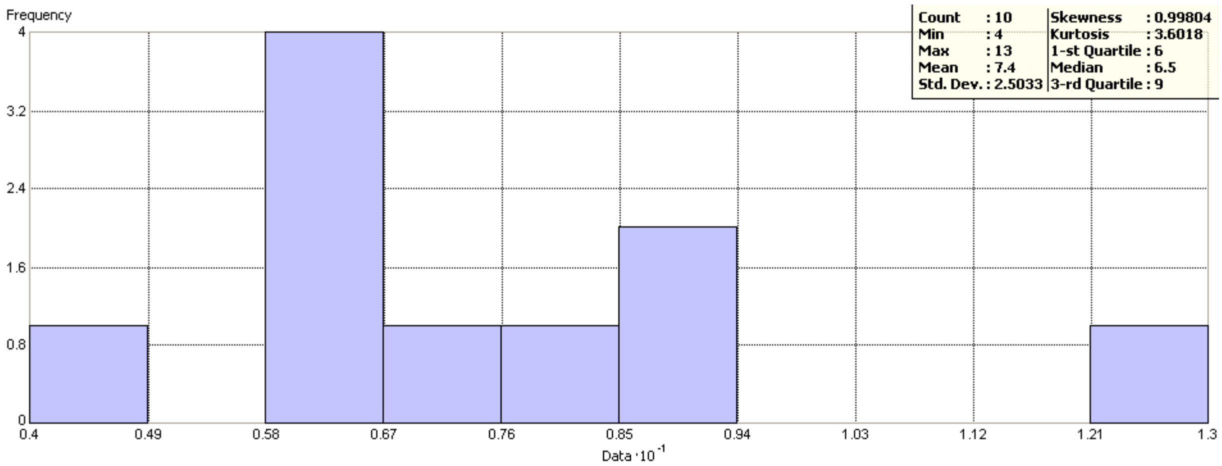


Figure A: Histogram of species richness in lower bank zone.

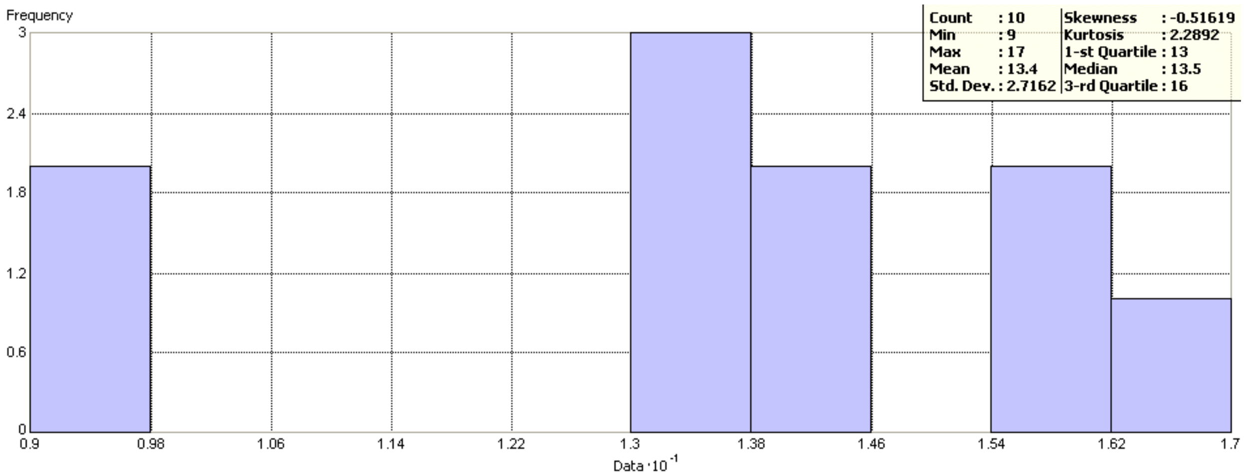


Figure B: Histogram of species richness in middle bank zone.

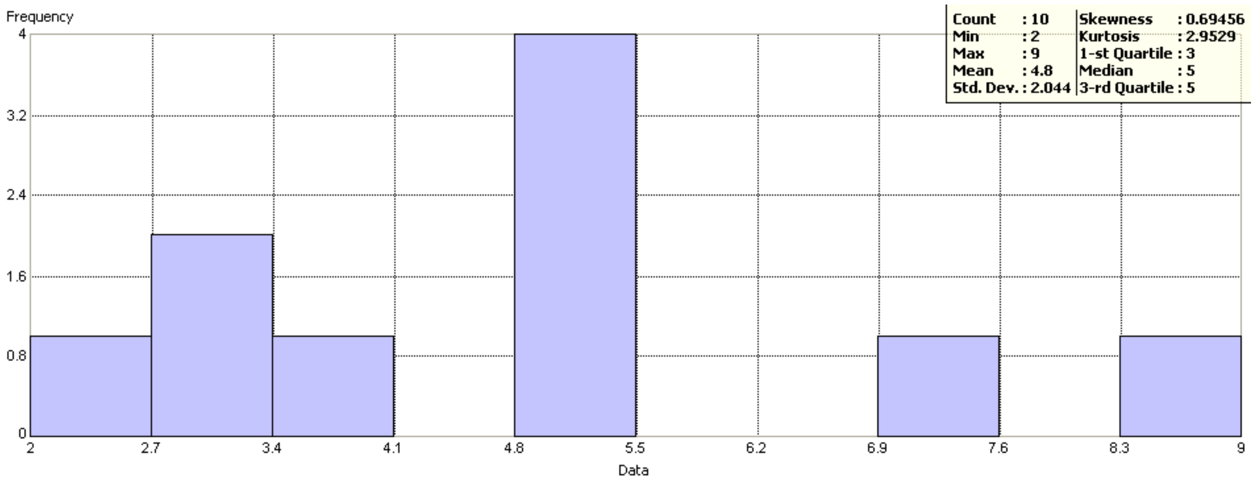


Figure C: Histogram of species richness in top bank zone.

Appendix 12: ESDA histogram of species richness data recorded during the vegetation survey for middle floodplain (A) and upper floodplain (B) zones.

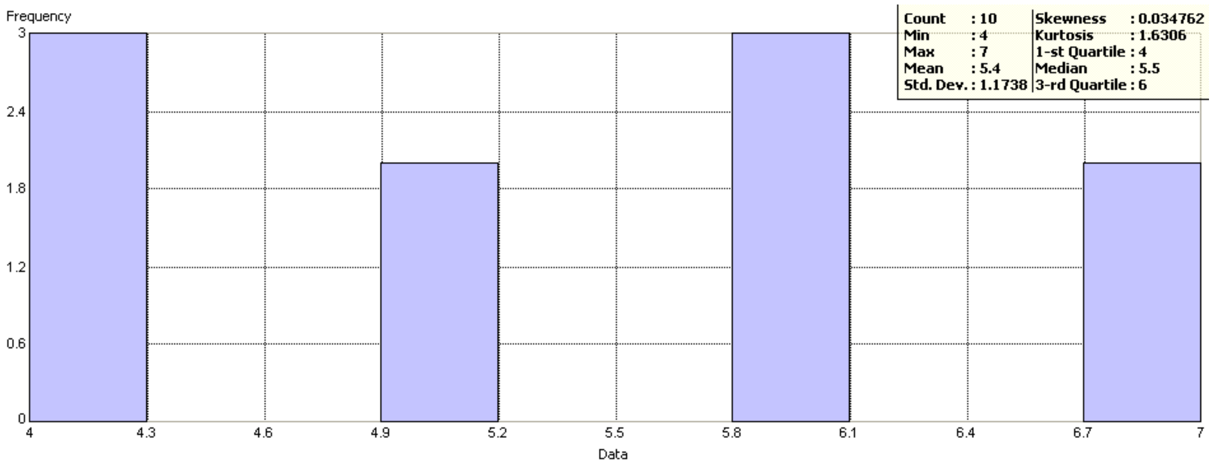


Figure A: Histogram of species richness in middle floodplain zone.

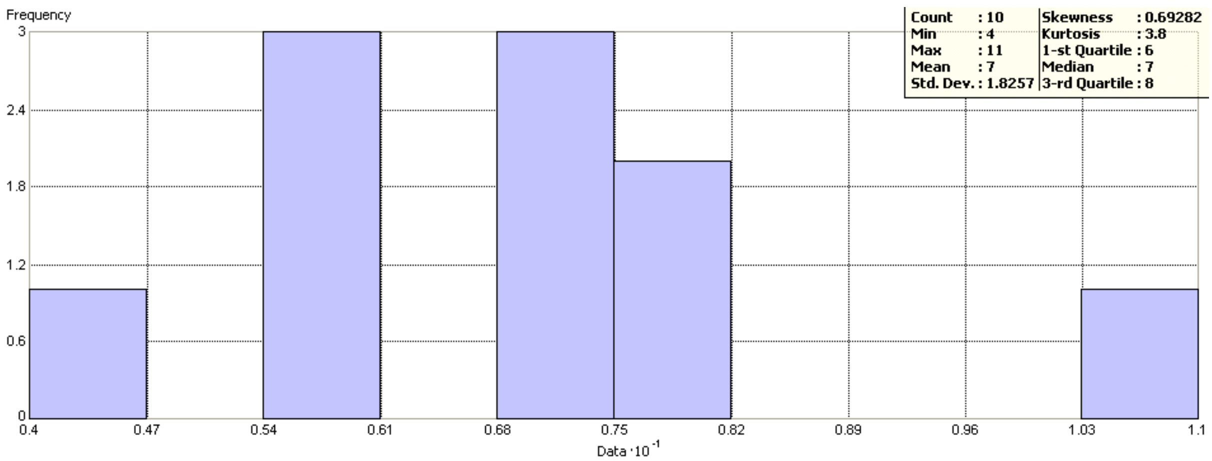


Figure B: Histogram of species richness in upper floodplain zone.

Appendix 13: ESDA histogram (A) and normal QQ plot (B) of all microtopographical data recorded during entire vegetation survey.

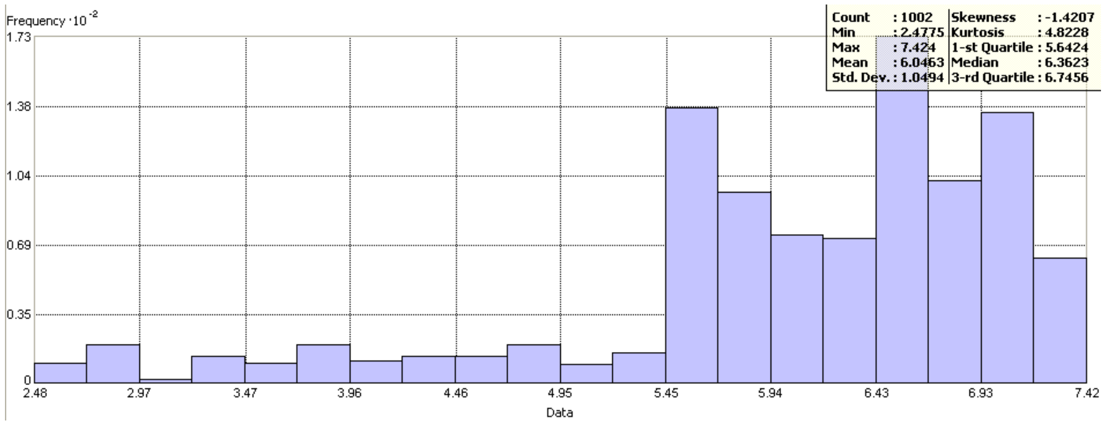


Figure A: Histogram of microtopographical data recorded during vegetation survey.

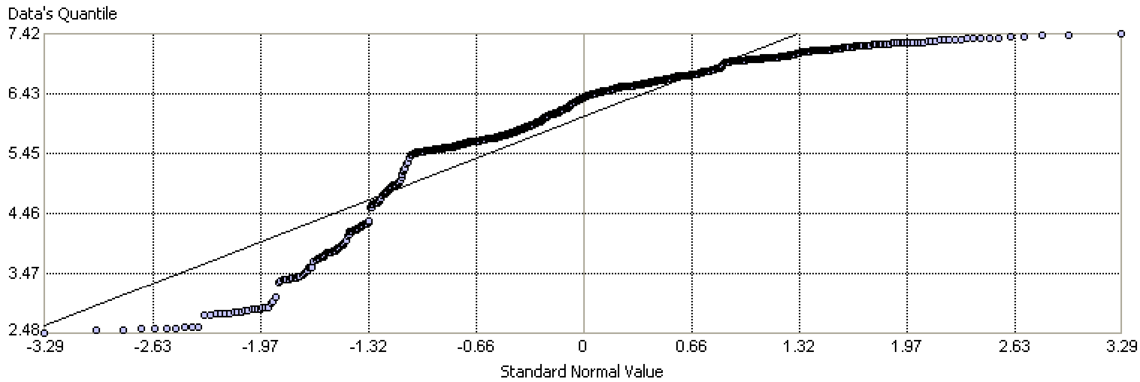


Figure B: Normal QQ plot of microtopographical data recorded during vegetation survey.

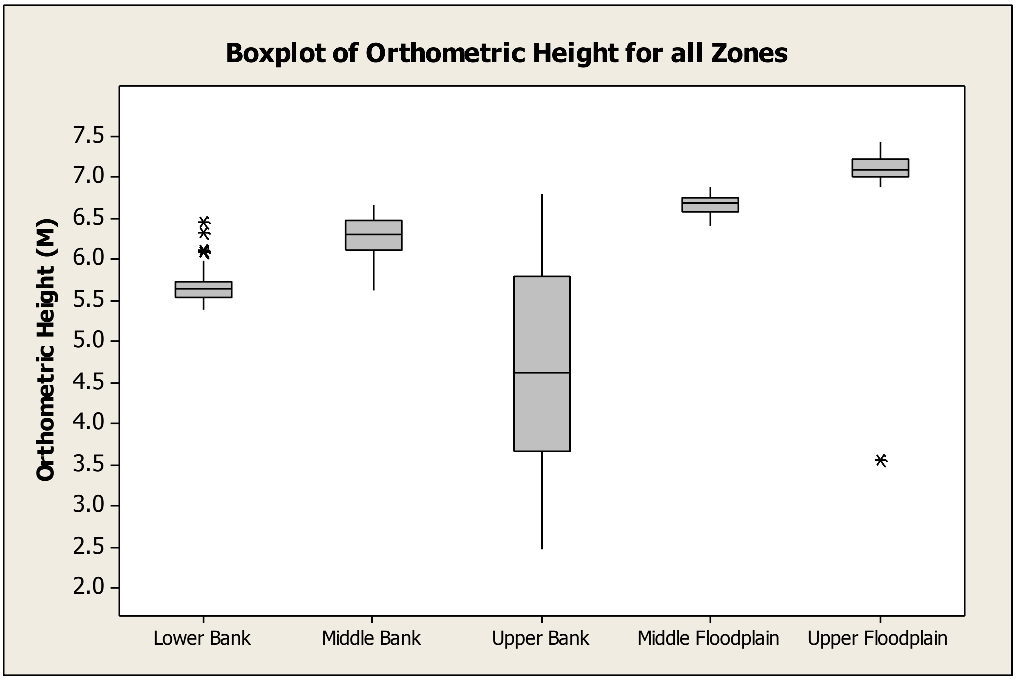


Figure C: Boxplot of microtopographical data recorded during vegetation survey.

Appendix 14: ESDA histogram (A), normal QQ plot (B) and box plot (C) of microtopographical data recorded during vegetation survey of lower bank zone.

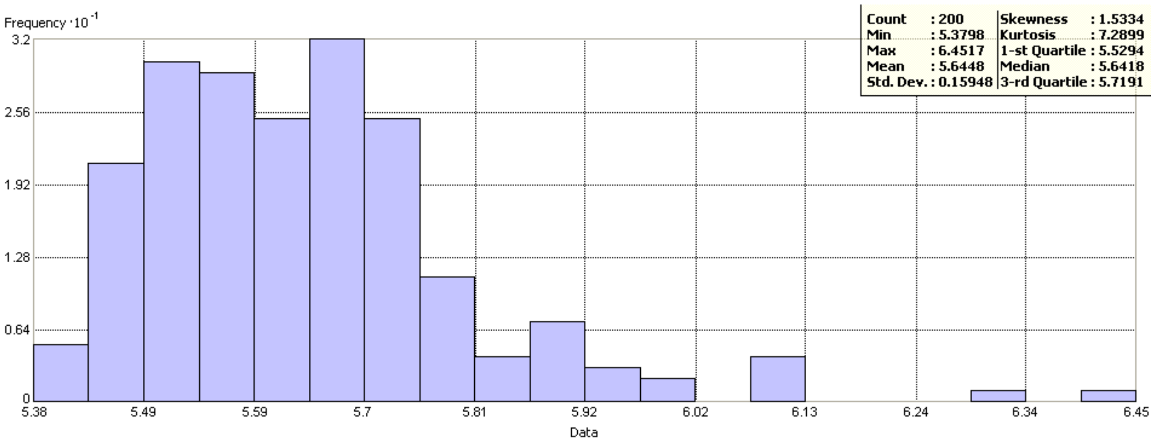


Figure A: Histogram of microtopographical data in lower bank zone.

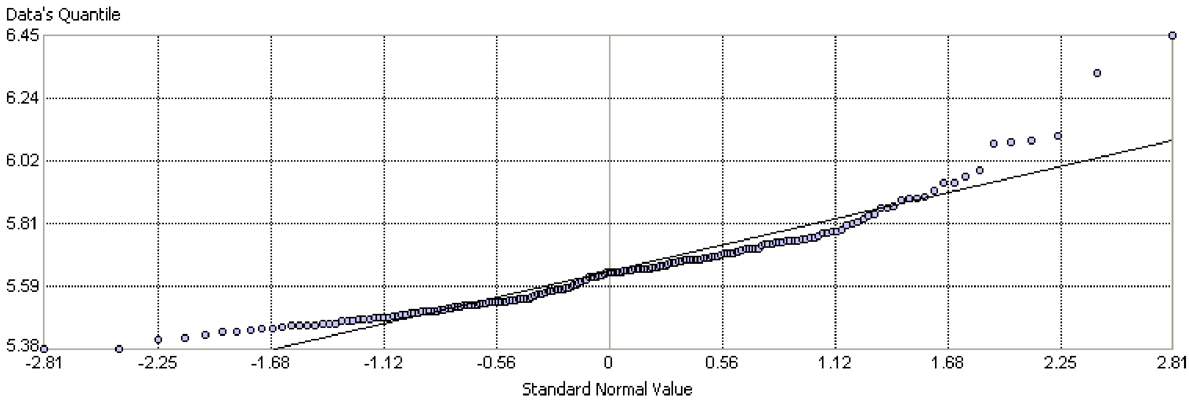


Figure B: Normal QQ plot of microtopographical data in lower bank zone.

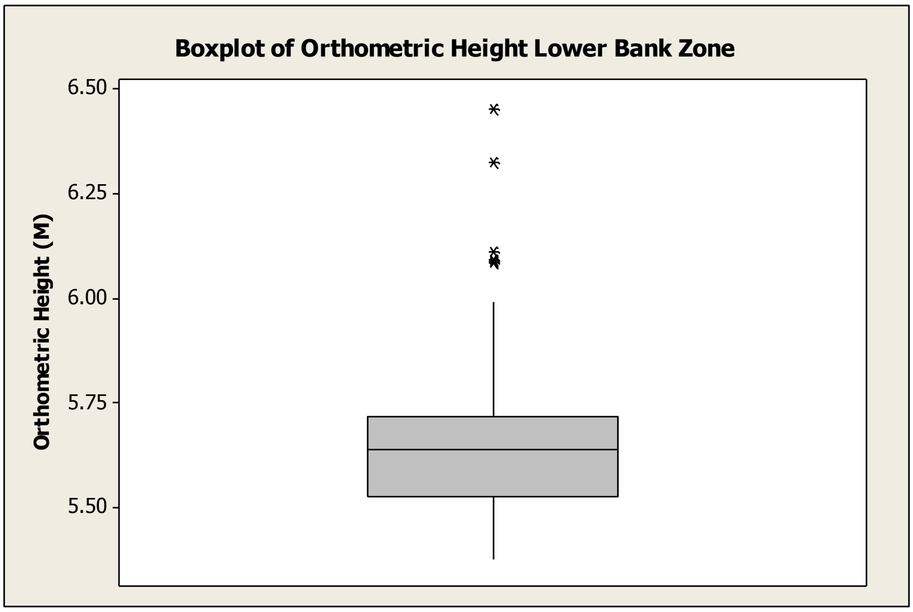


Figure C: Boxplot of microtopographical data in lower bank zone.

Appendix 15: ESDA histogram (A), normal QQ plot (B) and box plot (C) of microtopographical data recorded during vegetation survey of middle bank zone.

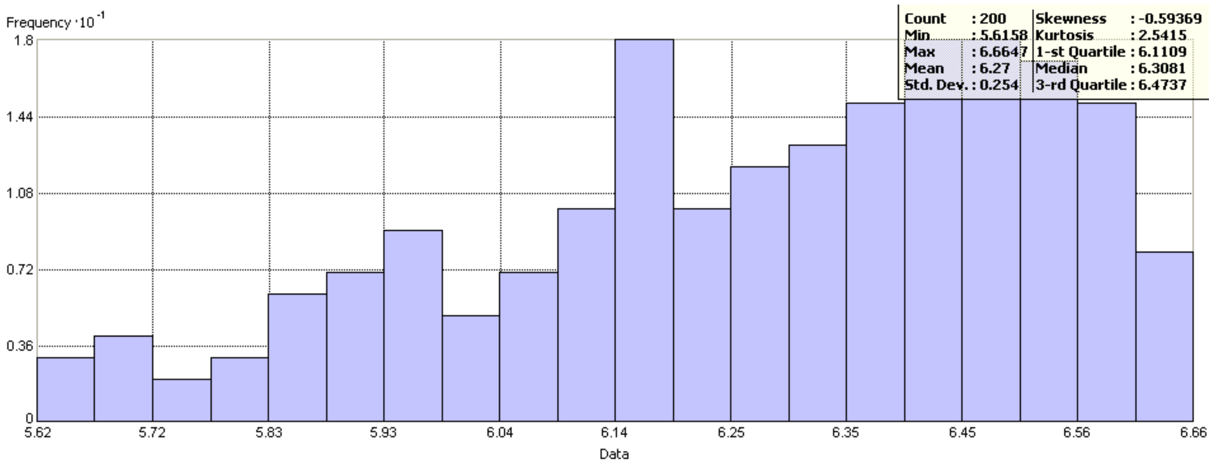


Figure A: Histogram of microtopographical data in middle bank zone.

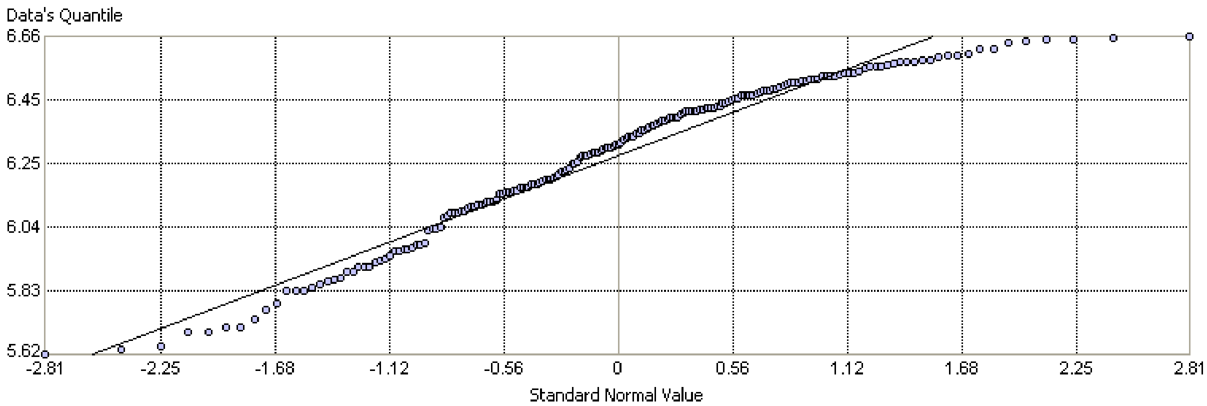


Figure B: Normal QQ plot of microtopographical data in middle bank zone.

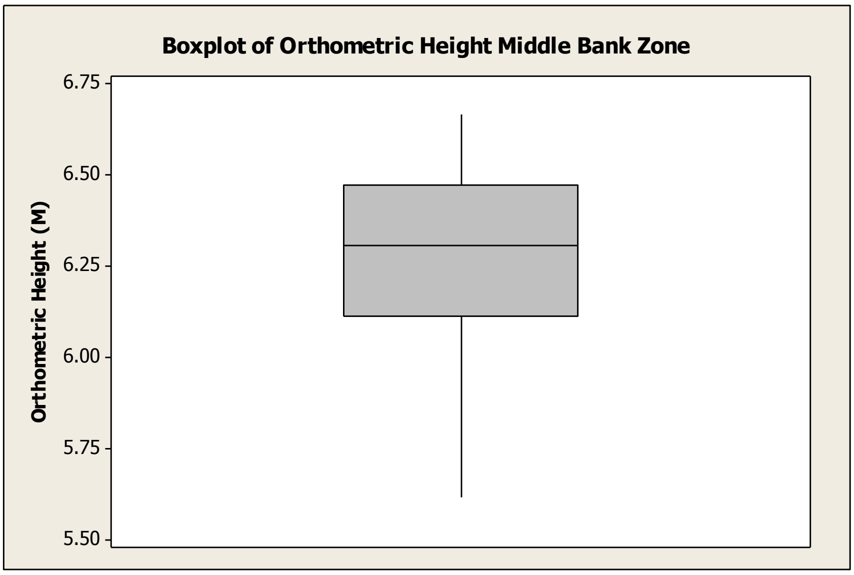


Figure C: Boxplot of microtopographical data in middle bank zone.

Appendix 16: ESDA histogram (A), normal QQ plot (B) and box plot (C) of microtopographical data recorded during vegetation survey of top bank zone.

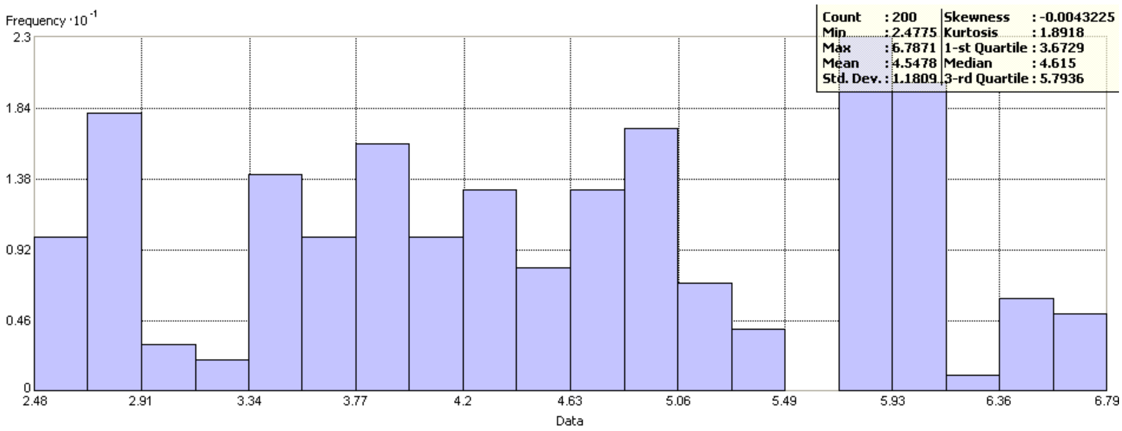


Figure A: Histogram of microtopographical data in top bank zone.

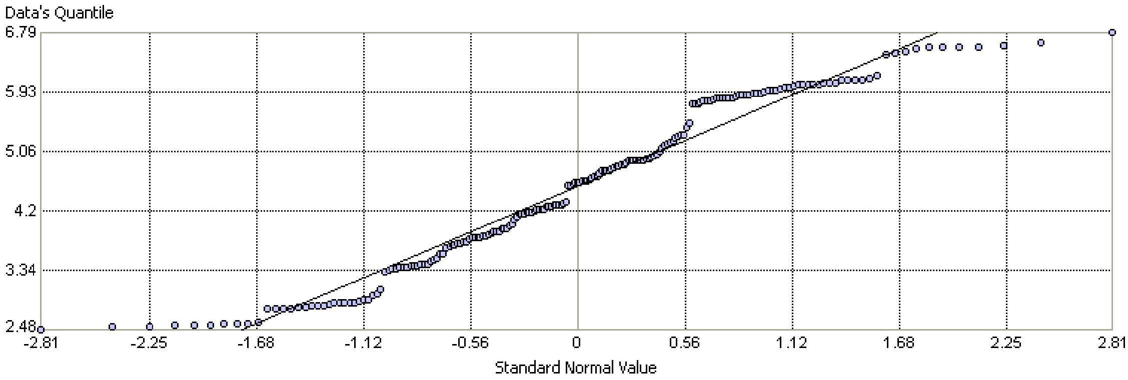


Figure B: Normal QQ plot of microtopographical data in top bank zone.

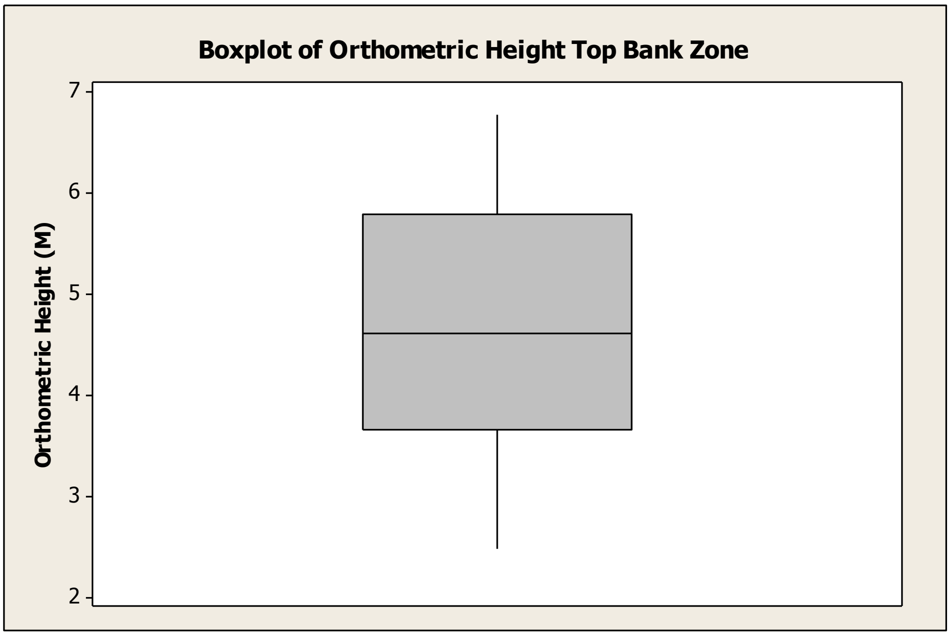


Figure C: Boxplot of microtopographical data in top bank zone.

Appendix 17: ESDA histogram (A), normal QQ plot (B) and box plot (C) of microtopographical data recorded during vegetation survey of middle floodplain zone.

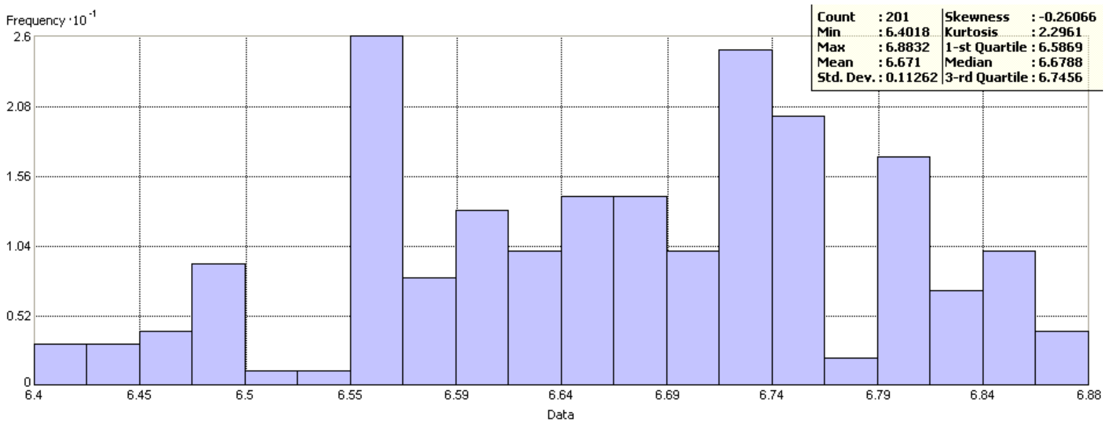


Figure A: Histogram of microtopographical data in middle floodplain zone.

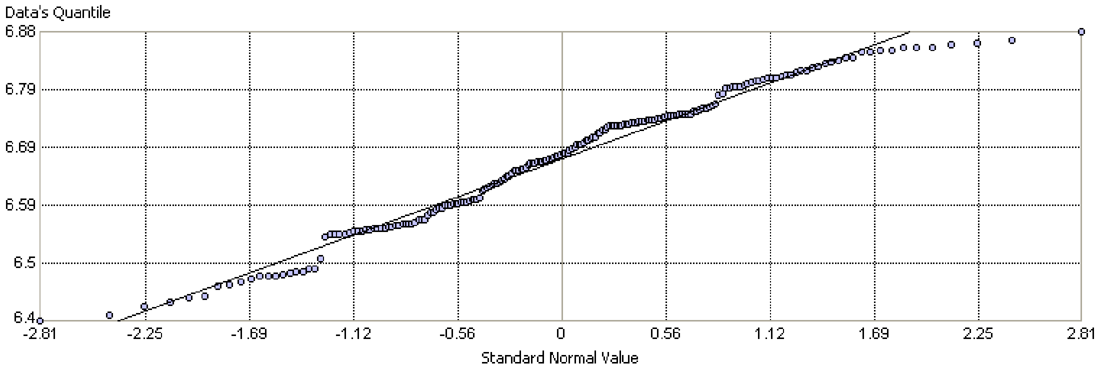


Figure B: Normal QQ plot of microtopographical data in middle floodplain zone.

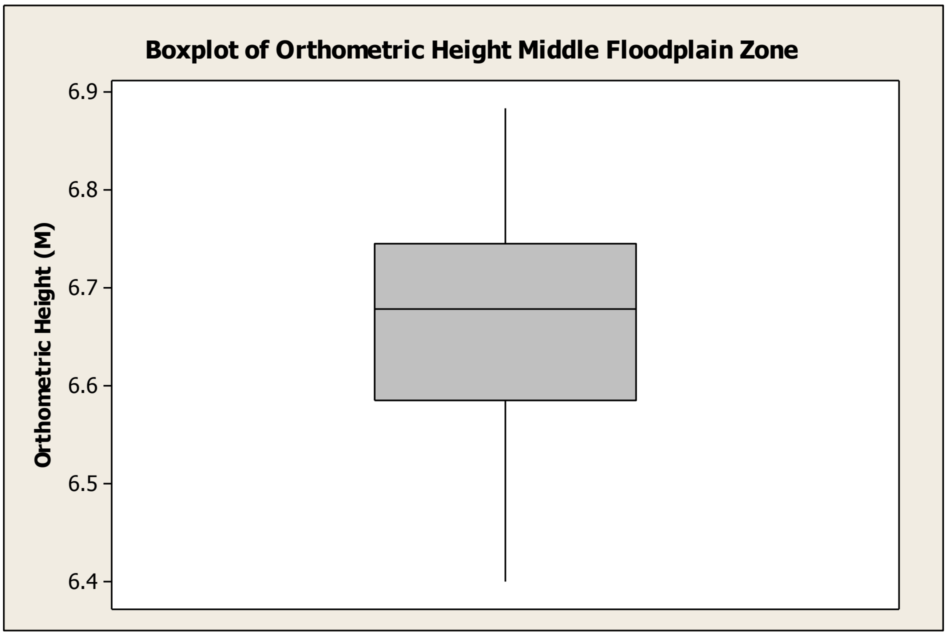


Figure C: Boxplot of microtopographical recorded in middle floodplain zone.

Appendix 18: ESDA histogram (A), normal QQ plot (B) and box plot (C) of microtopographical data recorded during vegetation survey of upper floodplain zone.

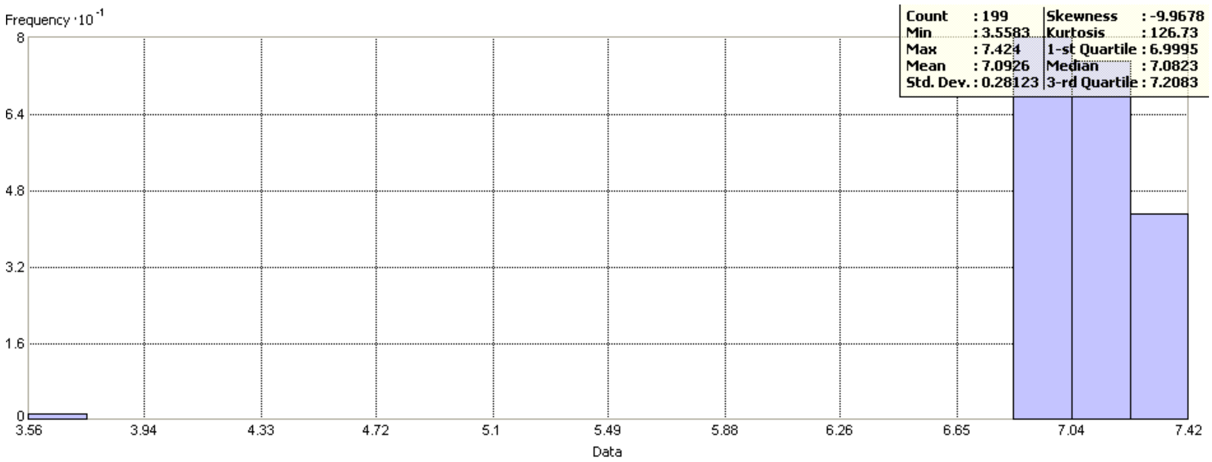


Figure A: Histogram of microtopographical data in upper floodplain zone.

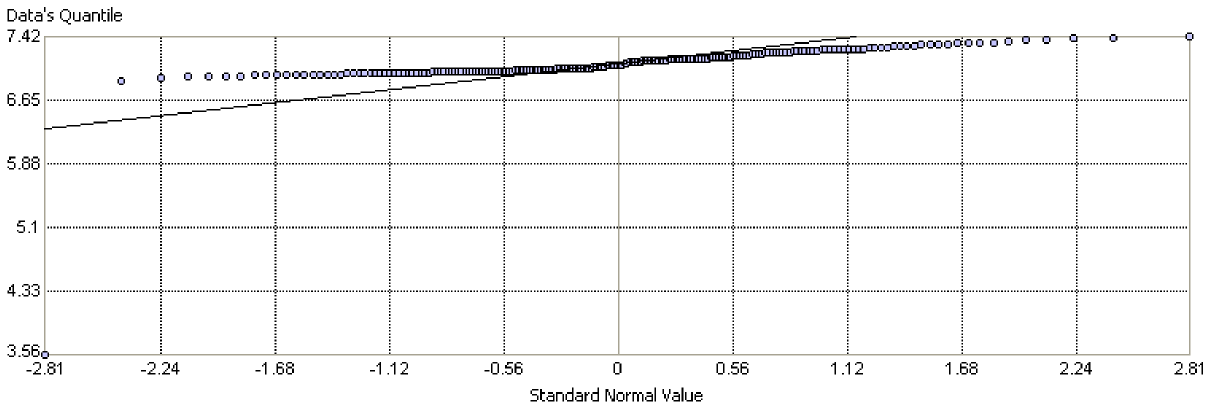


Figure B: Normal QQ plot of microtopographical data in upper floodplain zone.

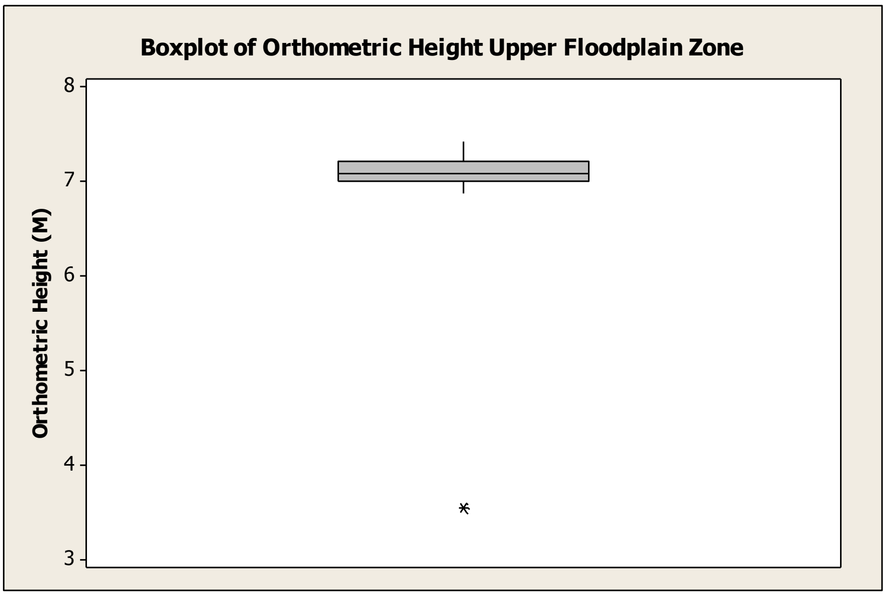
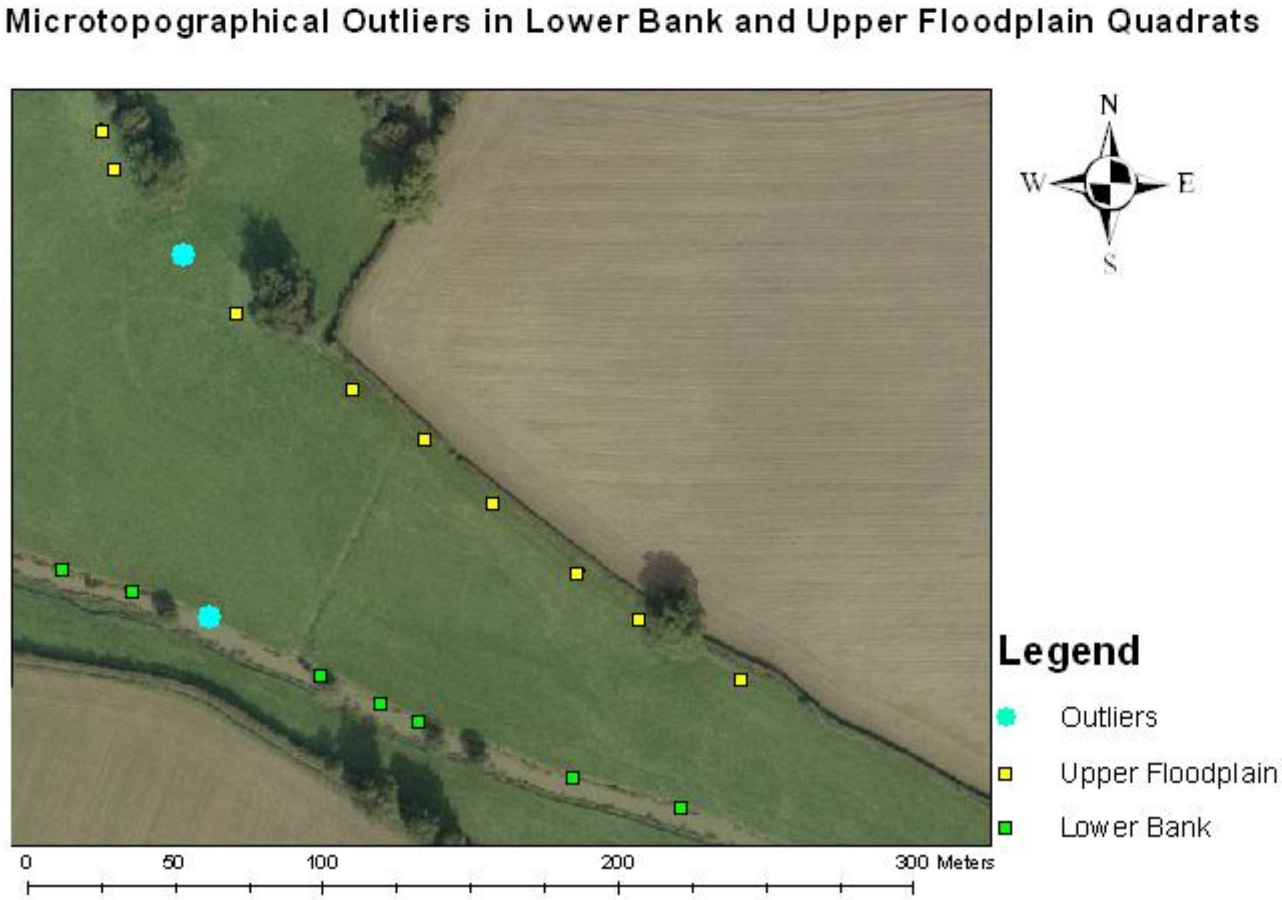


Figure C: Boxplot of microtopographical data recorded in upper floodplain zone.

Appendix 19: Microtopographical outliers identified in the vegetation survey



Appendix 20: ESDA histogram (A), normal QQ plot (B) and boxplot (C) of soil pH recorded in all zones.

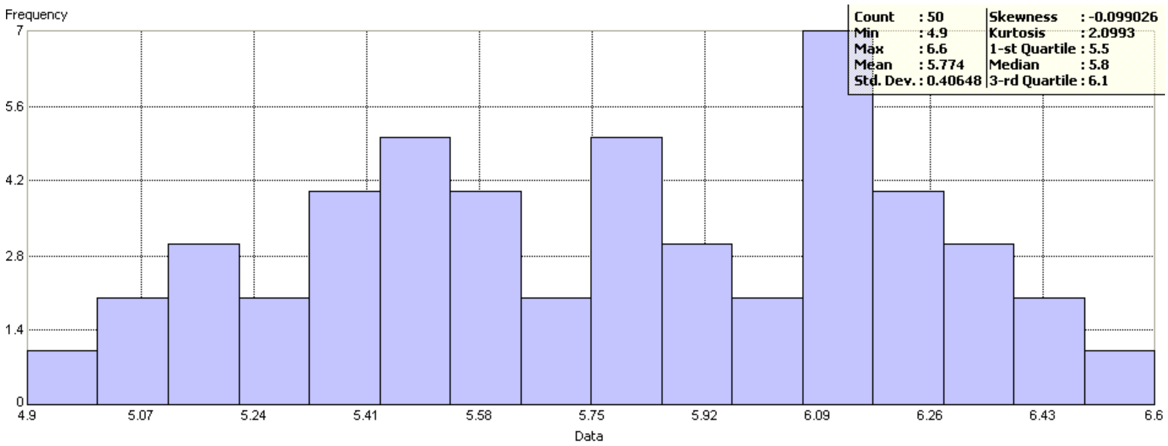


Figure A: Histogram of Soil pH in all zones.

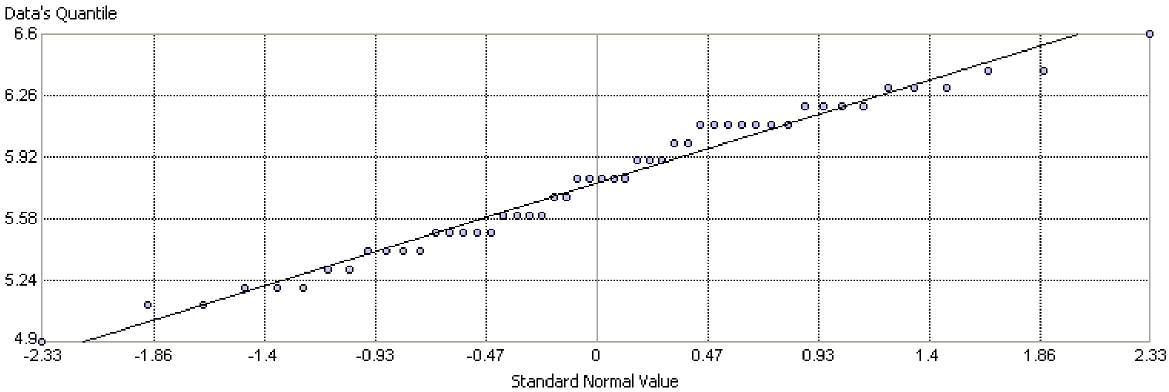


Figure B: Normal QQ plot of soil pH in all zones.

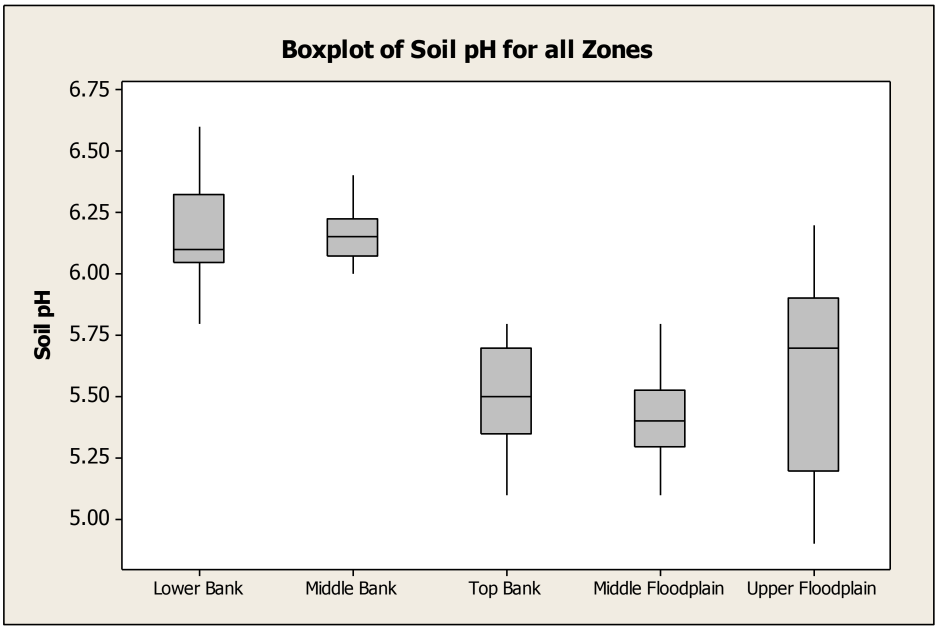


Figure C: Boxplot of soil pH for all zones.

Appendix 21: ESDA histogram (A), normal QQ plot (B) and box plot (C) of soil pH data recorded in lower bank zone.

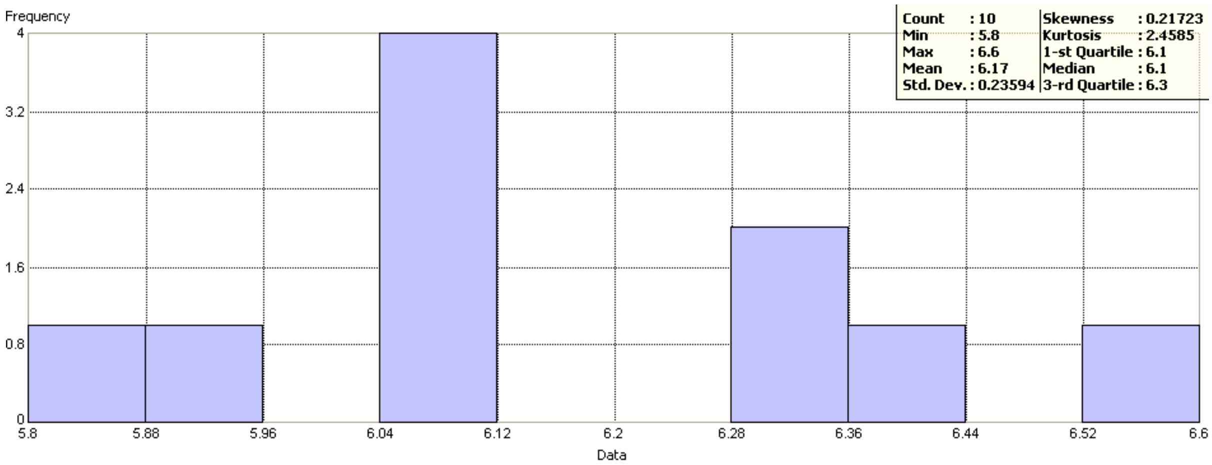


Figure A: Histogram of Soil pH in lower bank zone.

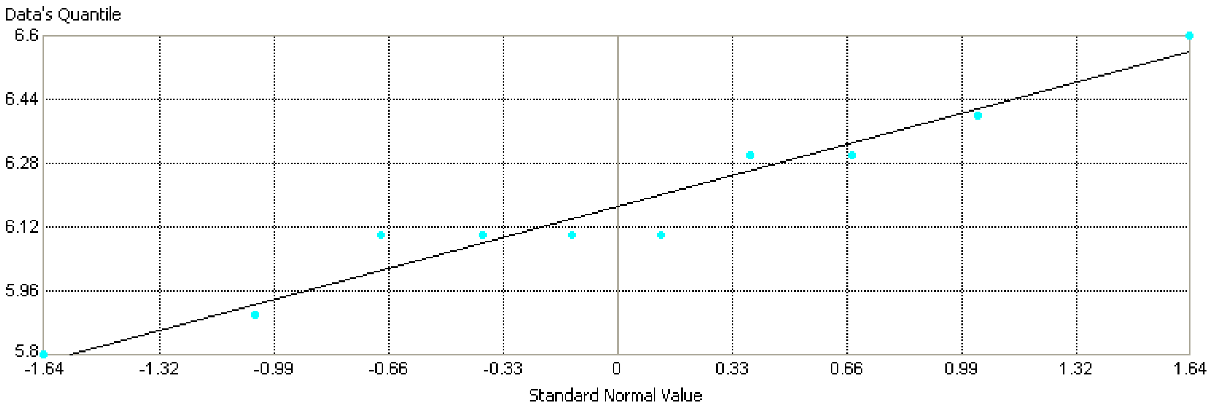


Figure B: Normal QQ plot of soil pH in lower bank zone.

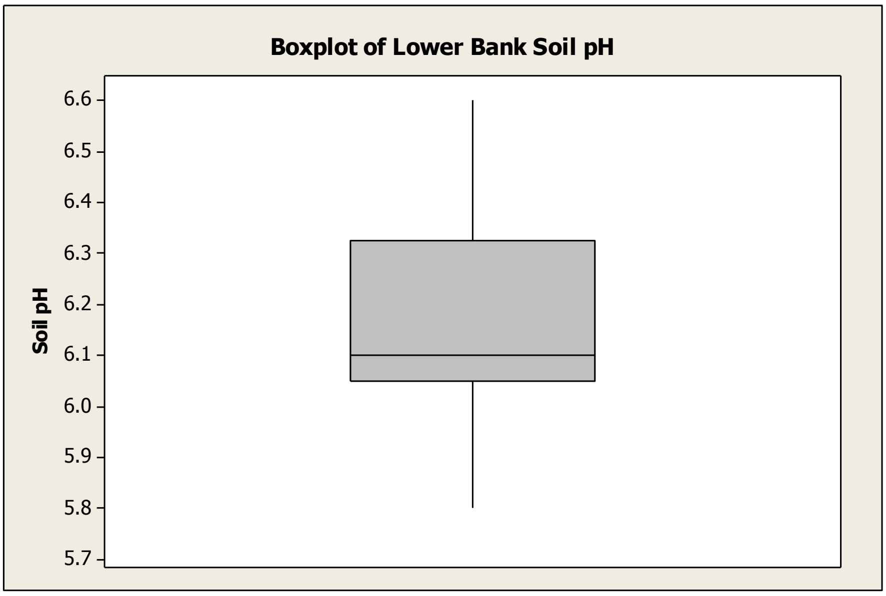


Figure C: Boxplot of soil pH in lower bank zone.

Appendix 22: ESDA histogram (A), normal QQ plot (B) and box plot (C) of soil pH data recorded in middle bank zone.

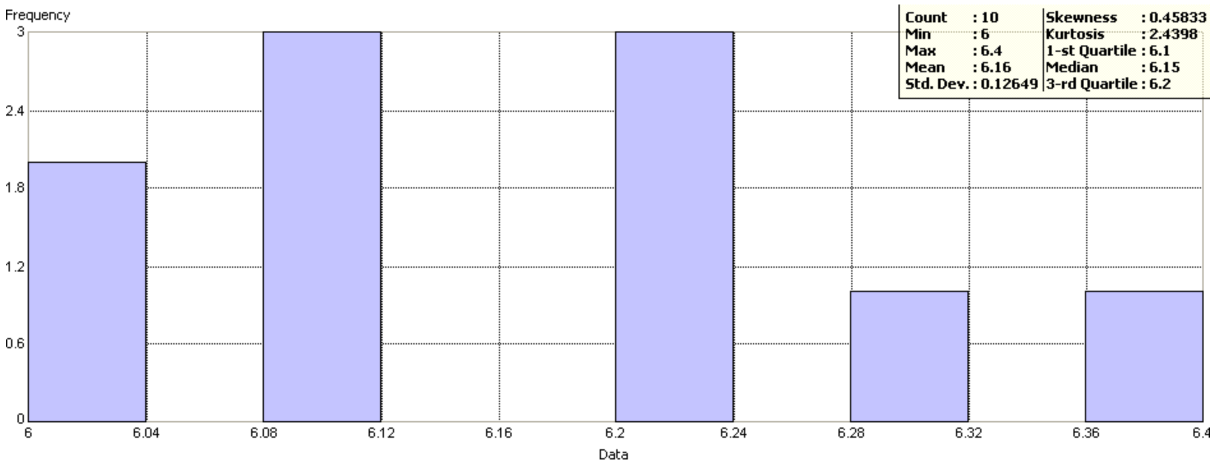


Figure A: Histogram of Soil pH in middle bank zone.

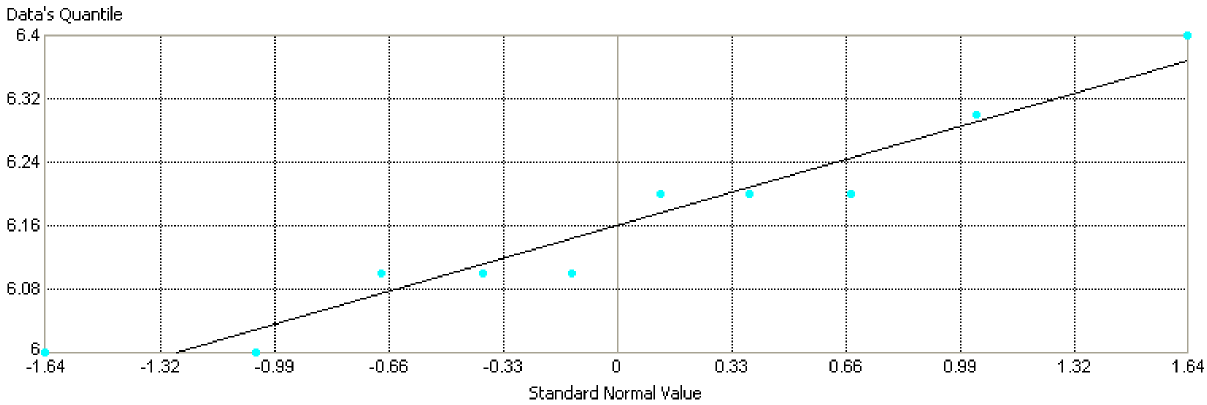


Figure B: Normal QQ plot of soil pH in middle bank zone.

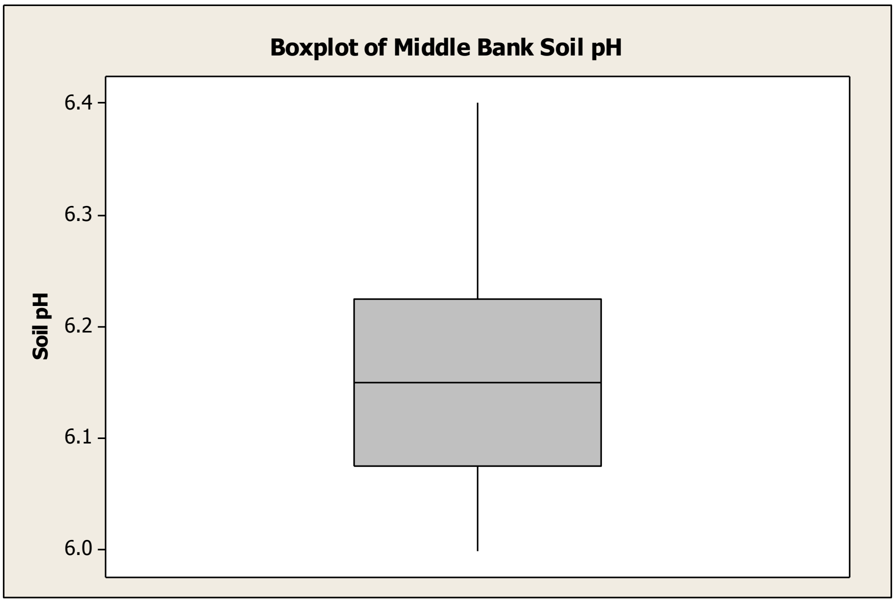


Figure C: Boxplot of soil pH in middle bank zone.

Appendix 23: ESDA histogram (A), normal QQ plot (B) and box plot (C) of soil pH data recorded in top bank zone.

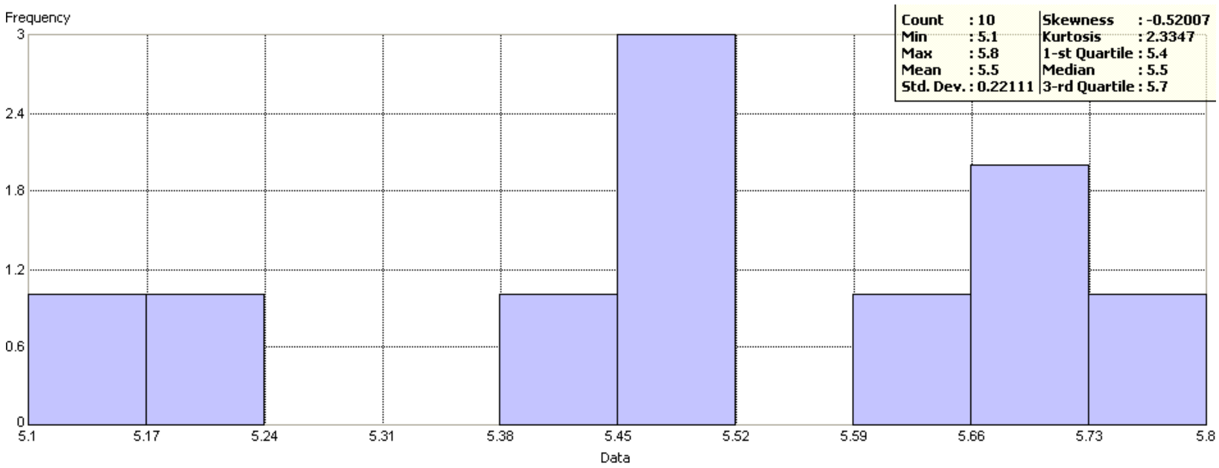


Figure A: Histogram of Soil pH in top bank zone.

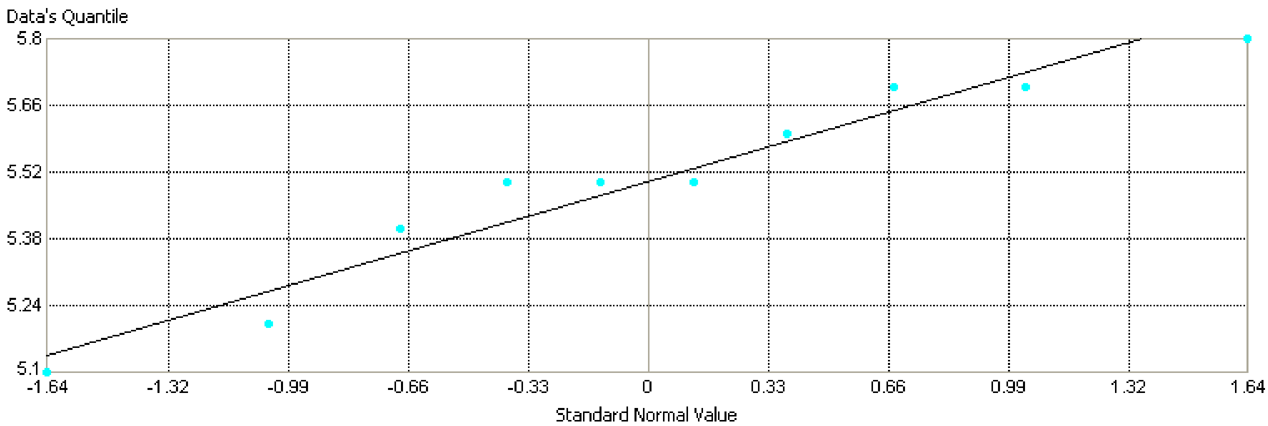


Figure B: Normal QQ plot of soil pH in top bank zone.

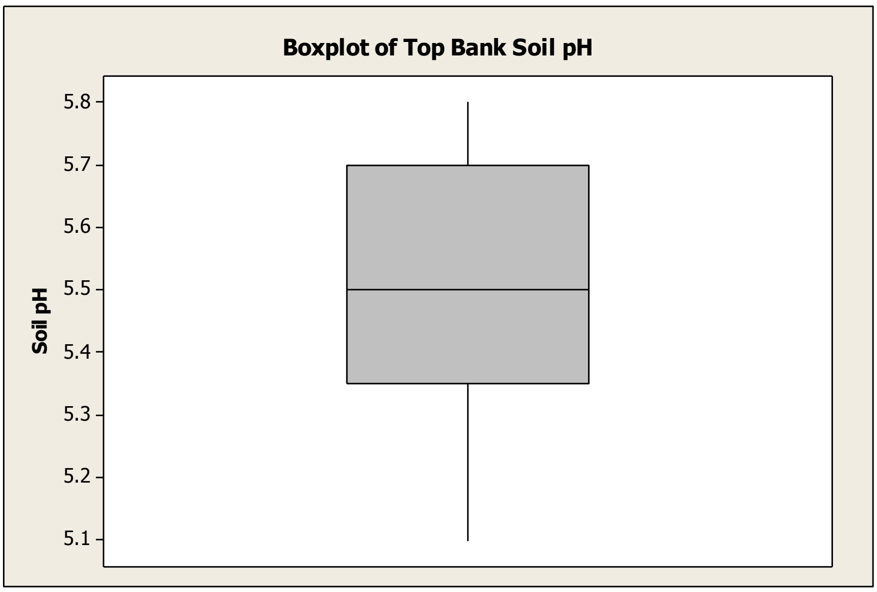


Figure C: Boxplot of soil pH in top bank zone.

Appendix 24: ESDA histogram (A), normal QQ plot (B) and box plot (C) of soil pH data recorded in middle floodplain zone quadrats.

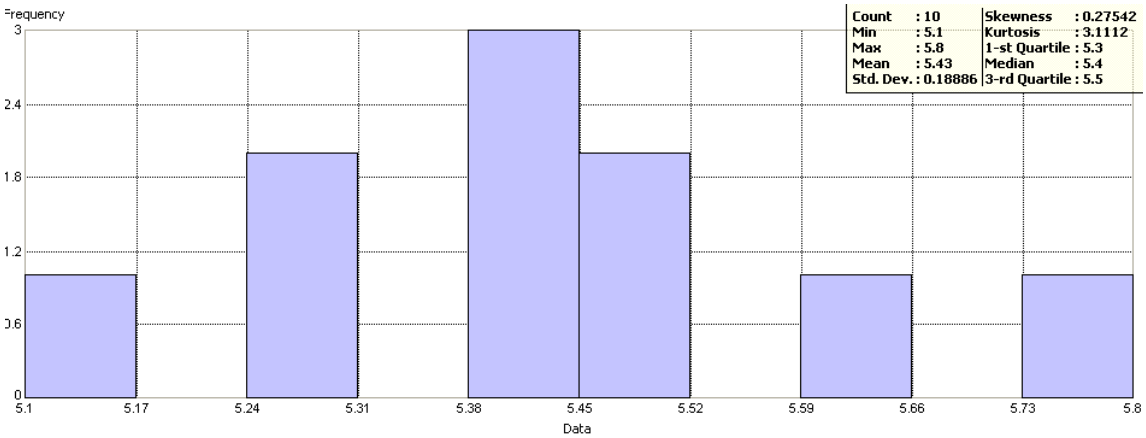


Figure A: Histogram of Soil pH in middle floodplain zone.

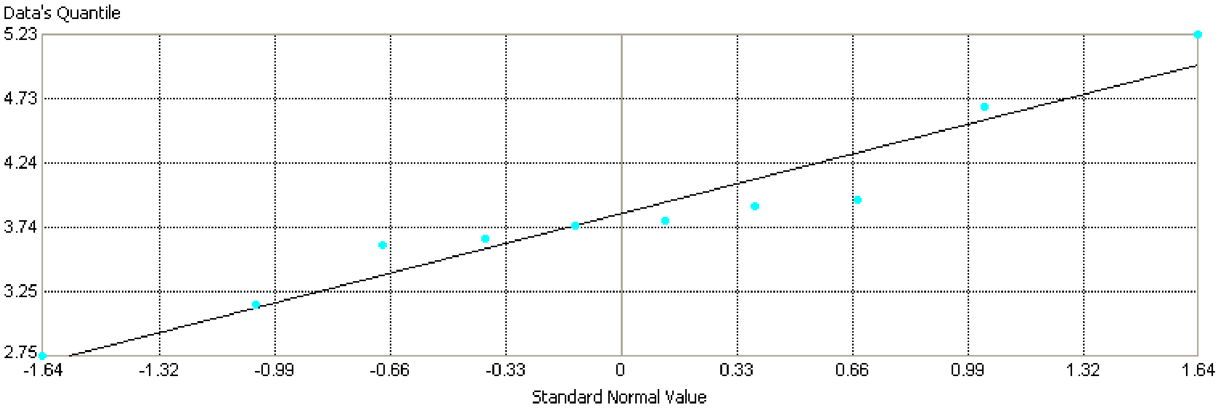


Figure B: Normal QQ plot of soil pH in middle floodplain zone.

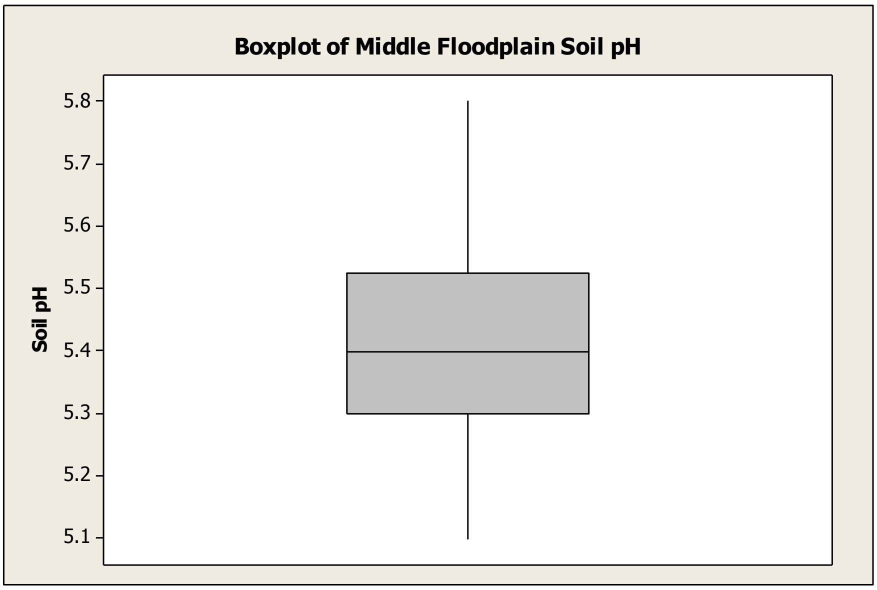


Figure C: Boxplot of soil pH in middle floodplain zone.

Appendix 25: ESDA histogram (A), normal QQ plot (B) and boxplot (C) of soil pH data recorded in upper floodplain zone quadrats.

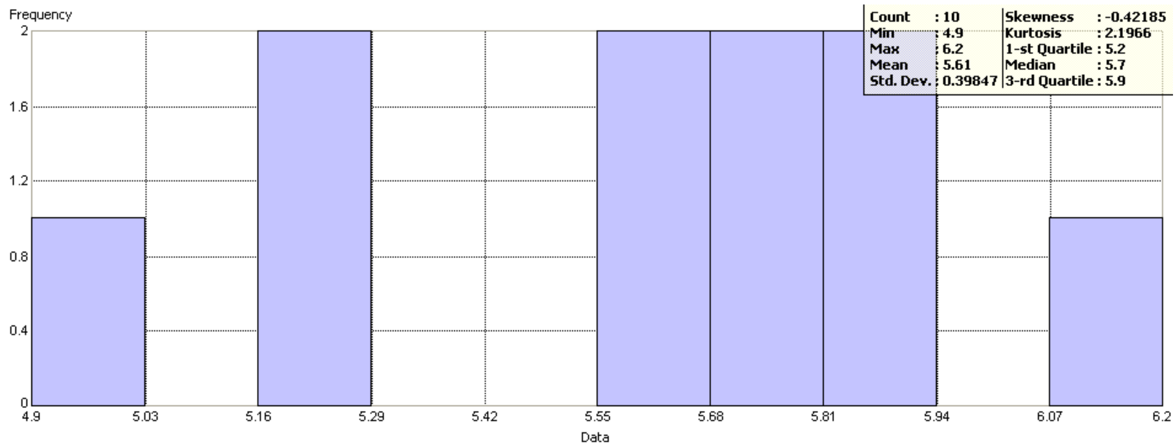


Figure A: Histogram of Soil pH in upper floodplain zone.

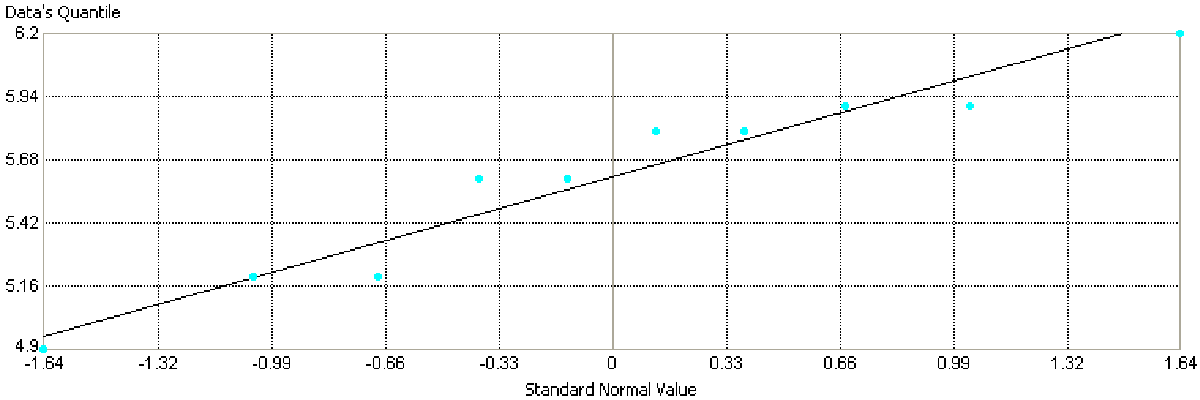


Figure B: Normal QQ plot of soil pH in upper floodplain zone.

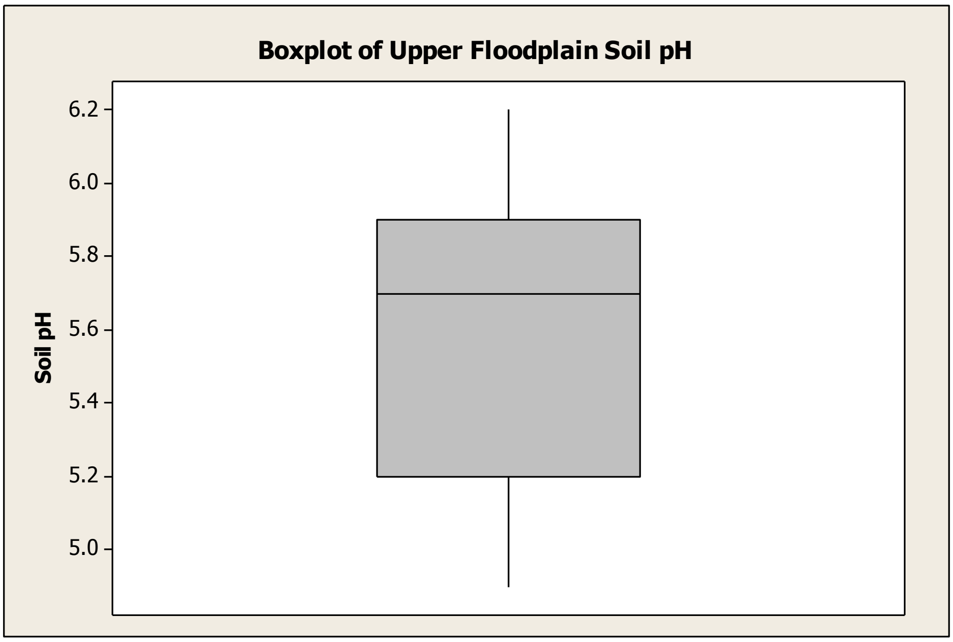


Figure C: Boxplot of soil pH in upper floodplain zone.

Appendix 26: ESDA histogram (A) and normal QQ plot (B) of microtopographical data recorded during the transect survey.

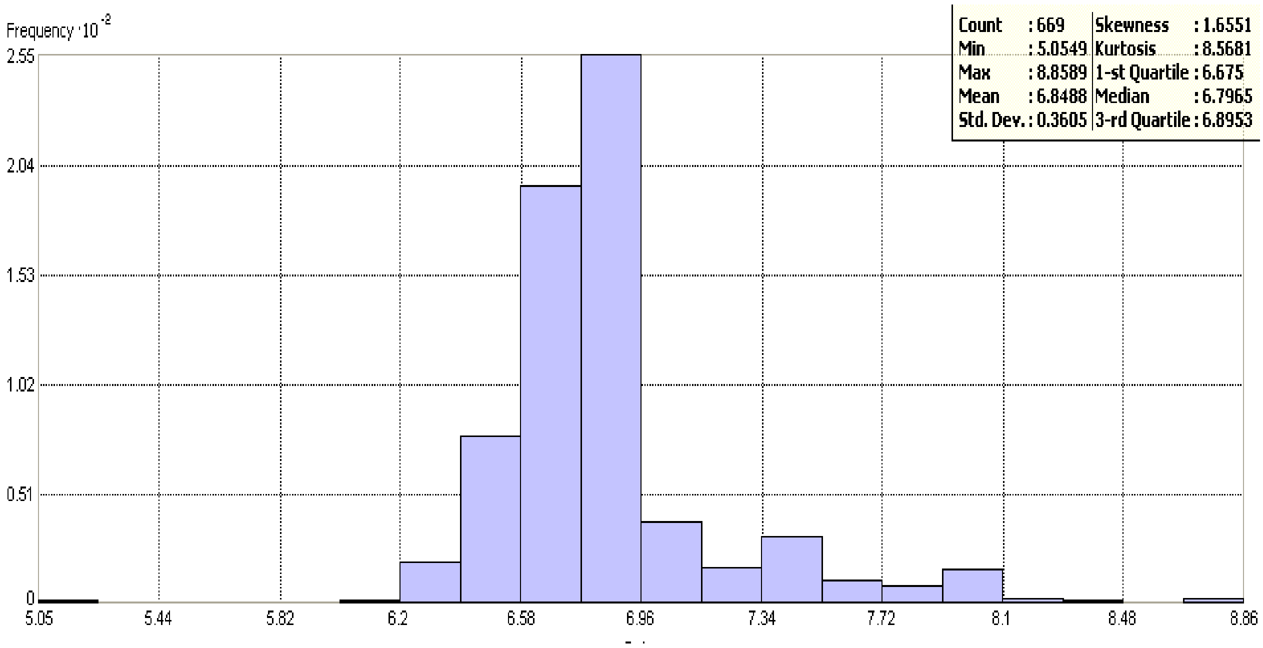


Figure A: Histogram of microtopography recorded during the transect survey.

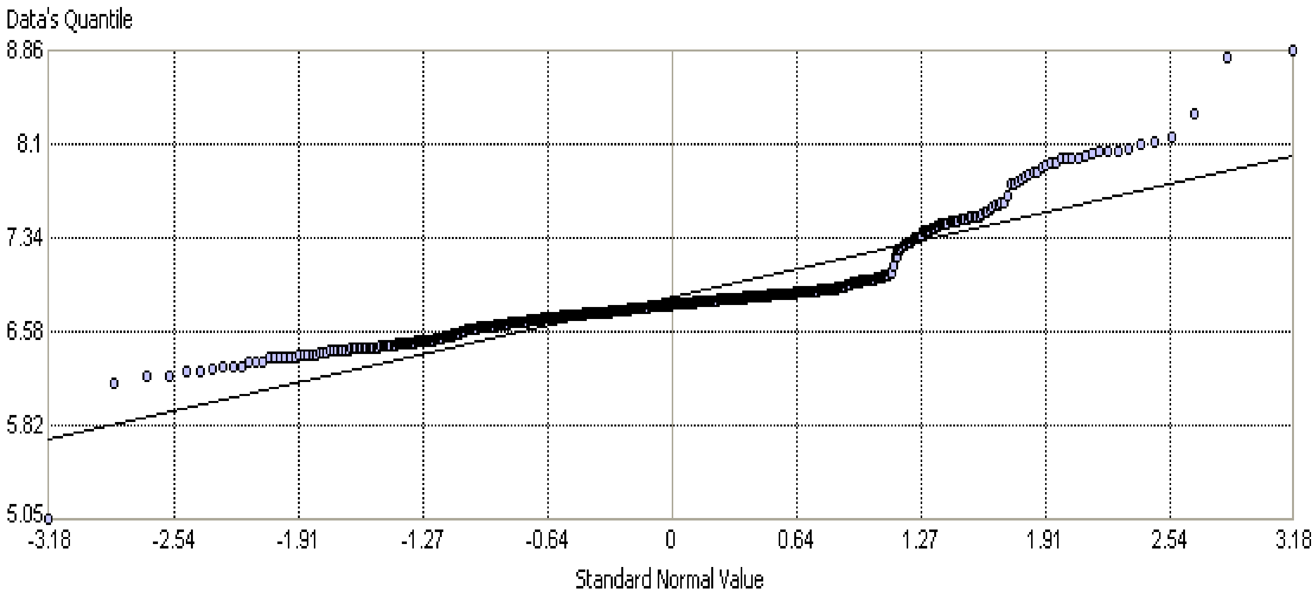


Figure B: Normal QQ plot of microtopography recorded during the transect survey.

Appendix 27: ESDA histogram (A), normal QQ plot (B) and box plot (C) of microtopographical data recorded during transect 1 (top bank).

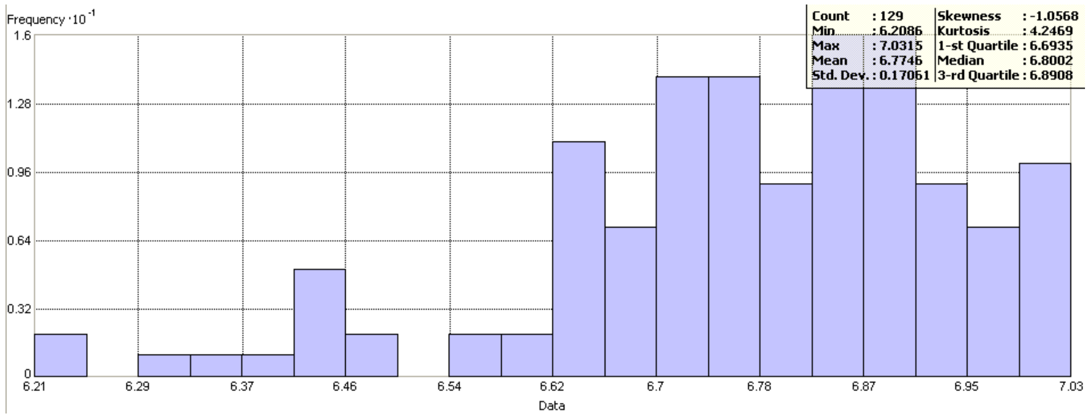


Figure A: Histogram of microtopography recorded during transect 1.

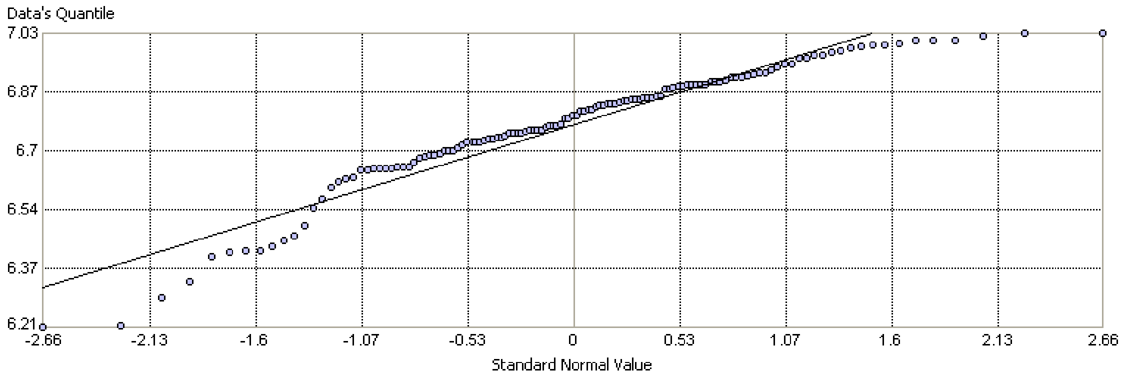


Figure B: Normal QQ plot of microtopography recorded during transect 1.

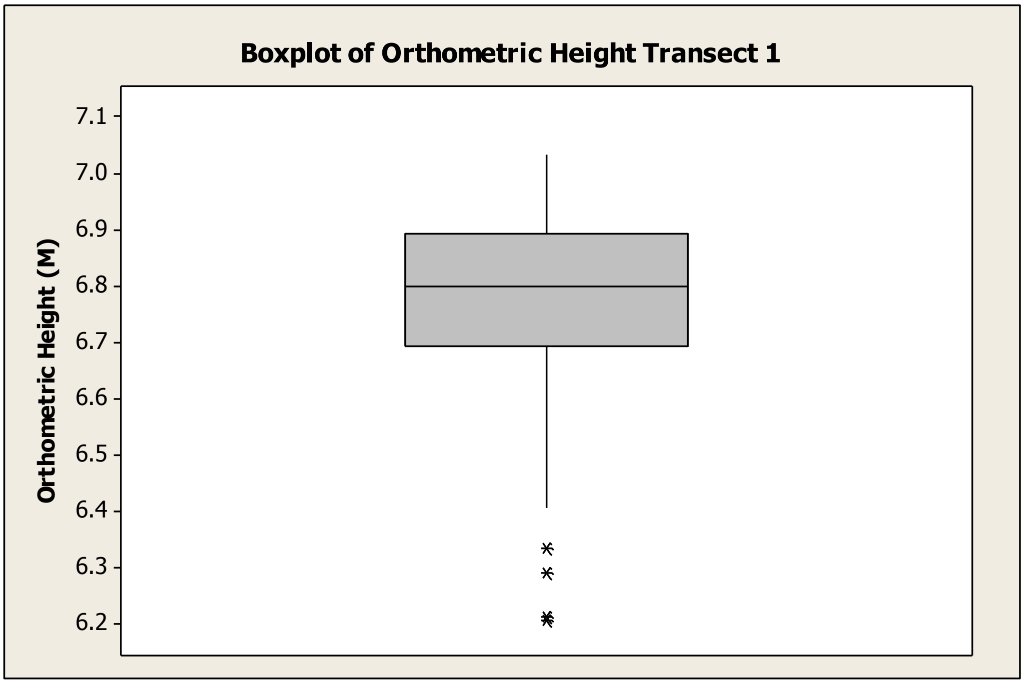


Figure C: Box plot of microtopography recorded during transect 1.

Appendix 28: ESDA histogram (A), normal QQ plot (B) and box plot (C) of microtopographical data recorded during transect 2 (middle floodplain).

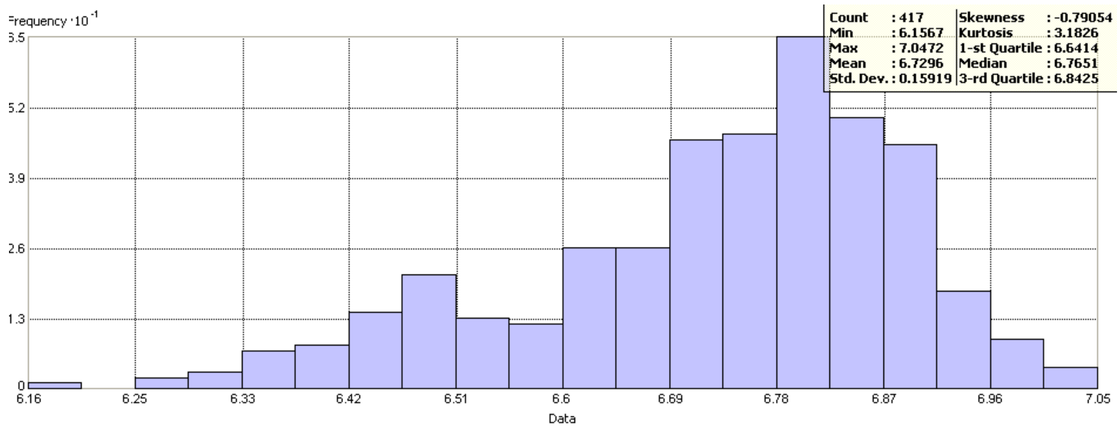


Figure A: Histogram of microtopography recorded during transect 2.

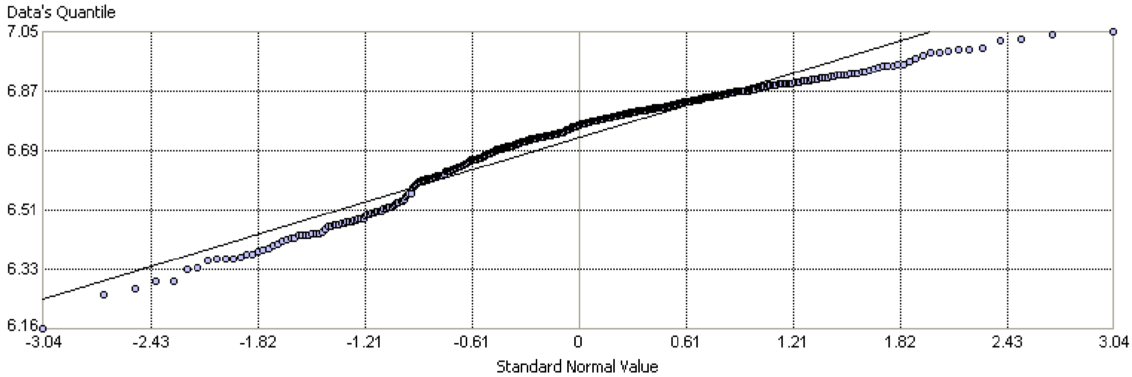


Figure B: Normal QQ plot of microtopography recorded during transect 2.

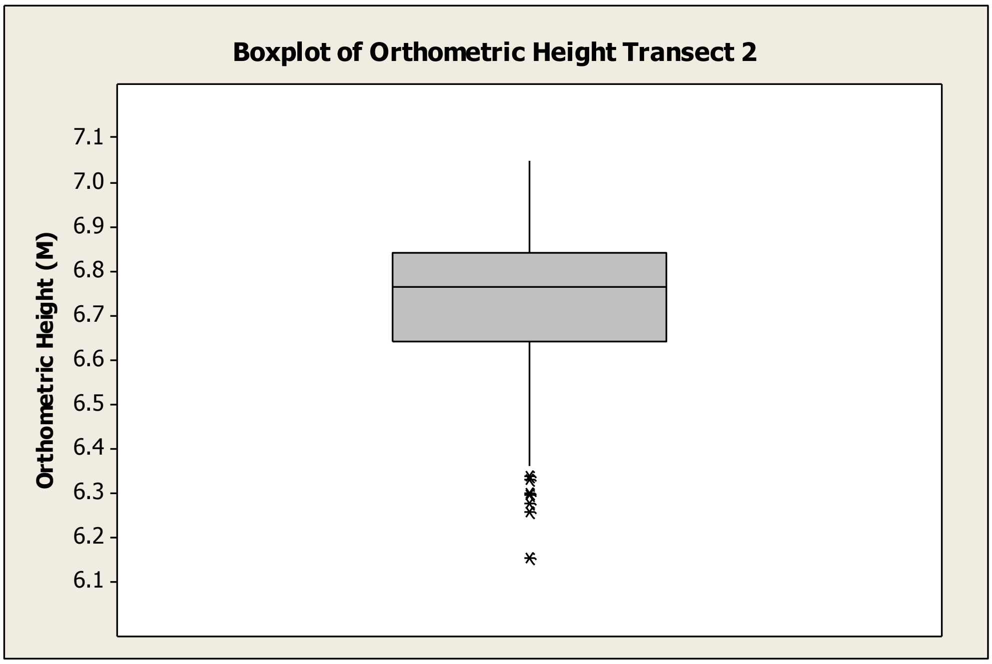


Figure C: Box plot of microtopography recorded during transect 2.

Appendix 29: ESDA histogram (A), normal QQ plot (B) and box plot (C) of microtopographical data recorded during transect 3 (upper floodplain).

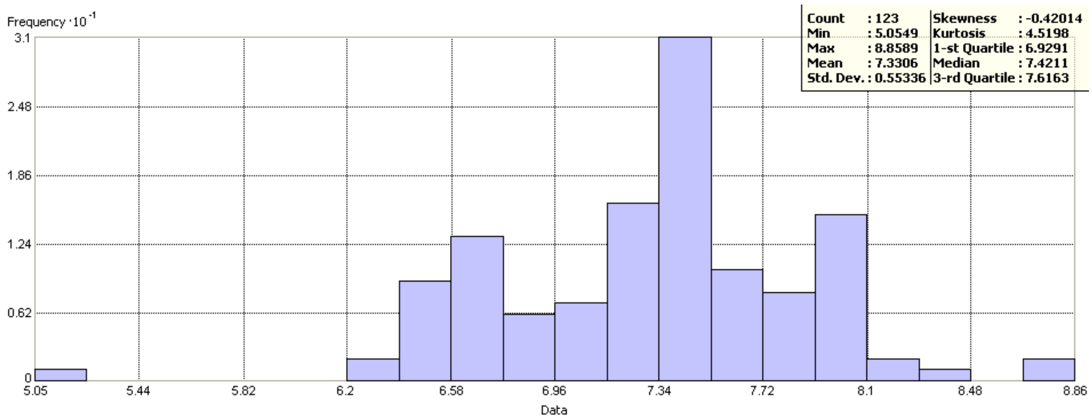


Figure A: Histogram of microtopography recorded during transect 3.

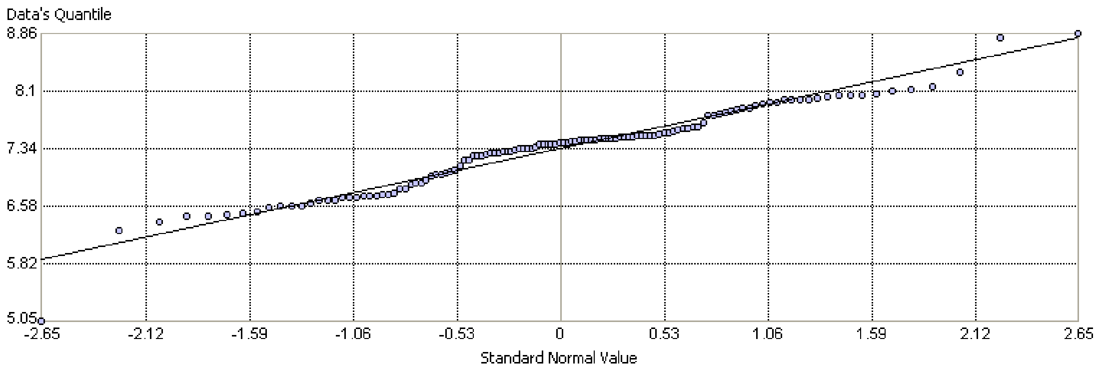


Figure B: Normal QQ plot of microtopography recorded during transect 3.

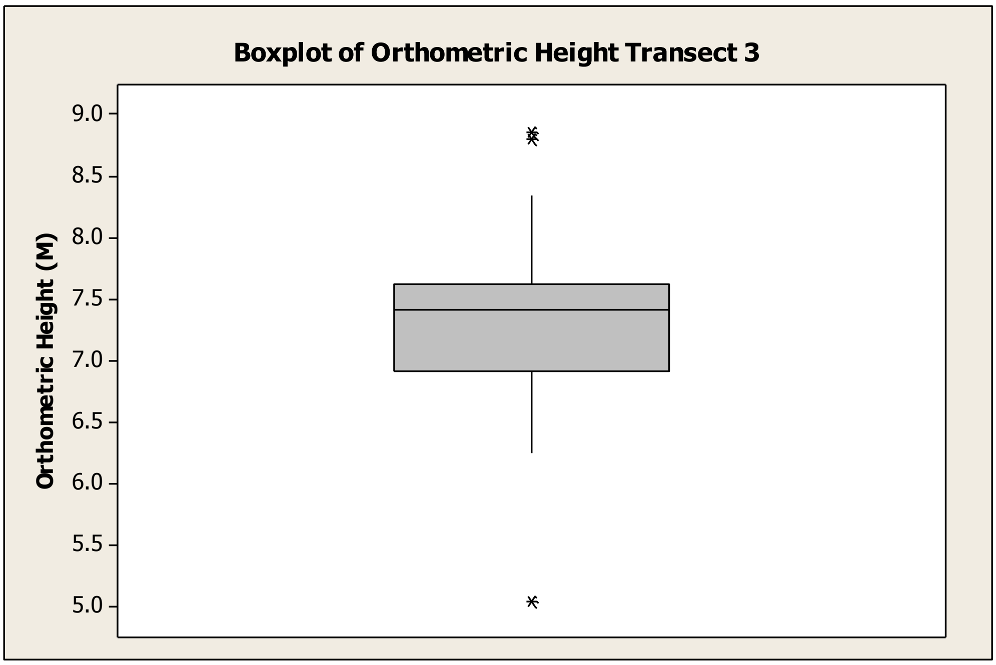


Figure C: Box plot of microtopography recorded during transect 3.

Appendix 30: ESDA histogram (A) and normal QQ plot (B) of soil moisture data recorded during the transect survey.

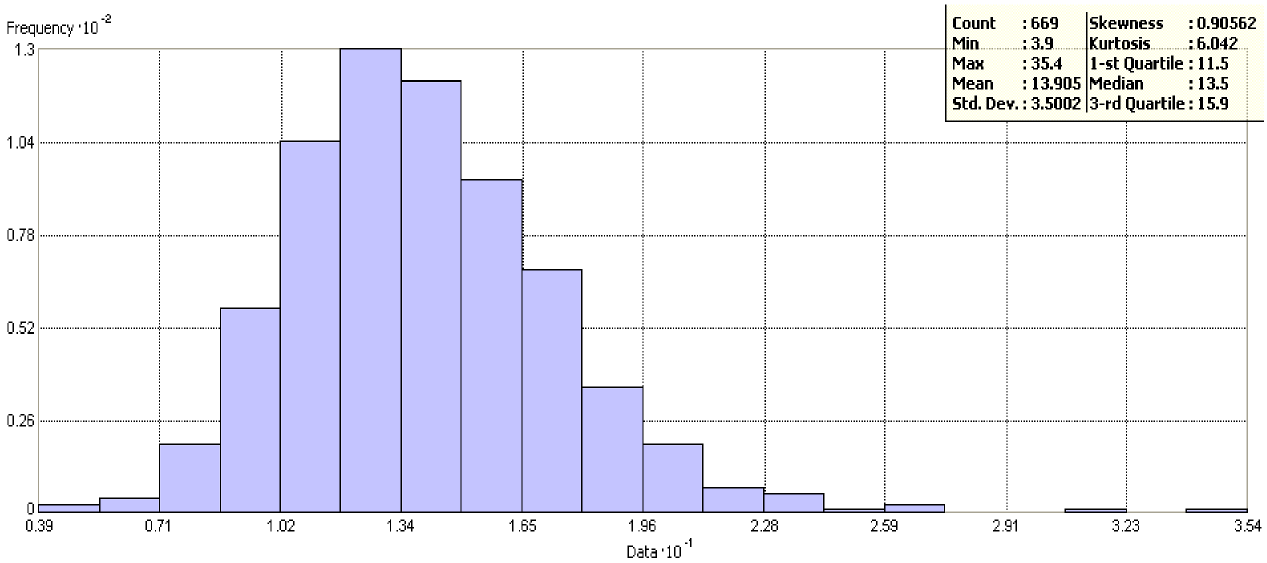


Figure A: Histogram of soil moisture recorded during the transect survey.

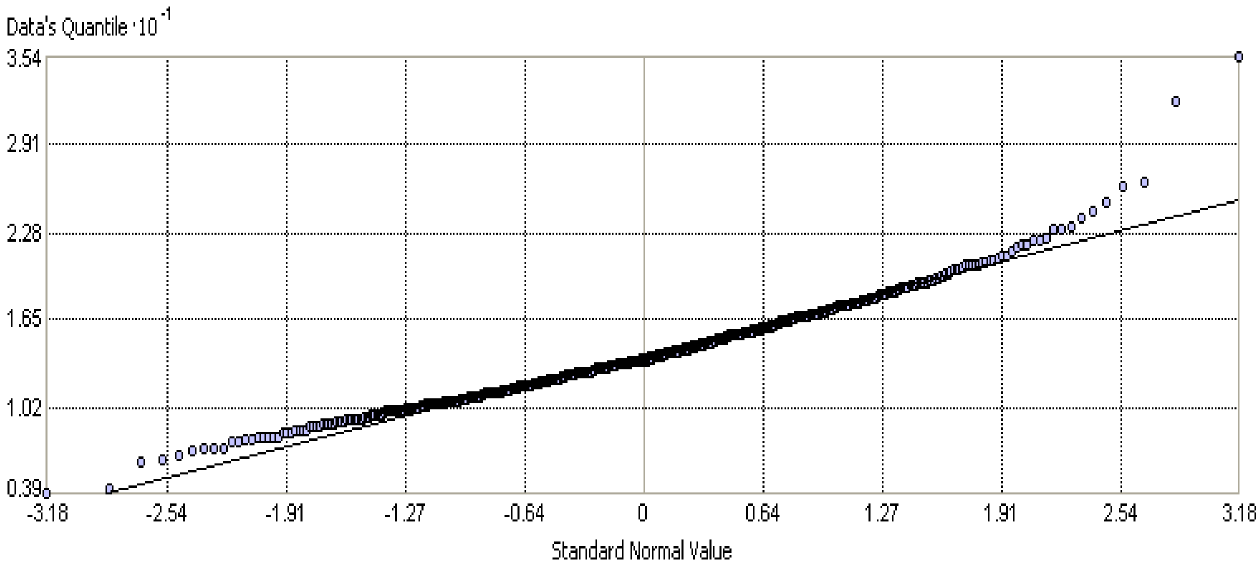


Figure B: Normal QQ plot of soil moisture recorded during the transect survey.

Appendix 31: ESDA histogram (A), normal QQ plot (B) and box plot (C) of soil moisture data recorded during transect 1 (top bank).

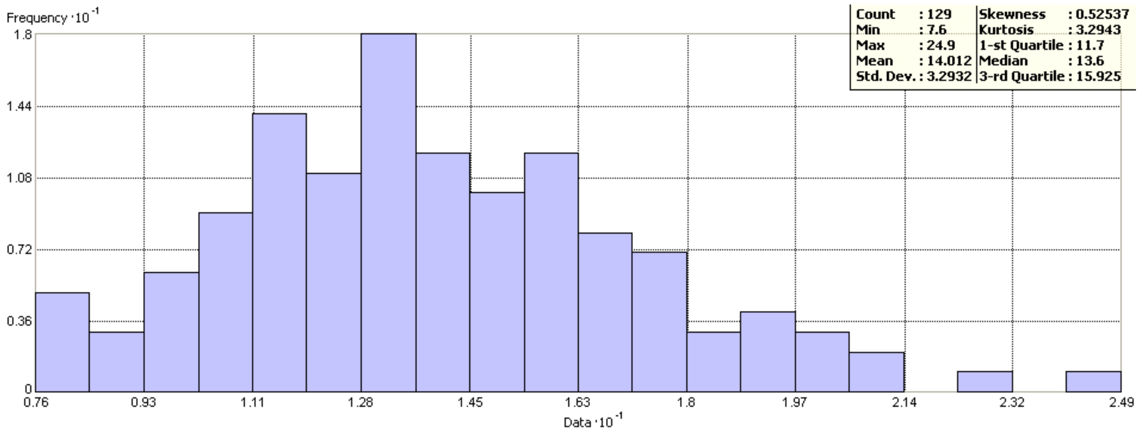


Figure A: Histogram of soil moisture recorded during transect 1.

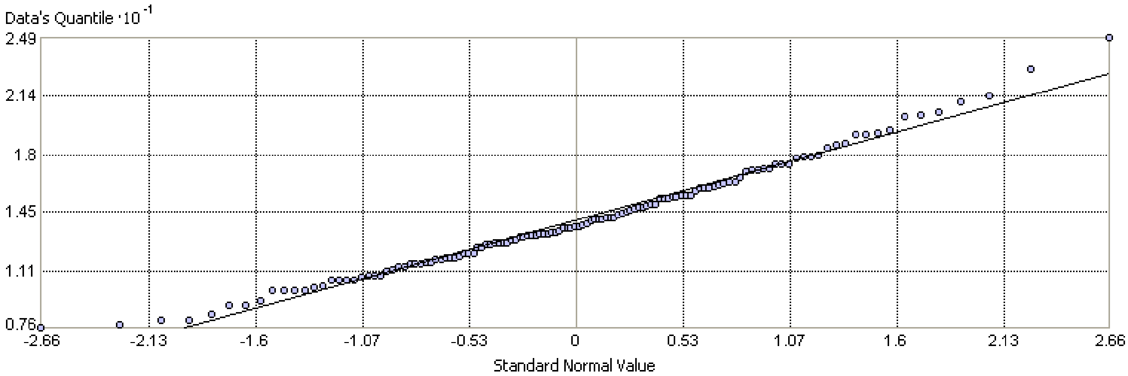


Figure B: Normal QQ plot of soil moisture recorded during transect 1.

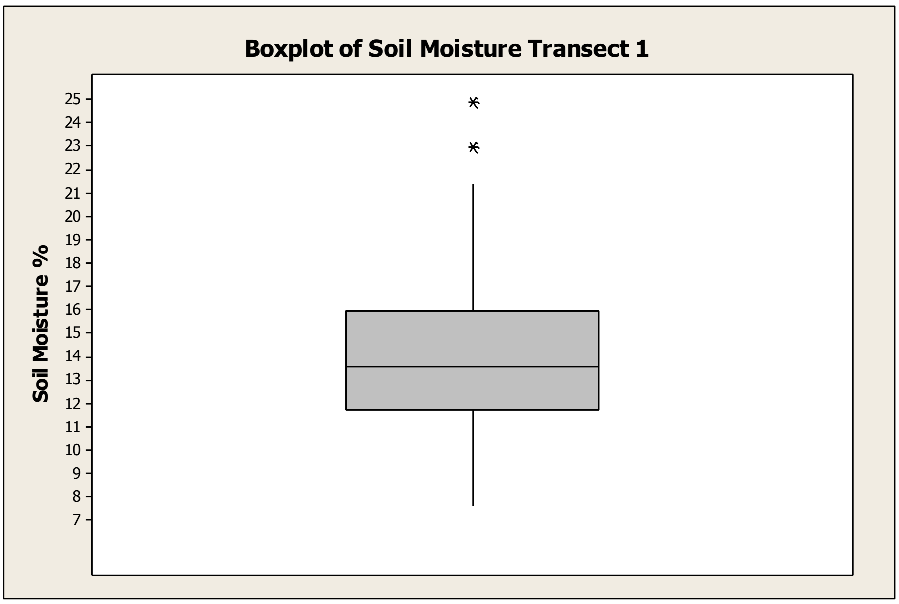


Figure C: Box plot of soil moisture recorded during the transect 1.

Appendix 32: ESDA histogram (A), normal QQ plot (B) and box plot (C) of soil moisture data recorded during transect 2 (middle floodplain).

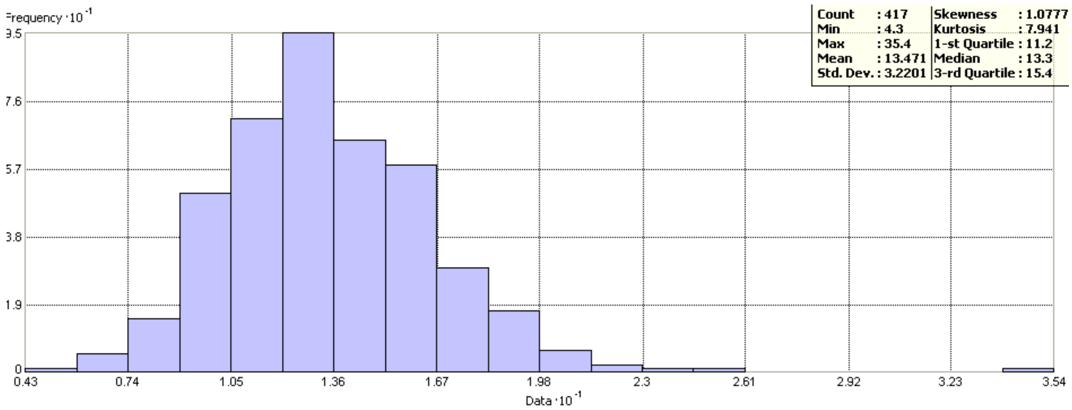


Figure A: Histogram of soil moisture recorded during transect 2.

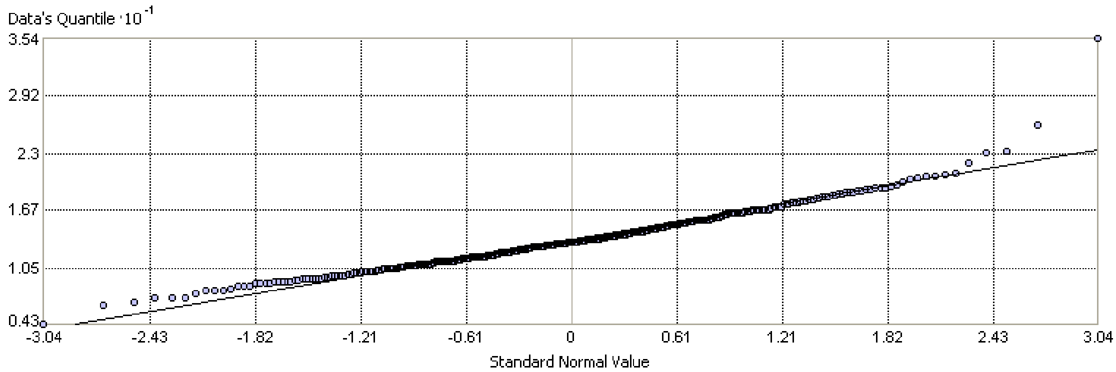


Figure B: Normal QQ plot of soil moisture recorded during transect 2.

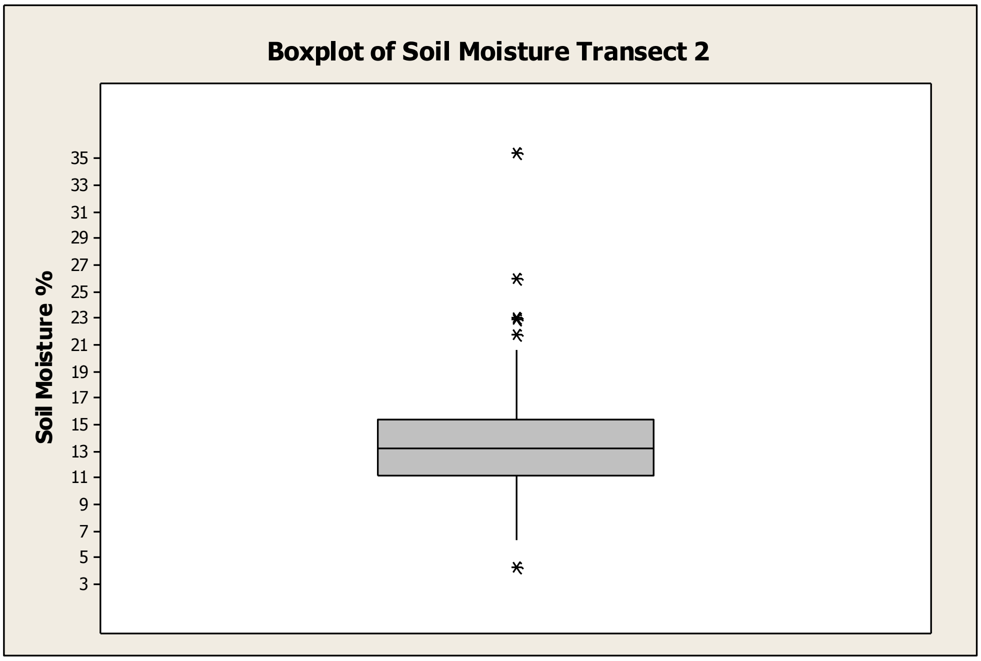


Figure C: Box plot of soil moisture recorded during transect 2.

Appendix 33: ESDA histogram (A), normal QQ plot (B) and box plot (C) of soil moisture data recorded during transect 3 (upper floodplain).

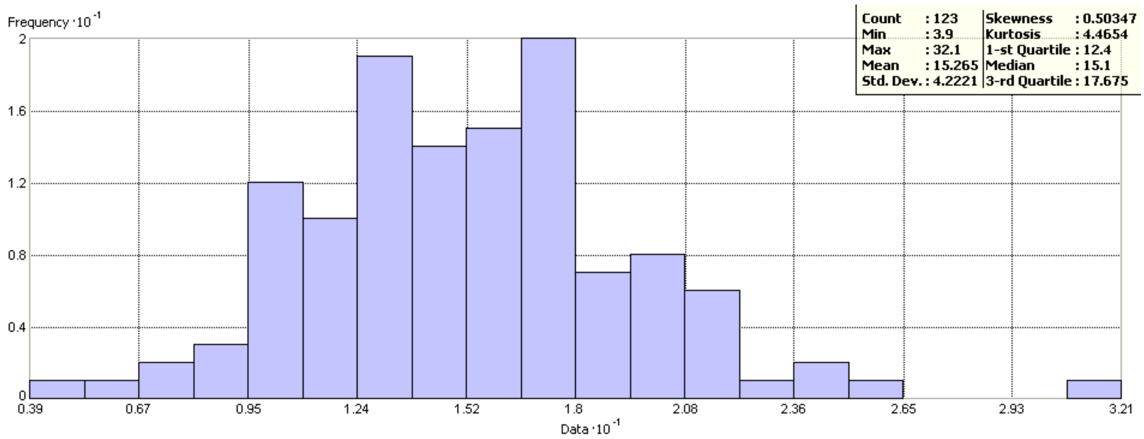


Figure A: Histogram of soil moisture recorded during transect 3.

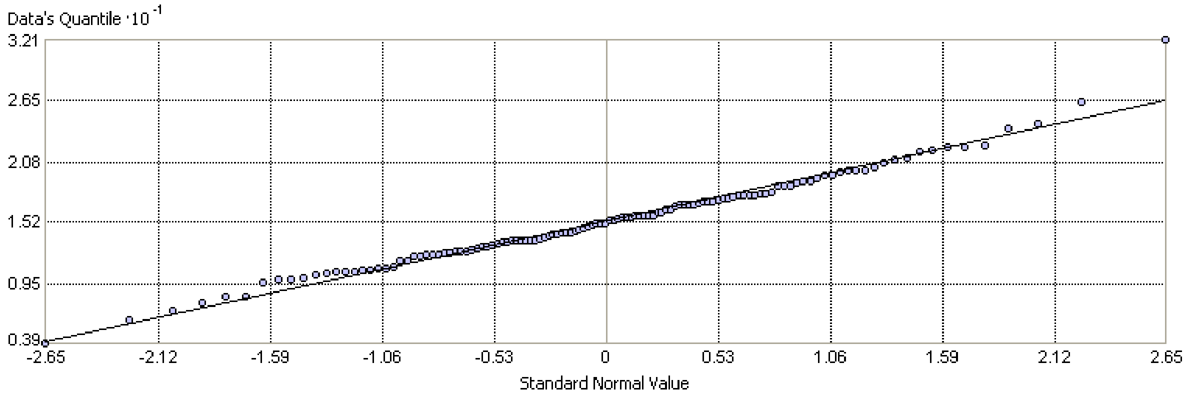


Figure B: Normal QQ plot of soil moisture recorded during transect 3.

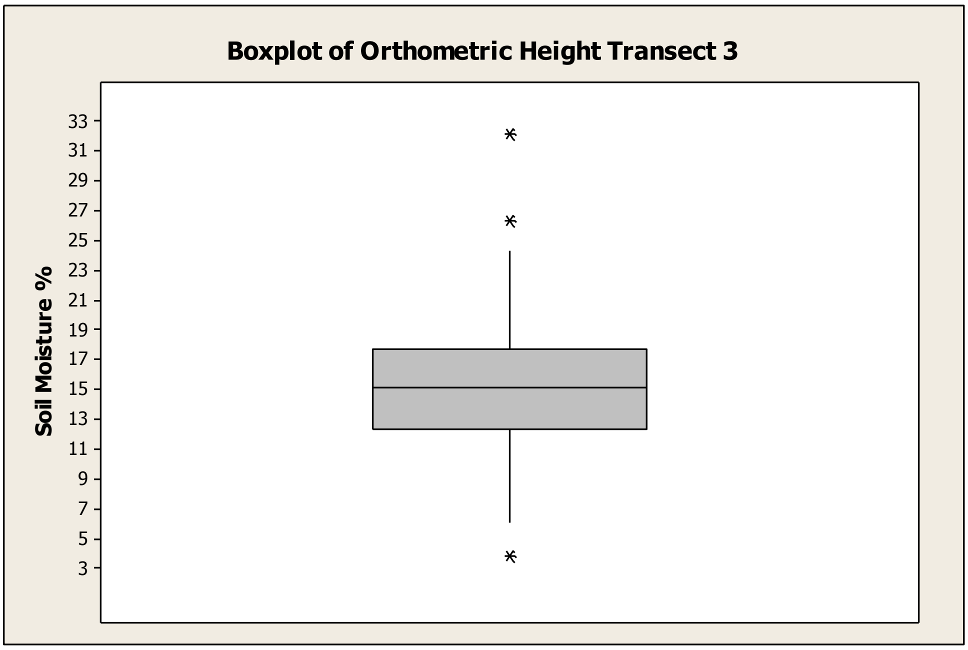


Figure C: Box plot of soil moisture recorded during transect 3.