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**University of Southampton**

FACULTY OF SOCIAL AND HUMAN SCIENCES

Geography and Environment

**Understanding the effects of cattle grazing in  
English chalk streams**

by

**Trevor Alan Bond**

Thesis for the degree of Doctor of Philosophy

September 2012

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF SOCIAL AND HUMAN SCIENCE

Doctor of Philosophy

UNDERSTANDING THE EFFECTS OF CATTLE GRAZING IN ENGLISH CHALK STREAMS

by Trevor Alan Bond

Accounting for much of the landscape of southern England, chalk stream environments hold significant cultural, economic and ecological value. However, attempts to retain this value are often hindered by the remnants of historic management practices that have occurred across several millennia, as well as contemporary demands upon chalk stream amenity, including water abstraction, recreational use and fisheries management. One land-use that is believed to have a detrimental effect upon chalk streams, but which has been inadequately researched, is cattle grazing.

Within this thesis the effects of cattle grazing in English chalk streams are assessed using a range of techniques. Terrestrial laser-scanning is employed to show that cattle can cause small, local changes in river bank topography. Direct and remote observations are used to link cattle behaviour to landscape utilisation, and a statistically significant correlation between air temperature and in-stream cattle activity is identified. Laboratory faecal analysis is conducted to establish the nutrient loading due to cattle, with results showing that cattle faeces contain significant concentrations of phosphate. In-stream water turbidity monitoring is combined with remotely sensed cattle behaviour data to demonstrate that in-stream cattle activity has a minimal effect upon suspended sediment concentrations in an English chalk stream. A study using the diffuse fine sediment risk model, SCIMAP, highlights the hydrologically disconnected nature of English chalk streams, with model outputs concluding that topography, rather than land-use (cattle grazing), is the key control on diffuse fine sediment risk in English chalk streams.

Combined, these individual findings provide a detailed, inter-disciplinary assessment that concludes the effects of cattle grazing in English chalk streams are different to those recorded in research from other environments, with physio-chemical effects (i.e. nutrient loading) being of greater significance than geomorphological agency (i.e. river bank destabilisation). This overarching conclusion has implications for the management of cattle grazing in English chalk streams, and these are discussed.

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## **Academic Thesis: Declaration Of Authorship**

I, Trevor Alan Bond, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

### **Understanding the effects of cattle grazing in English chalk streams**

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;

6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Either none of this work has been published before submission, or parts of this work have been published as: Bond, T. A., Sear, D. A. and Edwards, M. E. (2012) Temperature-driven river utilisation and preferential defecation by cattle in and English chalk stream. *Livestock Science*, **146**, 59-66.

Signed:

Date:

## **Acknowledgements**

The author would like to thank the following for their advice, support and help in the completion of this thesis: Susanna Black, Simon Dixon, Chris Hackney, Emma Waight, Peter Morgan, David Sear, Mary Edwards, Peter Langdon, Hayley Essex, Tim Sykes, Rue Ekins, Robert Raimés, Stephen Darby, Julian Leyland, Samantha Austin (nee Bateman), Kimberley Davies, John Duncan, Cherith Webb, Sarah Pogue, Peter Shaw, Felix Eigenbord and Gary Watmough.

This work is dedicated to my niece, Keira Janet Heathcote.



## 1. Introduction

Contemporary concerns over the condition of historically modified lowland lotic ecosystems are tempered by an ever increasing desire to sustainability utilise the ecological services they provide (Lawton *et al.*, 2010). Hence, the implementation of legislation (e.g. the European Union Water Framework Directive: WFD, 2000; Kaiki and Page, 2003) aimed at rectifying detrimental human-induced river changes, is often at odds with modern day river usage demands (Kallis and Butler, 2001; Moss, 2004).

In the UK, and England specifically, groundwater-fed chalk streams and their associated floodplain wetlands are at the forefront of the conflict between biodiversity conservation and optimal land management (Lawton *et al.*, 2010). Pressures on these ecosystems, including water abstraction, water pollution, fine sediment inputs and invasive species establishment, can act against sustainability objectives (Mainstone, 1999; Withers and Jarvie, 2008).

One such pressure whose impacts within chalk stream environments are poorly understood is cattle grazing. Although much has been written about the ecological and geomorphological consequences of cattle grazing in certain ecosystems (e.g. Quinn *et al.*, 1992; Mwendera *et al.*, 1997; Clary and Kinney, 2002; Marty, 2005), there are few studies pertinent to chalk streams. Nonetheless, the supposedly generic impacts of cattle grazing, such as river bank destabilisation (Trimble, 1994) and vascular plant mortality (Croel and Kneitel, 2011) have been cited in land management plans as a basis for cattle exclusion (Sarr, 2002). Yet, there are numerous examples of cattle grazing being used as a conservation tool (Adler *et al.*, 2001; Sarr, 2002; Hayes and Holl, 2003; Pykälä, 2005).

There is much to be said for the politics of land management, and the role of stakeholder education and perspective, in determining policy (Clothier, 2009). However, the main reason for disparities in approaches to cattle grazing for management is an unclear scientific basis. This confusion stems from a patchy and often contradictory body of

academic literature that provides no clear consensus on the effects of cattle grazing (e.g. Belsky *et al.* 1999 versus Pykälä, 2003).

Establishing the condition of the existing knowledge base with respect to the impacts of cattle grazing upon chalk streams requires the accumulation and evaluation of literature from several disciplines. Ecology, ethology and geomorphology provide much of the background theory; palaeoecology and palaeohydrology provide much of the background history; and environmental management and issues of sustainability provide much of the background context. However, in order to understand how all of these seemingly disparate fields connect it is helpful to have a framework in which to place them. Complexity science provides a good backdrop against which to view inter-linked disciplines such as zoogeomorphology, hydrobiology and landscape ecology. In particular, the role of organisms as ecosystem engineers can be investigated, both with specific reference to the effects of cattle grazing in chalk streams, but also in terms of the generic effects of animal interactions with fluvial systems.

### **1.1. Ecology, geomorphology and complexity science**

Understanding the linkages between ecological and geomorphological systems is crucial to effective environmental management (Viles *et al.*, 2008). This is reflected both in the increasing body of scientific research into biogeomorphology (Phillips, 1995; Hughes, 1997; Naylor *et al.*, 2002), and the increasing awareness of ecology-geomorphology interactions by policy makers (JNCC, 2004; Lawton *et al.*, 2010). Contemporary work over the course of the last two decades has demonstrated that not only are ecological and geomorphological systems irrevocably connected, but that the response to perturbation by one system to the other is often complex and non-linear (Viles *et al.*, 2008). Numerous conceptual and computational models have hypothesised these relationships (Knox, 1972; Bull, 1991; Baptist, 2005), whilst several empirical studies have demonstrated them. (Hupp *et al.*, 1995; Hugenholtz and Wolfe, 2005)

What has emerged from this meeting of disciplines is the unification of ecology and geomorphology under a shared complexity theory framework delineated into four principles themes, as prescribed by Stallins (2006):

- Multiple causality; a response is a function of multiple variables, and that any variable typically elicits multiple responses.
- Ecosystem engineers; biota within ecosystems can significantly influence geomorphic agency, with the potential to generate both resistive and disruptive, non-linear forces that vary in space and time.
- Ecological topology; the structure and hierarchy of related spatiotemporal domains of causality, in which feedbacks, self-organisation, stability, slaving, and linear and non-linear processes can occur.
- Ecological memory; the role of antecedent conditions and past events in determining the patterns and nature of on-going and future ecological and geomorphic processes.

These themes provide a framework that attempts to account for the events that occur at the interface of ecology and geomorphology. Against this backdrop, particular systems and specific biota can be placed, and their biogeomorphic interactions considered. Of pertinence to this thesis are the interactions between animals and natural fluvial systems, of which there are a growing number of examples.

### **1.2. Animal interactions with fluvial systems: existing knowledge**

The existing literature on animal interactions with natural fluvial systems has considered a range of different animals and systems. For several decades the importance of geomorphology upon organisms and the habitats in which they live has been accepted, with the integration of fluvial geomorphology and hydrobiology into an interdisciplinary river science improving our understanding of riverine ecosystems and how they should be

## Introduction

conserved, managed and maintained (Bravard *et al.*, 1986; Amoros *et al.*, 1987; Newson and Newson, 2000; Rice *et al.*, 2010). Whether it be the high intra-gravel flow rates necessary for successful bull trout spawning (Baxter and Hauer, 2000) or the variation in benthic community composition resulting from small-scale differences in the physical structure of North American streams (Carter *et al.*, 2003), fluvial geomorphology and the ecology of aquatic systems are irrefutably connected.

Most recently these ideas have developed further to consider not only the effect of fluvial systems upon biota, but also the effect of biota upon fluvial systems. A recent special issue of the journal *Geomorphology* considers zoogeomorphology and the role of organisms as ecosystem engineers, highlighting the increasing number of studies in this field (Butler and Sawyer, 2012). For example, Butler (2006) cites a number of case studies from North America, including the role of beavers in trapping sediment behind dams and the mobilisation of sediment by burrowing prairie dogs. Statzner (2012) has exhibited how silk-spinning caddis flies and crayfish can influence fluvial processes occurring within lotic bed substrate, modifying sediment movement locally. Hupy and Koehler (2012) even classify geomorphic changes resulting from the explosion of military munitions as zoogeomorphology, although it is debatable whether human agency should be considered zoogeomorphology.

What emerges from these studies is a realisation that not only do animals act as geomorphic agents in a range of fluvial systems, but that this agency can be significant. There is no better example of this than in work by Hassan *et al.* (2008), who have shown that mass salmon spawning can be responsible for moving nearly half of the annual bedload yield in Canadian streams, with subsequent consequences upon river morphology and sediment transport rates. Moreover, MacDonald *et al.* (2010) have suggested there may be positive feedback mechanisms at work in British Columbian streams, with the removal of fine sediment by salmon during spawning improving the condition of spawning gravels for future years.

### 1.3. Animal interactions with fluvial systems: future research

Despite recent developments, zoogeomorphology remains a young discipline and as such there are numerous avenues for future research. The ultimate goal is to understand animal interactions with fluvial systems within a holistic framework. Such a framework would consider: spatial and temporal variations in animal populations; natural variability in hydrological and geomorphological processes and rates of change; climate change; ecological processes (including competition, predation and disease); and environmental influences (Ward, 2001).

As noted by Naiman and Rogers (1997) in their relatively early work, river systems are affected by synergistic forces, both between animals and between river systems and animals. Moreover, such forces influence both biological and geomorphological forms and processes (Naiman and Rogers, 1997). Hence, studies that consider all of these elements are best equipped to understand interactions between animals and fluvial systems (Viles *et al.*, 2008).

In practice it is impossible to conduct research that incorporates empirical data on every biotic and abiotic component of a fluvial system; it is more viable to undertake focused studies that then contribute to our overall understanding by being placed into the holistic framework. Such studies should, where possible, consider as many variables as is realistically possible so as to maximise our knowledge of that specific set of interactions (Naiman and Rogers, 1997). In all instances it is important to have contextual meta-data (e.g. meteorological, climatic, animal gender, animal breed, animal population density, etc.) that sets the scene and allows the study to be appropriately placed within the larger framework (Ward, 2001).

It is with these thoughts in mind that the research detailed herein is conducted. Whilst it is not realistic to attempt to understand every interaction between cattle and chalk stream environments, it is possible to concentrate on those of greatest scientific interest. Moreover, a plethora of auxiliary information can be provided so that this work can be

evaluated relative to the studies that proceed and precede it. The following aims, objectives and expected outcomes explain how this will be done within this thesis.

## **1.4. Aims and objectives**

The overall aim of the project is to **understand the effects of cattle grazing in English chalk streams**. Within this overall aim are a number of specific aims:

- To improve the scientific knowledge base of cattle-river interactions
- To improve understanding of landscape utilisation by cattle in chalk stream environments
- To improve understanding of how cattle affect chalk stream environments in terms of geomorphology, hydrology, biology and ecology

These specific aims will be met by a number of objectives:

- To coalesce and review existing knowledge pertaining to cattle impacts upon chalk stream environments
- To conduct a behavioural study that monitors cattle to quantitatively describe and categorise their activity across three chalk stream study sites
- To link observed cattle behaviour to landscape utilisation and discrete landscape features through the use of GPS
- To quantify the effect of cattle in terms of a number of key abiotic indicators, including nutrient inputs, in-stream suspended sediment, river bank destabilisation and terrestrial soil erodibility
- To link short-term, reach-scale effects resulting from cattle activity to potential, catchment-scale, long-term changes in geomorphology, hydrology, biology and ecology
- To identify areas of potential future research

Through these aims and objectives it is hoped that a number of outcomes will be achieved:

- An improved understanding of the mechanisms that drive cattle activity within chalk stream environments
- An improved, quantitative, scientific understanding of the effects of cattle in chalk stream environments
- A better-informed, objective, scientific basis for future management decisions concerning chalk stream environments

## **1.5. Thesis outline**

This chapter (**Chapter 1**) introduces the thesis topic and considers the reasons to conduct research into the effects of cattle grazing in chalk streams. The aims and objectives of study are presented, as well as the thesis outline, detailing the content of this document.

**Chapter 2** marks the beginning of the ‘literature review’ element of the thesis, providing an introduction to English chalk streams discussing: what they are, where they are, why they are important, their history and their future.

**Chapter 3** focusses upon cattle. A brief history of English cattle and some statistics pertinent to contemporary cattle distributions are presented. The three main effects of cattle grazing (herbivory, animal transit and excretion) upon geomorphology, hydrology and ecology are discussed. Thereafter, the potential ethological controls on grazing effects are debated before our existing knowledge base with respect to cattle grazing in rivers, and chalk streams specifically, is presented.

**Chapter 4** contains a number of theories and hypotheses as to how cattle might interact with chalk streams and how the subsequent effects of that interaction may manifest. Drivers of cattle behaviour in chalk stream environments are considered before the

potential effects of cattle grazing are discussed. The points put forward are then framed in the context of ecological windows.

**Chapter 5** reviews the existing methodologies that have previously been employed to monitor cattle behaviour and assess their geomorphic and ecological impact.

Observational and GPS studies of cattle behaviour are discussed first. Studies dealing with the effects of cattle grazing upon abiotic and biotic components of ecosystems are then considered. Finally, existing studies involving computer and conceptual modelling are presented.

**Chapter 6** is the first of two results chapters containing empirically gathered primary data. Focusing upon cattle behaviour and the drivers of cattle-river interaction, the chapter contains two studies conducted within chalk stream environments: a manual observation study and a GPS cattle collar study. Methods, analysis, results, discussion and conclusions from a 500 hour observational study into cattle behaviour in chalk stream environments (Bond *et al.*, 2012) are presented. A study monitoring cattle behaviour in chalk streams remotely using GPS cattle collars is also presented.

**Chapter 7** incorporates a number of empirical studies undertaken to improve our understanding of the effects of cattle grazing in chalk streams. Chemical analysis of bovine faecal matter is undertaken to establish the total contribution from allochthonous organic matter to nutrient loading. The effects of cattle grazing upon soil shear stress are assessed using a cohesive strength meter. Terrestrial laser scanning is used to quantify cattle-induced river bank destabilisation over time. In-stream sensors are used to measure instantaneous changes in water quality resulting from cattle river crossing events. Other data from in-stream telemetry, low-altitude aerial photography and anecdotal observations are also presented.

**Chapter 8** deals with the modelling component of the study using the SCIMAP diffuse pollution and fine sediment connectivity model. Outputs from this model, as well as a discussion of their application in this context, are discussed.



**Chapter 9** is the concluding chapter. The key elements and conclusion of each previous chapter are revisited. Potential avenues for future research and the contribution of the thesis to science are discussed.

## **2. Chalk streams**

### **2.1. Introduction**

Whilst much has been written about the importance of chalk streams within the river management literature, relatively little has been written about their character.

Nonetheless, work by Raven *et al.* (1998), Sear *et al.* (1999), Mainstone (1999) and Smith *et al.* (2003) can be supplemented with river-specific studies (e.g. Sear *et al.*, 2005) to provide a good definition of the geomorphic and ecological characteristics of chalk streams.

### **2.2. What is a chalk stream?**

Chalk streams have a number of defining characteristics. The most important of these is their Cretaceous upper chalk geology and groundwater dominated flow regimes (Berrie, 1992; Raven *et al.* (1998); Smith *et al.* (2003). Any river whose base-flow index (BFI: the volume of river flow derived from groundwater aquifers) exceeds 75%, and whose course runs over chalk geology, can be classified as a chalk stream (Smith *et al.*, 2003)

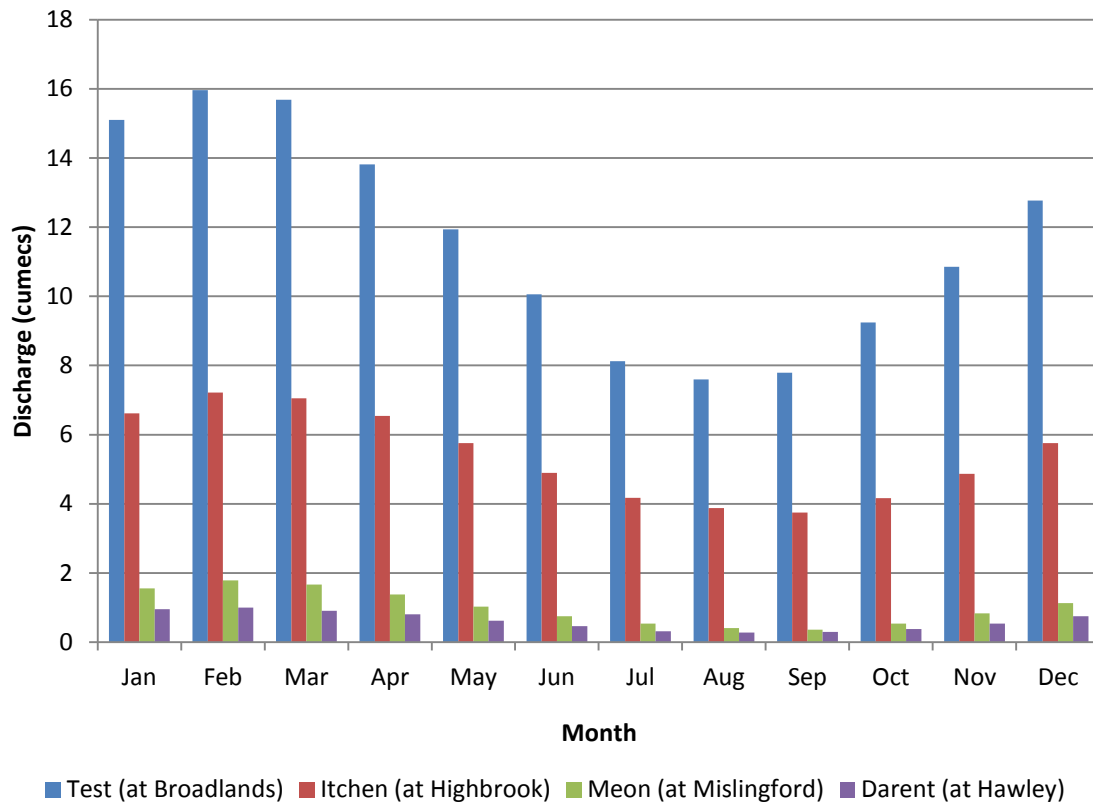


**Figure 2.1. Average monthly discharge for a selection of English chalk streams for the period 1960-2000 (NRFA, 2012).**

The chalk geology controls many geomorphic and hydrologic characteristics of chalk stream catchments, which are characterised by stable planforms, low stream densities, and clear, alkaline waters (UKBAP, 1995; Sear *et al.*, 1999). At the catchment scale, permeable rocks and soils have a high infiltration capacity, leading to dampened flood hydrographs, few tributaries and low connectivity with the landscape (Figure 2.2; 546)Raven *et al.*, 1998). At the reach scale, upstream headwaters (winterbournes) may experience a naturally dry period of low flows at the end of summer and the water table may fall because of insufficient precipitation inputs into chalk aquifers (Raven *et al.*, 1998; Smith *et al.*, 2003). In downstream reaches swallow-holes may exist in to which chalk streams may disappear, only to emerge further down the watercourse; this can cause variable flow rates Smith *et al.* (2003).

## Chalk streams

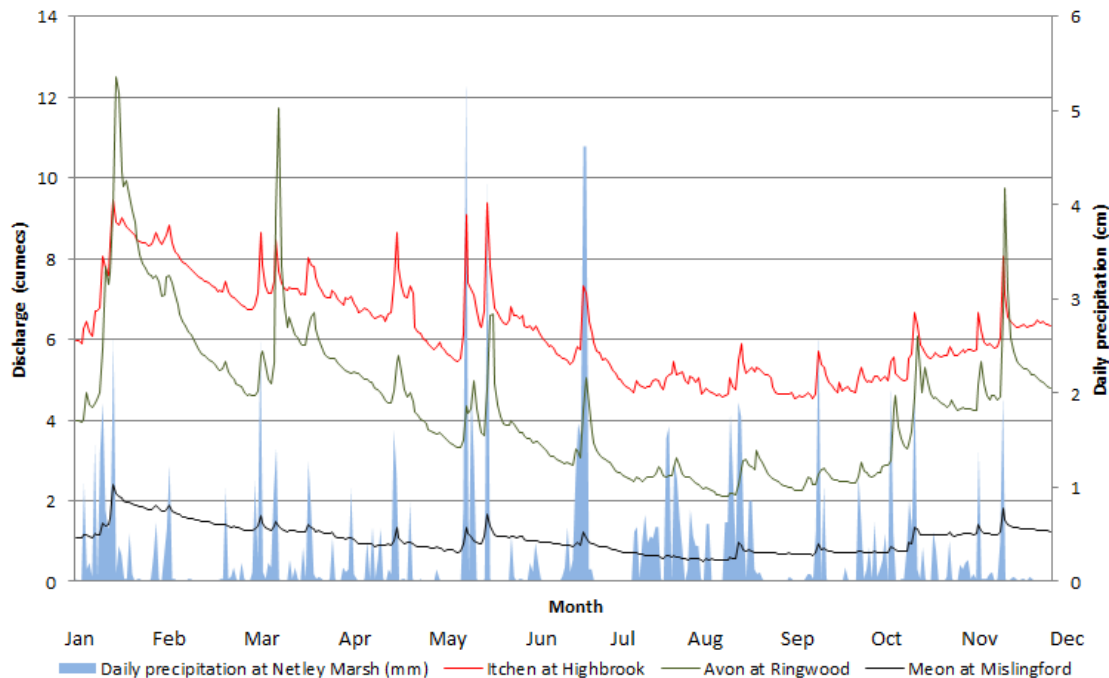


**Figure 2.2. Hydrographs for three different rivers in southern England. Rainfall data from Netley Marsh (New Forest) is provided. Note the relatively strong response of the River Avon (mixed chalk geology) to rainfall compared to the River Itchen (large chalk stream) and the River Meon (classic chalk stream).**

Natural chalk streams also have relatively low suspended sediment concentrations, high water clarity and comparatively stable thermal regimes (Mackey and Berrie, 1991; Sear *et al.*, 1999; Webb and Zhang, 1999; Heywood and Walling, 2003: Figure 2.3). The shallow gradient and attenuated flood peaks of chalk streams limit their stream power and competence, with a resultant absence of coarse gravel sedimentological features (Acornley and Sear, 1999; Sear *et al.*, 1999; Heywood and Walling, 2003).

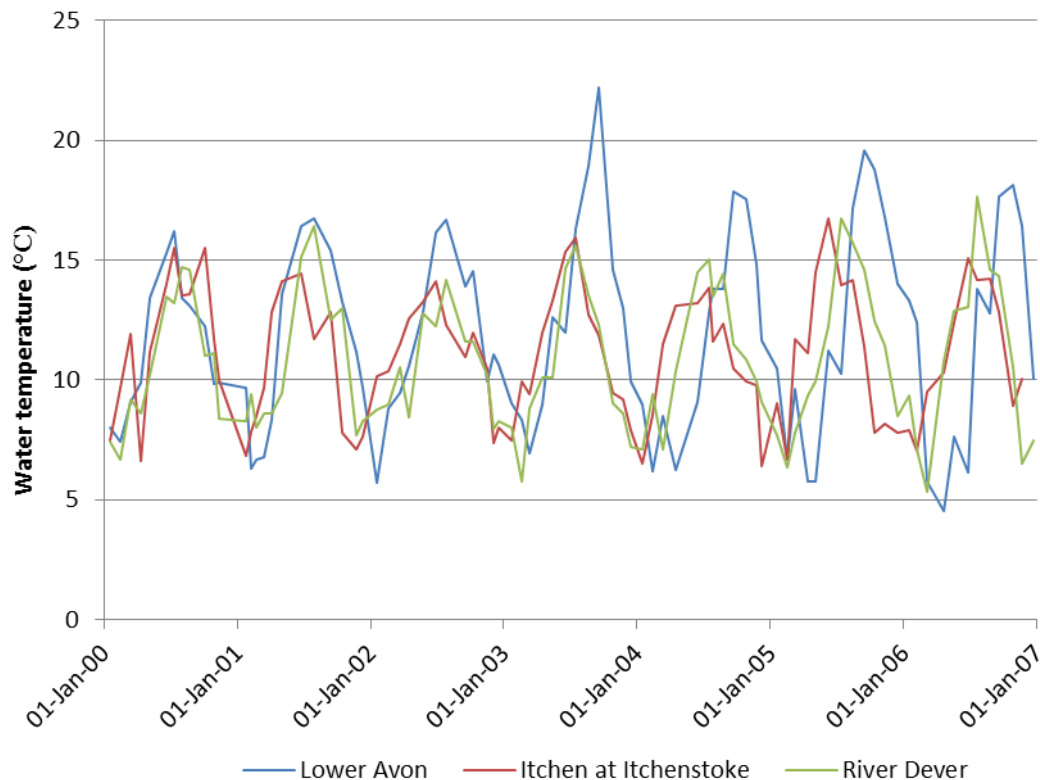


**Figure 2.3. The seasonal range in water temperature in classic chalk streams (i.e. the River Itchen at Itchen Stoke and the River Dever) is generally lower than non-groundwater fed or mixed chalk geology rivers (i.e. the Lower Avon). Data from the Environment Agency’s Freshwater Temperature Archive.**

Large chalk streams are instead characterised by high width to depth ratios, long periods of high flows (bankfull or near bankfull) and gravel beds that experience relatively little bedload transport (Acornley and Sear, 1999; Sear *et al.*, 1999; Sear *et al.*, 2003). Fast flows exceeding  $0.1\text{ms}^{-1}$  are common, especially in 3<sup>rd</sup> order or greater streams, and these maintain a clean gravel-pebble substrate (Raven *et al.*, 1998; Smith *et al.*, 2003; Figure 2.4). Water temperatures are generally stable and warm, water clarity and light availability are high, and consequentially productivity is also high (Berrie, 1992; Mainstone *et al.*, 1999; Sear *et al.*, 1999).



**Figure 2.4. A typical chalk stream gravel bed (the River Itchen at Winnall Moors). Note the water clarity and shallow flow.**

With few tributaries and rare overbank flows, chalk stream surface waters can be relatively poorly connected to their catchments, both laterally and longitudinally (Demars and Harper, 2005; Lapworth *et al.*, 2009). Because sediment inputs from hillslope processes and other natural agency are minimal, any activities that increase fine sediment supply are relatively important compared to river catchments with high connectivity (Raven *et al.*, 1998; Mainstone, 1999; Collins and Davison, 2009).

In the absence of an active gravel supply or other large, mobile sediment, geomorphic features, such as pool-riffle sequences, are created naturally in chalk streams by woody debris (Sear *et al.*, 1999; German and Sear, 2003; Environment Agency, 2009). Woody debris is derived from overhanging trees at the riparian margin, the species of which may

### *Chalk streams*

include, amongst others, willow, alder and occasionally oak (Raven *et al.*, 1998; Smith *et al.*, 2003).

All of these defining features come together to produce the perhaps the most valuable characteristic of chalk streams: high ecological diversity, both in-stream and within the riparian zone. Naturally occurring macrophyte species such as common water-starwort (*Callitriche stagnalis*) and common water-crowfoot (*Ranunculus aquatilis*) grow well in the fast-flowing waters found in chalk streams (Berrie, 1992; Environment Agency, 2004). These and other macrophytes provide cover for numerous macroinvertebrates during their larval stage (e.g. dragonflies and damselflies), as well as providing food for beetles and water voles (*Arvicola terrestris*: (Whitehead, 1935; Natural England, 2008; Tindall, 2009), and acting as a silt-sediment retention trap (Wharton *et al.*, 2006). A wide range of fish species are also found in chalk streams, most notably brown trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*) but also grayling (*Thymallus thymallus*), brook lamprey (*Lampetra* spp.) and bullhead (*Cottus gobio*: Mann *et al.*, 1989; Environment Agency, 2004). Otters may reside within chalk streams, whilst bird species such as lapwing (*Vanellus vanellus*), snipe (*Gallinago gallinago*) and redshank (*Tringa tetanus*) can be found in surrounding floodplain wetlands (Environment Agency, 2004; RSPB, 2009).

| Species                                           | Habitat                                                                             | IUCN listing    | Threats                                                                      |
|---------------------------------------------------|-------------------------------------------------------------------------------------|-----------------|------------------------------------------------------------------------------|
| <b>Plants</b>                                     |                                                                                     |                 |                                                                              |
| Ranunculus peltatus (Pond-Water crowfoot)         | Fast flowing, deep water; stable bed substrate                                      | Least Concern   | Drought, low flows; weed cutting                                             |
| Ranunculus penicillatus (Stream-Water crowfoot)   | Fast flowing, deep water; stable bed substrate                                      | Least Concern   | Drought, low flows; weed cutting                                             |
| Ranunculus fluitans (River-Water crowfoot)        | Fast flowing, deep water; stable bed substrate                                      | Least Concern   | Drought, low flows; weed cutting                                             |
| Oenanthe fluviatilis (River-Water dropwort)       | Slow or sluggish water; stable bed substrate                                        | Near Threatened | Habitat loss; navigation                                                     |
| <b>Invertebrates</b>                              |                                                                                     |                 |                                                                              |
| Austropotamobius pallipes (White-Clawed Crayfish) | Well oxygenated, low turbidity flow; wood , substrate or sediment providing shelter | Endangered      | Invasive species; dredging; water pollution; river management; fine sediment |
| Oulimnius troglodytes (riffle beetle)             | Well oxygenated water                                                               | Not Evaluated   | Low flows; riffle removal                                                    |
| Riolus cupreus (aquatic beetle)                   | Riffles; fast flowing water; not dependent upon in-                                 | Not Evaluated   | Low flows; riffle removal                                                    |



## Chalk streams

|                                              |                                                                                     |                 |                                                                                  |
|----------------------------------------------|-------------------------------------------------------------------------------------|-----------------|----------------------------------------------------------------------------------|
|                                              | stream vegetation                                                                   |                 |                                                                                  |
| Riolus subviolaceus<br>(aquatic beetle)      | Riffles; fast flowing water;<br>not dependent upon in-<br>stream vegetation         | Not Evaluated   | Low flows; riffle removal                                                        |
| Agabus Biguttatus (aquatic<br>beetle)        | Riffles; fast flowing water;<br>not dependent upon in-<br>stream vegetation         | Not Evaluated   | Low flows; riffle removal                                                        |
| Metatype fragilis<br>(caddisfly)             | Highly calcareous<br>environments; cold, flowing<br>water                           | Not Evaluated   | Increased sedimentation; habitat disturbance;<br>predation                       |
| Ylodes conspersus<br>(caddisfly)             | Highly calcareous<br>environments; cold, flowing<br>water                           | Not Evaluated   | Increased sedimentation; habitat disturbance;<br>predation                       |
| Baetis atrebatinus (mayfly)                  | Calcareous waters; marginal<br>plants                                               | Not Evaluated   | Acidification; water pollution; low flows; wetland<br>drainage; channel blockage |
| Paraleptophlebia weneri<br>(mayfly)          | Calcareous waters; marginal<br>plants                                               | Not Evaluated   | Acidification; water pollution; low flows; wetland<br>drainage; channel blockage |
| Coenagrion mercurial<br>(Southern Damselfly) | Unshaded, permanently<br>flowing channels; abundant<br>marginal aquatic vegetation; | Near Threatened | Drought; habitat loss; water pollution; mowing                                   |

## Chalk streams

|                                                   |                                                                                  |                                          |                                                                                                                          |
|---------------------------------------------------|----------------------------------------------------------------------------------|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
|                                                   | silt channel substrate;<br>berms; in-stream emergent<br>dicot; bankside monocots |                                          |                                                                                                                          |
| Valvata macrostoma (Large<br>Mouthed Valve snail) | Ditches (ideally moderately<br>grazed by cattle); high water<br>quality          | Least Concern                            | Pollution; water quality                                                                                                 |
| Vertigo moulinsiana<br>(Desmoulins's Whorl snail) | Wetland habitats; emergent<br>vegetation                                         | Lower Risk:<br>Conservation<br>Dependent | Pollution; habitat loss; climate change                                                                                  |
| Pisidium tenuilineatum<br>(Freshwater pea mussel) | Fast flow; clear substrate                                                       | Not Evaluated                            | Water pollution; fine sediment                                                                                           |
| <b>Fish</b>                                       |                                                                                  |                                          |                                                                                                                          |
| Salmo salar (Atlantic<br>salmon)                  |                                                                                  | Lower Risk:<br>Least Concern             | Fine sediment; organic material; pesticides,<br>herbicides; drought; weed cutting; climate change;<br>effluent discharge |
| Cottus gobio (Bullhead)                           |                                                                                  | Least Concern                            | Water pollution; low flows                                                                                               |
| Lampetra planeria (Brook<br>lamprey)              |                                                                                  | Not Evaluated                            | Water pollution                                                                                                          |
| Lampetra fluviatilis (River<br>lamprey)           | Strong-currents; estuaries;<br>coastal waters; detritus-rich                     | Least Concern                            | Water pollution                                                                                                          |

## *Chalk streams*

|                                    |                                                                                                         |               |                                                                                                                                     |
|------------------------------------|---------------------------------------------------------------------------------------------------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------|
|                                    | sediments                                                                                               |               |                                                                                                                                     |
| Petromyzon marinus (Sea lamprey)   | Spawns in strong-currents; detritus-rich sediments                                                      | Least Concern | Water pollution                                                                                                                     |
| Cobitis taenia (Spined loach)      | Dense vegetation for spawning; sand or silt bed substrate                                               | Least Concern | None known                                                                                                                          |
| Thymallus thymallus (Grayling)     | Well-oxygenated, cold, fast flowing water; spawns in shallows and riffles with a clean gravel substrate | Least Concern | Predatory birds, pollution, dam construction, climate change, river regulation                                                      |
| <b>Birds</b>                       |                                                                                                         |               |                                                                                                                                     |
| Alcedo atthis (Common kingfisher)  |                                                                                                         | Least Concern | Bioaccumulation                                                                                                                     |
| Cettia cetti (Cetti's warbler)     |                                                                                                         | Least Concern | Habitat destruction; climate change                                                                                                 |
| Cygnus columbianus (Bewick's swan) | Wetlands                                                                                                | Least Concern | Loss of wetland habitat due to drainage; cessation of wetland management and grazing leading to scrub overgrowth; mowing of meadows |
| Tringa ochropus (Gren sandpiper)   | Wetlands, ditches, marshes, water meadows, alder                                                        | Least Concern | Avian influenza                                                                                                                     |

## Chalk streams

|                                        |                                                                                                                                                      |               |                                                                                                                                 |
|----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|---------------------------------------------------------------------------------------------------------------------------------|
| Emberiza schoeniclus<br>(Reed bunting) | woodland                                                                                                                                             | Least Concern | Pesticides; fertiliser; habitat loss                                                                                            |
| Rallus aquaticus (Water rail)          | Muddy ground; shallow, slow-flowing water; dense riparian, submerged, emergent or aquatic vegetation; reeds; a combination of dry and wet conditions | Least Concern | None known                                                                                                                      |
| Vanellus vanellus (Northern lapwing)   | Wet natural grassland, water meadows; short sward height; areas of bare soil; a combination of dry and wet conditions                                | Least Concern | Wetland drainage; land-use intensification; scrub overgrowth; predation of eggs by small mammals, particularly invasive species |
| Gallinago gallinago<br>(Common snipe)  | Grassy riparian margins; dry ground for nesting; grazed land; rushes and purple-moor grass                                                           | Least Concern | Wetland drainage and grassland improvement; land-management practices; avian influenza; reed bed mowing and peat extraction     |
| Tringa totanus (Common                 | Wetland grasses; short                                                                                                                               | Least Concern | Agricultural intensification; wetland drainage;                                                                                 |

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## Chalk streams

|                                          |                                                                                                  |                 |                                                                                                                                                    |
|------------------------------------------|--------------------------------------------------------------------------------------------------|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| redshank)                                | sward height; water meadows; grazed land                                                         |                 | flood control; afforestation; avian influenza; predation by invasive species                                                                       |
| <b>Mammals</b>                           |                                                                                                  |                 |                                                                                                                                                    |
| Lutra lutra (Eurasian otter)             | Riparian vegetation; cavities or holes within river banks; linear aquatic-terrestrial transition | Near Threatened | Channelisation; riparian vegetation removal; dam construction; wetland drainage, aquaculture; pollution                                            |
| Arvicola amphibius (European water vole) | Steep river banks; lush grass                                                                    | Least Concern   | Habitat loss; water pollution; predation by and competition with invasive species                                                                  |
| Neomys fodiens (Eurasian water shrew)    | Wetland habitats and marshes                                                                     | Least Concern   | Loss of wetland habitat due to drainage and conversion to agricultural land; water pollution; removal of natural vegetation from the riparian zone |
| Myotis daubentonii (Daubenton's bat)     | Reliant on water sources for prey; tree hollows; caves; buildings                                | Least Concern   | Water quality; loss of roost sites                                                                                                                 |

**Table 2.1. Designated priority species found within chalk streams. A comprehensive list of these species English and European vulnerability classifications can be found in Mainstone, 1999, Table 3.1 (Clapham *et al.*, 1957; Hardisty and Potter, 1971; Haslam, 1978; Mainstone, 1999; Preston *et al.*, 2002; Rouquette and Thompson, 2005; Boudot, 2006; Milisa *et al.*, 2006; Strachan and Moorhouse (2006); Freyhof, 2008; Freyhof and Kottelat, 2008; Birdlife International, 2009; Schowalter, 2009; Füreder *et al.*, 2010; Freyhof, 2011; Kemp *et al.*, 2011).**

These ecological parameters are so well established and widely accepted that some institutions and scientists use the presence of archetypal chalk stream species for river classification, even when human intervention may have modified the functionality of a non-chalk stream to replicate a chalk stream (Smith *et al.*, 2003).

### 2.3. Chalk stream classification

Beyond the broad definition of what constitutes a chalk streams, there are five specific classifications of chalk stream, as identified by Mainstone (1999) and Smith *et al.* (2003; Figure 2.5)

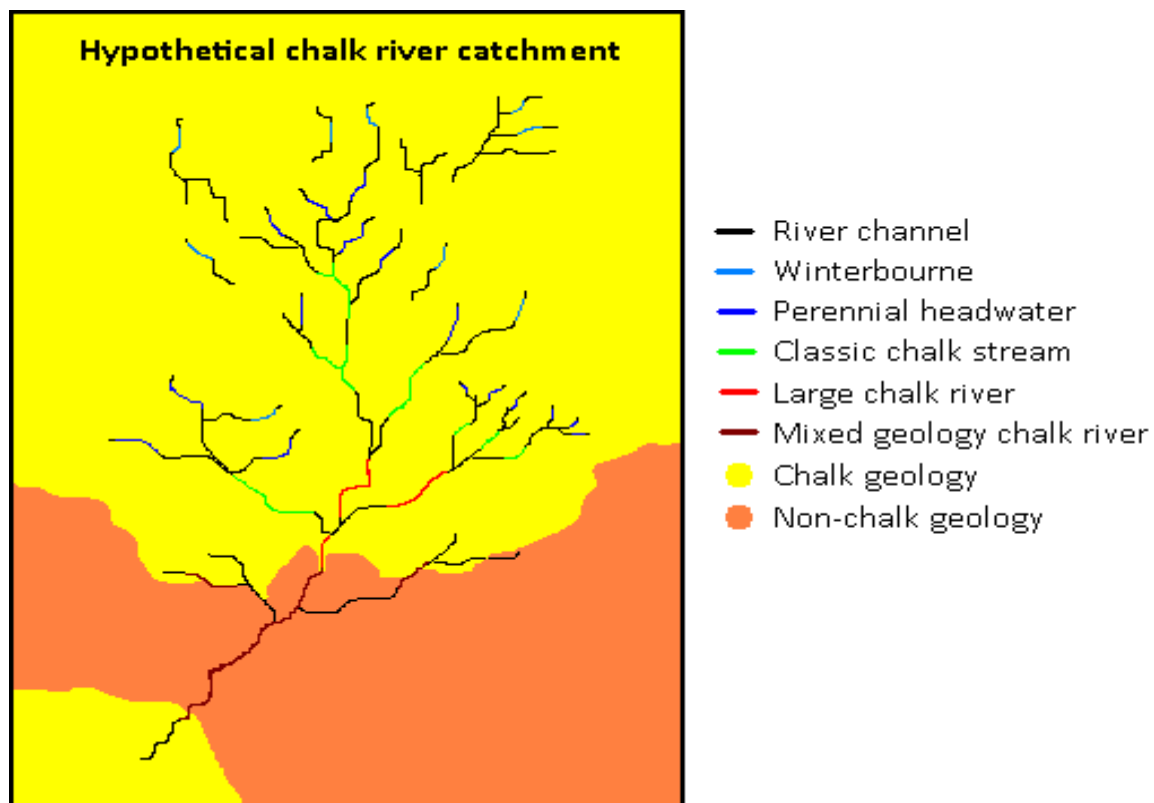


**Figure 2.5. A hypothetical chalk stream catchment, showing the location and relative positions of different types of chalk stream.**

Winterbournes are those chalk streams that experience a natural, annual dry period (Mainstone, 1999). They are typically found in the upper reaches of chalk stream catchments, and occur due to the exhaustion of rainwater held in chalk aquifers; when the

## *Chalk streams*

water table falls below the level of the stream bed, during the summer months, river flow ceases (Smith *et al.*, 2003). Examples include Nailbourne, a tributary of the River Stour in Kent, and South Winterbourne, a tributary of the River Frome in Dorset.

Perennial headwaters are largely permanent first order streams that occur in the upper reaches of chalk stream catchments (Mainstone, 1999). Unlike winterbournes, perennial headwaters are fed by relatively reliable, static springs, and rarely experience a cessation in flow (Smith *et al.*, 2003). Most chalk streams have perennial headwaters, including parts of the River Anton and River Dever in Hampshire, both tributaries of the River Test.

Classic chalk streams usually occur in the mid-reaches of a chalk stream catchment, with stream orders greater than one but less than four, comparatively fast, perennial flow ( $>0.1\text{ms}^{-1}$ ), and channel widths typically no greater than 10m (Mainstone, 1999; Smith *et al.*, 2003). The river Wylfe in Wiltshire could be classified as classic chalk stream for much of its course.

Large chalk streams are similar to classic chalk streams, only larger (generally wider than 10m), with chalk constituting more than 80% of their underlying geology (Mainstone, 1999; Smith *et al.*, 2003). Significant parts of some of the best known chalk streams are of this classification, including the middle reaches of the river's Test, Itchen and Meon in Hampshire.

Mixed geology chalk streams, such as the River Avon, derive a significant part of their flow from areas that are underlain with non-chalk geology (Mainstone, 1999). Channel morphology, bed substrate, water quality and flood hydrographs are likely to be more variable in such systems, relative to the previously discussed large chalk streams (Smith *et al.*, 2003).

## **2.4. Where are the chalk streams in the UK?**

According to the Environment Agency (2004) there are 161 chalk streams in the UK, all in England, spanning from the River Hull in Humberside to the River Frome in Dorset (Figure 2.6). Their distribution is determined by the presence of underlying chalk formed during the Upper Cretaceous approximately 100-65 million years ago (Raven *et al.*, 1998; Brechly and Rawson, 2006).



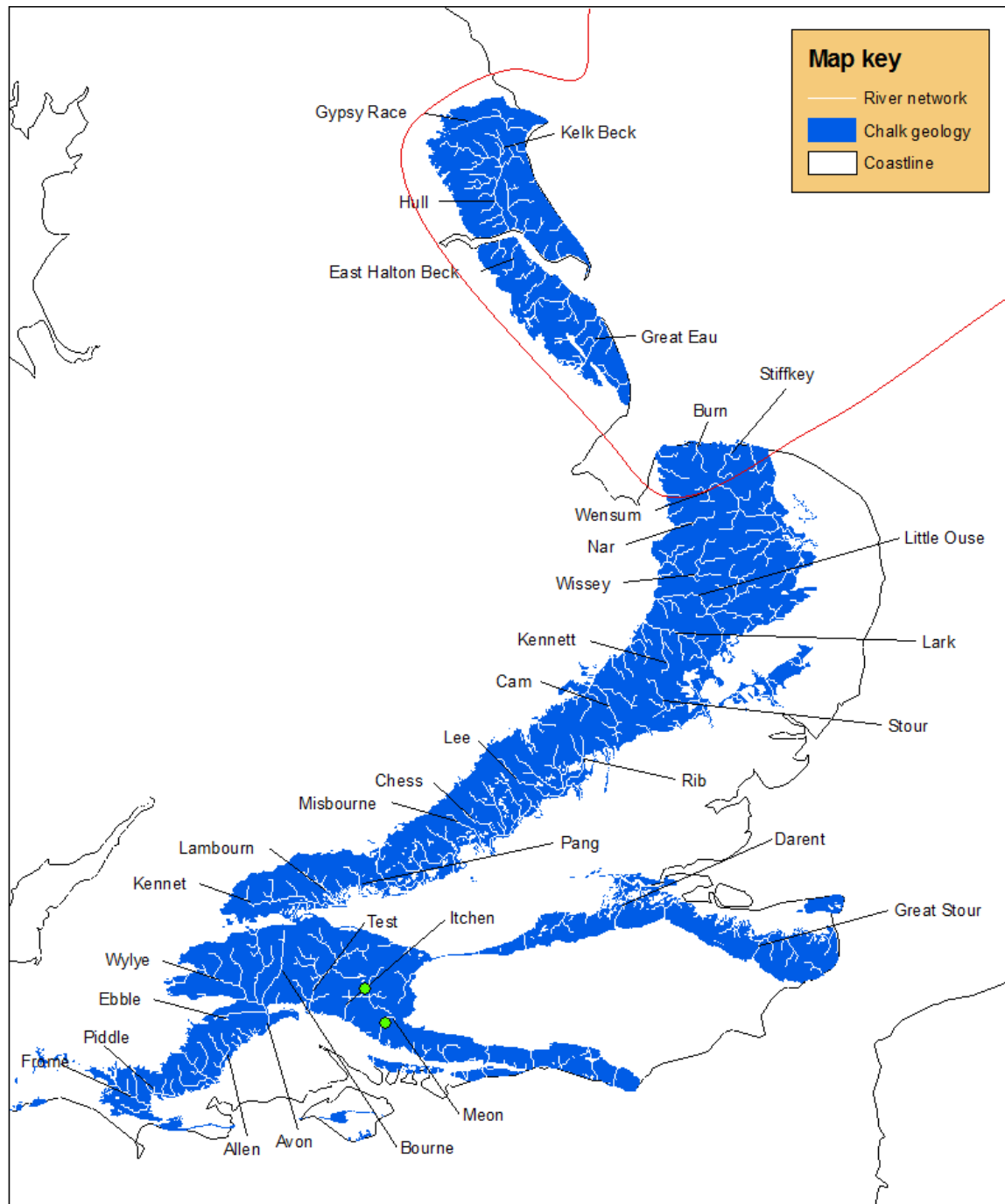


**Figure 2.6. A map of England's chalk stream network. A number of individual rivers are highlighted. The red line marks the maximum extent of the British and Irish Ice Sheet at the time of the last glaciation. Our study sites on the Cheriton stream at Tichborne and on the River Meon at Droxford are shown in green.**

## 2.5. Chalk stream history

Understanding the evolutionary history of England's chalk streams is important in establishing reference conditions for conservation management (Mainstone, 1999). However, establishing an accurate palaeogeographical narrative is difficult. Since the end of the Last Glacial Maximum there have been significant climatic, eustatic and isostatic changes across the British Isles (Fretwell *et al.*, 2008; Gehrels, 2009). These changes induced ecological changes in plant and animal density, distribution and species composition, which in-turn feedback to partly determine river characteristics (Lister and Stuart, 2008; Johnson, 2009). Additionally, throughout the second-half of the Holocene, and particularly over the past 400 years, humans have greatly modified the rivers of lowland England (Sear *et al.*, 1999; Smith *et al.*, 2003; Bates *et al.*, 2008). Consequently, many naturally low-energy chalk streams have been altered significantly over the past several thousand years. What is more, although there are some identifiable widespread events, many chalk stream valleys exhibit a unique local history whose detail is dependent upon location and anthropogenic forcing (Petts and Amoros, 1996; French *et al.*, 2005). Hence, although attempts have been made at developing a conceptual model for chalk stream habitat and landscape change (e.g. German and Sear, 2003), the complex history of these ecosystems devalues model usefulness when applied generically (Sear and Arnell, 2006).

### 2.5.1. Natural environmental change

One of the major difficulties in establishing a universally applicable conceptual model of chalk stream channel evolution is temporal scale. Because the landscape of the UK has changed over the course of the Quaternary, as a consequence of climate change and glacial-interglacial cycles, determining a reference condition for chalk streams is a challenging process. Although it is logical to consider the history of chalk stream channel evolution from the beginning of the most recent interglacial, it is important to remember the role of geological and geomorphic changes that occurred before this time in determining historic and current form and process (Kilner *et al.*, 2005; Gao, 2006)

2.5.1.1. *Glacial and inter-glacial cycles*

Alongside consideration of the temporal scale over which chalk streams in the UK have been affected is consideration of the spatial scale. With respect to glacial-interglacial cycles, different parts of the UK have been subject to different glacial, glacio-fluvial and glacio-eustatic processes over the Quaternary (Bell and Walker, 2005). Specifically, England's northern chalk landscape (in Yorkshire, Lincolnshire and Norfolk) was glaciated during the Devensian whilst the south was not (Sear *et al.*, 1999; Sejrup *et al.*, 2009). Consequently, northern chalk landscapes were subject to sub-glacial processes such as fracturing, and contemporary northern chalk stream catchments contain sub-glacial deposits including clay tills (Marks *et al.*, 2004). Conversely, southern chalk landscapes were subject to peri-glacial and pro-glacial processes such as outwash flows, and hence contain pro-glacial deposits (Brand *et al.*, 2002). Valley gravels, which now act as bed substrate and provide an essential habitat for a number of archetypal chalk stream species, were also deposited during this period (Prestwich, 1891; Sparks, 1957; Berrie, 1992).

The glaciation was also responsible for the formation of dry valleys; chalk valleys through which prehistoric rivers used to travel but that no longer maintain surface flows (Chandler, 1909; Morgan, 1971; Ballantyne and Harris, 1994). Today these features occur across large parts of southern England, representing an important component of the country's cultural and landscape history (Reid, 1887; Small, 1964).

A complex terrestrial landscape history in chalkland England was modified further by relative sea-level rise. Ice-sheet degeneration at the end of the Devensian stadial led to large freshwater inputs into the world's oceans, with a resultant rise in global sea-level (Church *et al.*, 2001; Clark *et al.*, 2009). At the same time, regional isostatic crustal readjustment was initiated, with southern England beginning to return to its former tectonic position following the decline of the BIIS ice mass; this process continues today (Lambeck, 1991; Lambeck, 1993). Consequently, chalk stream valleys proximate to the

coast were further modified by marine incursions, with evidence from alternating freshwater-marine deposits in chalkland stratigraphy (Sear *et al.*, 2005).

### 2.5.1.2. Vegetation history

Climate change throughout the Quaternary period also affected ecology, with knock-on effects for chalk stream morphology. The glacial and peri-glacial conditions that existed during the Devensian inhibited the survival of many plant and animals species (Brenchly and Rawson, 2006). As a result, many such plants and animals retreated to suitable refugia in continental Europe before gradually migrating northwards during the early Holocene as climate ameliorated (Deacon, 1974; Lister and Stuart, 2008). This was particularly true of trees, whose rate of return and eventual distribution following global warming was dependent upon seed dispersal strategy, natural ecological processes (the role of competition, succession and . quality) and proximity to waterways (Godwin, 1975; West, 1977; West, 1980; Huntley and Birks, 1983). These controls led to a dominance of wind-dispersed *Betula* (birch) across much of England in the early Holocene (West, 1980). Thereafter, birch trees were joined by taller *Pinus* (pine) and the first broad-leaved, shading tree species, *Corylus* (hazel: Deacon, 1974; West, 1980). *Quercus* (oak), *Ulmus* (elm) and *Tilia* (lime) established during the Mesolithic, after which hazel declined and *Alnus* (alder) became dominant (West, 1980). By the Neolithic, and before the first significant human impact, the predominant vegetation cover across much of England was mixed broad-leaved deciduous forest; oak and alder were the dominant species with small communities of lime trees existing where soils conditions were appropriate (West, 1980). Although few studies have considered the vegetation present in chalk stream valleys at this time, it is likely to have been similar to the rest of England, with *Salix* (willow) species inhabiting riparian margins alongside oak and alder (Parker *et al.*, 2008a).

It is important to note that the aforementioned ecological landscape history is a generic one. This history is constructed from an assemblage of discrete palaeoecological records whose pollen and macrofossils can at best provide a local or regional perspective. This is especially true of the chalk downlands of the south-east of England, where relatively few,

spatially distinct, comparatively poorly dated, low temporal resolution sequences are found (Allen, 2007). Consequently, it is not possible to say with certainty that lowland England was entirely densely forested prior to human impact, or what effect this might have had upon chalk stream characteristics. For example, in many records from across Britain and Central Europe, the boreal phase of the Mesolithic is characterised by evidence of fire and tree decline. Whilst historically (Hazzledine-Warren *et al.*, 1933) and more recently (Brown, 1997) this has been taken as evidence of pioneering agriculturalists clearing areas to grow crops, it may instead be attributable to natural agency in the form of lightning strikes (Mighall *et al.*, 2008).

Regardless of the cause, the presence of the Mesolithic fire horizon suggests a more complex vegetation narrative than that chronicled previously in this document so far. It is not, however, the only point of debate in the discussion of pre-human Holocene vegetation (and therefore landscape) history. The Vera Hypothesis, as it has been referred to in the literature (e.g. Sazbó, 2009), is drawn from F. M. W. Vera's title *Grazing Ecology and Forest History*, in which it is proposed that Europe's (including lowland England's) post-glacial, pre-human vegetation cover was a park-like mosaic of open woodland and grassland clearances maintained by large, mammalian, ungulate herbivores (Vera, 2001). The model, which relies heavily upon palynological evidence from Holland, remains a point of contention (see Hodder and Bullock [2005] for a summary of the debate). Indeed, the vigour with which the veracity of this hypothesis has been disputed is, even in palaeoecological circles, quite extreme; Bulmer (2002, pp. 687 describes the work as "...an outrageous hypothesis..." in his book review, whilst Bradshaw *et al.* (2003) provide a no more conclusive, evidence-based perspective. More recent work by Hall (2008) into habitat utilisation by *Bos primigenius*, the formerly abundant, extinct ancestor of modern cattle, measured a series of spatially variable ecological parameters to establish their preferred habitat. As well as providing evidence in support of the Vera Hypothesis, that areas devoid of woodland were maintained by large herbivores, Hall (2008) also concluded that *Bos primigenius* selected habitats on floodplains and proximate to rivers; the effects of large herbivores upon river channel processes and morphology may have occurred throughout the Holocene.

Both naturally occurring grazing and fire events may have affected vegetation cover prior to human impact. This is relevant to conservation ecologists needing to set reference conditions for restoration, and has ramifications for our understanding of pre-human chalk stream systems. Specifically, whether or not river catchments were partially or heavily vegetated, and whether there were or were not grazing animals present, is likely to have influenced chalk stream morphology (sediment availability, channel width, bank stability) and ecology (competition, stress and disturbance: Grime, 1974; Vera, 2001).

Clearly across much of Europe and chalkland England the prehistoric narrative of landscape change is incomplete or inclusive. Hence, identifying accurate, local reference conditions is difficult. The presence of humans, particularly over the last 5,000 years, exacerbates this problem.

### **2.5.2. The effects of humans**

Human impact throughout the Holocene has led to widespread landscape change across lowland England (Bell, 1982, Brown and Barber, 1985). Although these impacts were initially small-scale and local, over time their cumulative effect was dramatic (Bell and Walker, 2005). Moreover, whilst the legacy of certain human activities, such as deforestation, are obvious today, others are not; Collins *et al.* (2006) note how near the modern day chalk stream Kennet the construction of a wooden bridge over the Thames palaeochannel led to in-stream sedimentation. Furthermore, there were variations in the timing of anthropogenic impact that were determined by local differences in climate, soil quality, resource availability, economic systems and cultural values (Roberts, 1998; Bell and Walker, 2005).

A classic, simplistic history of human-induced land use change in chalkland England shows an increase in forest clearance from the late Neolithic onwards, with a period of small-scale, short-term agricultural clearings in the late Neolithic followed by a period of large-scale, long-term agricultural clearings in the Middle Bronze Age (Scaife, 1980; Scaife, 1982; Green, 2000). Evidence for these phases comes from pollen records, with

the large-scale clearance phase also supported by mollusc fossil evidence and stratigraphic records showing increased tilling, land degradation, soil erosion and colluviation from 4000 years before present onwards (Allen, 1992; Allen, 1994; Allen, 2000). More recent work by French *et al.* (2005) suggests that the start date of detectable human impact in southern chalkland England may be earlier than previous thought, with altered and slowed soil development suggesting anthropogenic exploitation as early as the late Mesolithic.

Throughout the Iron Age, local differences in the palynological record become more apparent, with certain parts of chalkland England experiencing woodland regeneration (e.g. Kingswood valley mire) whilst others experienced increased agricultural activity and forest clearance (e.g. Flitwick Moor: Waton, 1982; Scaife, 2000; Dark, 2006). Local differences in forest cover appear to remain until the end of the Roman occupation of Britain, at which point some sites record a short-lived period of tree regeneration leading up to the Middle Ages (Dark, 2006). During the medieval period, a step-like change is observed in the intensity of deforestation and land clearance across much of the northern, temperate world, including chalkland England (Williams, 2000; Dark, 2006). Flower (1977) notes how even the New Forest, which was established as a managed woodland as early as 1079AD, lost many of its oak trees to the production of Royal Navy ships throughout the Middle Ages (Tubbs, 2001). It is within the Middle Ages that the last substantial clearance of trees across chalkland England occurred, with only small areas of riparian Alder Carr woodland persisting alongside chalk streams by the modern period. Thereafter, many chalk streams in southern England became part of managed water meadows that persisted until the mid-20<sup>th</sup> century (Sear *et al.*, 1999; Sear and Arnell, 2006); Mainstone (1999) and others have suggested that this is the most realistic reference condition for modern day chalk streams.

Water mills, which originated in the Roman period but that existed in large numbers during the Dark Ages (The Domesday Book of 1086 lists approximately 6,000 water mills, with 10,000 by the 14<sup>th</sup> century, according to Langdon, 2004) and beyond, were constructed in chalk stream catchments for the purposes of power-generation and flour

production (The Domesday Book, 1086; Holt, 1988; Watts, 2002). These mills relied upon water being diverted from the main river along multiple man-made channels so that the power generated could be utilised continuously and efficiently (Berrie, 1992; Langdon, 2004). Ecologically, new habitats were created where water was dammed, whilst the diversion of water from the main channel and the creation of additional channels altered stream hydrology (Berrie, 1992, Everard, 2005). Many mills were still in use into the 19<sup>th</sup> century, and although other means of energy production led to their eventual decline, their construction has left a landscape legacy (Watts, 2002).

Another major human influence upon chalk stream environments was their conversion to water meadows (Everard, 2005). Water meadows are river-adjacent, man-made areas of irrigation, most commonly found in downstream floodplain reaches of chalk streams, although they may occur along headwaters and winterbourne sections also (Mainstone, 1999; Everard, 2005: Figure 2.7).



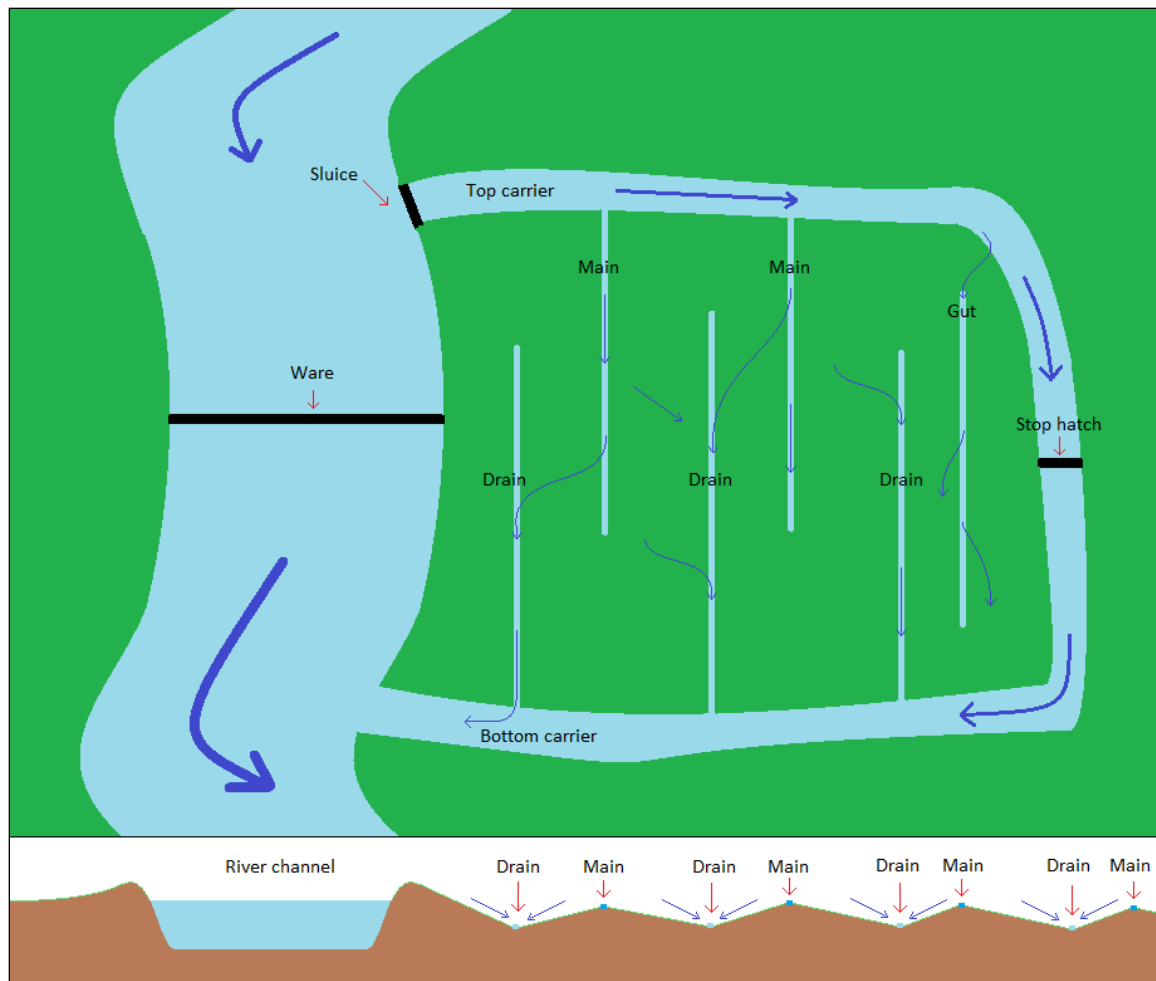


**Figure 2.7. Plan (top) and profile (bottom) sketch of a water meadow. Blue lines indicate water movement; red lines indicate features within the sketch. Water is held back using the ware and diverted into the top carrier. The stop hatch also helps hold back the flow, forcing water into the main carriers. From the main carriers, water flows over and through the soil to the drains, creating a constant trickle of water that prevents frost, enhances grass growth and protects the soil (Everard, 2005).**

Water meadows performed a number of functions that improved the efficiency of husbandry and agricultural practices: enhancing grass production early in the grazing season; reducing the likelihood of frozen soils and subsequent crop failure; and allowing for the production of an early hay crop (Cook *et al.*, 2003; Everard, 2005). These systems were first installed at the beginning in the 16<sup>th</sup> century and were continually managed until the early 1900's, when increasing mechanisation, the widespread use of fertilisers, and the urbanisation of formerly agricultural land, led to their decline (Cook *et al.*, 2003;

Everard, 2005). In more recent times, the perceived value of water meadows has again changed; land and river managers now recognise their ecological and cultural importance (Mainstone, 1999; Everard, 2005). Indeed, not only do water meadows provide ideal habitats for wetland species, but, and as previously mentioned, they are considered as a reference condition for chalk stream restoration (Mainstone, 1999). Resultantly, contemporary management plans often involve the maintenance of these distinctively man-made landscapes and their associated flora and fauna (Mainstone, 1999; Cook and Williamson, 2006).

### **2.5.3. Chalk stream history: examples**

Given the aforementioned spatial and temporal complexity associated with understanding UK chalk stream history, it is often beneficial to conduct river valley specific studies of channel evolution. Two chalk streams that have been considered in this way are the River Nar in Norfolk and the River Kennet in Cambridgeshire.

The historic development of the River Nar Site of Specific Scientific Interest has been chronicled in detail by Silvester (1988) and more recently by Sear *et al.* (2005). Distinct from inland chalk stream valleys, the lower Nar is characterised by alternating freshwater and sea-derived deposits as a consequence of climate driven marine incursions and regressions throughout the Holocene (Sear *et al.*, 2005). Incised fluvial terraces are also apparent and these, alongside alluvial deposits and the previously noted marine deposits, have created a unique lowland river catchment stratigraphy (Silvester, 1988; Sear *et al.*, 2005). With respect to channel evolution, it is probable that the River Nar experienced an almost archetypal transformation from a dynamic, braided river to a relatively stable, single channel meandering river over the course of the last 10,000 years (Sear *et al.*, 2005). The recent history of the Nar is also typical of many chalk streams, with intensive arable farming in the sloped upper catchment and low intensity pastoral grazing in lowland water meadows from the beginning of the modern period until the mid-late 20<sup>th</sup> century (Silvester, 1988; Sear *et al.*, 2005).

In the River Kennet, a tributary of the Thames, hydrological characteristics distinct from the regional signal are apparent during certain phases of the Holocene (Collins *et al.*, 2006). Although the river appears to have had a classic braided planform at the end of the Younger Dryas Stadial, the Kennet displays a comparatively quick transition to an anastomosed river by the beginning of the Holocene (Gibbard and Lewin, 2002; Collins *et al.*, 2006). Thereafter, an even more significant deviation from the model of post-glacial lowland river sedimentation occurs in the Kennet, with an approximate 6000 year period of continuous tufa deposition (Gibbard and Lewin, 2002; Collins *et al.*, 2006). These deposits combined with climatic changes from the mid-Holocene onwards and the onset of deforestation in the Neolithic to establish a meandering planform (Collins *et al.*, 2006). As with the River Nar and many other chalk streams, contemporary land-use in the Kennet was dominated by the grazing of animals in water meadows from the 1600's until the 1930's (Whitehead *et al.*, 2002). Over the past 60 years, land drainage, fertiliser use, dredging, intense arable agriculture, sewage inputs and land-use change in the form of urban expansion have led to further changes in the hydrology and condition of the River Kennet; increased surface run-off, reduced time to peak flow and increased nutrient loading (Whitehead *et al.*, 2002; Neal *et al.*, 2006; Collins *et al.*, 2012).

### **2.5.4. Chalk stream history: summary**

A synthesis of the previously discussed information regarding the history of chalk streams allows for the generation of a generic chalk stream history timeline (Figure 2.8).

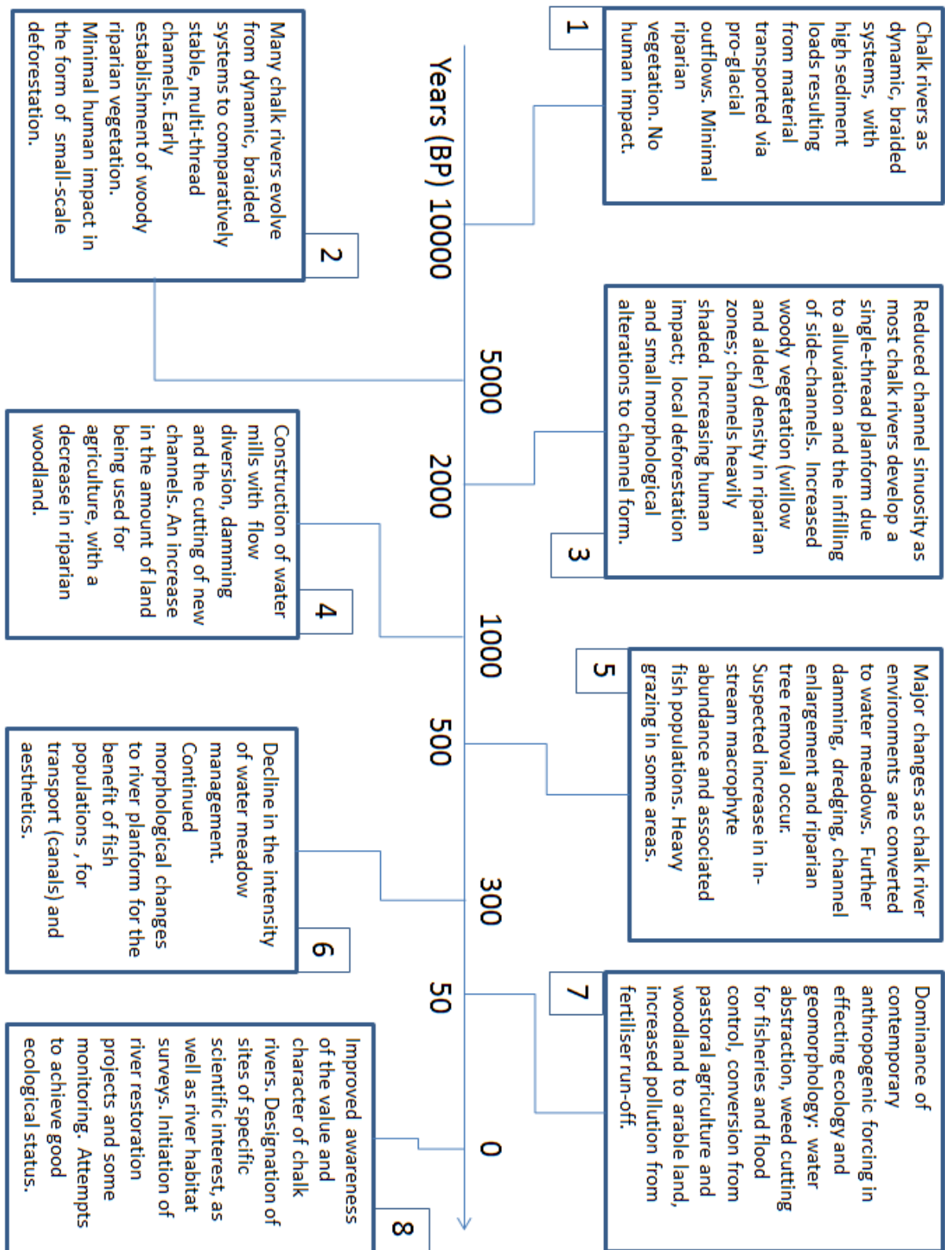


Figure 2.8. Generic chalk stream history timeline (Brown and Keough, 1992; Mainstone, 1999; Gibbard and Lewin, 2002; Smith *et al.*, 2003; Langdon, 2004; Sear *et al.*, 2005; Everard, 2007).

Although there may be some variation in the precise timing and scale of these different events, the general landscape history chronicled above is characteristic of most English chalk streams (Gibbard and Lewin, 2002; Sear *et al.*, 2005; Collins *et al.*, 2006). The natural evolution of river form from a braided to a single-thread meandering channel throughout the Holocene is punctuated by anthropogenically induced changes that began in the Neolithic with small-scale farming and deforestation (Gibbard and Lewin, 2003; Sear *et al.*, 2005). Further human-induced changes occurred; most notably the widespread construction of mills in the Dark Ages and the subsequent conversion of many chalk stream environments to water meadows, beginning in the 16<sup>th</sup> century (Holt, 1988; Sear *et al.*, 2005; Everard, 2007). Shading was reduced due to riparian tree removal, whilst many river courses were altered, with flows diverted and cross-sections modified (deepened and widened; Everard, 2007). Human impact continued in the 19<sup>th</sup> and 20<sup>th</sup> century with a reduction in river water quality due to increased runoff from agricultural and industrial sources, amongst other changes including a higher frequency of low flows due to water abstraction, and further channel modifications for navigation (Mainstone, 1999; Everard, 2007). More recently, some chalk streams have been managed intensely for the benefit of conservation, or in an attempt to return to a former ecological or geomorphological state (Mainstone, 1999).

Unfortunately, and despite the identification of several key periods in the history of English chalk streams, the above timeline offers few boundary conditions whose characteristics are known. Specifically, the ‘natural’ ecological reference point for chalk streams is uncertain. Existing biotic communities are at best a function of water meadow habitats and anthropogenic forcing dating back several hundreds of years, with the removal of riparian shading by humans increasing macrophyte abundance and primary productivity to create the conditions we see today.

But what were chalk streams like prior to human intervention: what is their ‘natural’ condition? Most likely there were more complex river planforms in the absence of channelization and water meadow creation by humans (Gibbard and Lewin, 2003; Sear *et*

*al.*, 2008). Increased channel complexity would also be facilitated by the abundance of woody debris, which would have accumulated in chalk streams not subject to deforestation (Newson and Large, 2006; Sear and Arnell, 2006; Corenbilt *et al.*, 2007). Light penetration to streams would be reduced by the presence of dense riparian vegetation, with a corresponding absence of in-stream macrophytes that characterise contemporary chalk streams (Dawson and Kern-Hansen, 1979; Dawson and Hallow, 1983). This would reduce salmonid fish species populations for two main reasons: reduced food availability due to the inexistence of prey habitats; and reduced shelter for juveniles from potential predators (although this may be offset by the shelter provided by woody debris: Pearson and Jones, 1978; Everett and Ruiz, 1993; Matthews, 1998; Baattrup-Pedersen and Riss, 2004; Kemp *et al.*, 2011).

Whether overall biodiversity would have been greater in prehistoric chalk streams is debatable; the mosaic of man-made, semi-natural and natural reaches that exist within certain chalk catchments, such as the Piddle in Dorset, provide habitats for a large number of species (Stevens, 1999). Whether, in the presence of cattle, as per the Vera Hypothesis (Vera, 2001), or fire events (Mighall *et al.*, 2008), sufficient natural disturbance would have occurred to create habitat and species diversity similar to that observed today is unclear. What is clear is that contemporary chalk stream habitats are some of the most species rich in England, and that this species richness makes chalk streams important.

## 2.6. The importance of chalk streams

The ecological significance of England's chalk streams is internationally recognised. England has the largest number of chalk streams of any European country, with a cumulative length of nearly four thousand kilometres (UKBAP, 1995; Jackson and McLeod, 2000; Lawton *et al.*, 2010). The cultural and economic value of such rivers is also high; water abstraction, irrigation, fisheries management, energy provision and navigation are just some of the demands placed upon chalk streams both historically and today (Environment Agency, 2004; Natural England, 2008). Consequently, the

## Chalk streams

conservation of chalk streams is a key concern for land managers, with ten chalk stream Sites of Special Scientific Interest (SSSI's) and four candidate Special Areas of Conservation (cSAC's) across England (Jackson and McLeod, 2000; Environment Agency, 2004).

Ecological diversity within chalk streams is accommodated by habitat diversity, which in healthy waterways is facilitated by (relict) side channels, clean gravel-pebble substrates, wetland meadows, *Ranunculus* beds, shading, woody debris structures, gravel runs, glides, pools and riffles (Raven *et al.*, 1998; Smith *et al.*, 2003; Environment Agency, 2004). Habitat diversity is especially important for those species that have different habitat optima during different stages of their life-cycle. For example, juvenile Atlantic salmon are thought to prefer shallow riffles because it maximises the effectiveness of their sit-and-wait feeding strategy (Armstrong *et al.*, 2003; Summers *et al.*, 2005). However, when migrating upstream to spawn, adult salmon will opt to travel through deep pools so as to avoid predation and exposure to sunlight (Armstrong *et al.*, 2003); deep pool preference is also seen in adult trout (Lewis, 1969). Consequently, ecosystems in which either habitat component is absent will be sub-optimal for Atlantic salmon.

It is not only salmon species that rely upon variations in flow dynamics to create their preferred life-stage habitat. A study of aquatic insect larvae from the Ardèche River in south-eastern France revealed that habitat suitability varied significantly between six different species (Sagnes *et al.*, 2008). Suitability of a particular hydraulic habitat was also found to change through time, with species accommodating different environments during different growth stages (Sagnes *et al.*, 2008).

The diversity of habitats available within chalk streams and riparian areas is such that this life-cycle specific habitat selection can occur longitudinally (e.g. salmon species spawning upstream but residing in marine environments when adult), vertically (e.g. mayfly larvae inhabiting an aquatic habitat but living predominately in the air as adults), horizontally (e.g. lapwing chicks nesting in the riparian zone but foraging at surface waters when adult), and temporally (e.g. brown trout occupying surface turbulent habitats

during the day but moving to pool habitats at night: Raven *et al.*, 1998; Wright and Symes, 1999; Armstrong *et al.*, 2003; Environment Agency, 2004; Summers *et al.*, 2005). Indeed many species will change habitat through more than one dimension during their lifetime.

## **2.7. Threats to chalk stream sustainability**

Often at odds with the maintenance of habitat diversity is the utilisation of amenities provided by chalk streams. Nearly all chalk streams in England have a long history of human intervention, which is punctuated by contemporary concerns regarding water abstraction, fisheries management, channel modification, land-use change and urbanisation (Mainstone, 1999; Lawton *et al.*, 2010).

In the UK, 55% of all groundwater-abstracted drinking water is sourced from chalk aquifers (Howden *et al.*, 2004). The abstraction of water for human consumption increases the likelihood of low flows in winterbournes during summer (Wright and Berrie, 1987; Smith *et al.*, 2003). Low flows often result in fine sediment deposition and aquatic habitat loss, which is deleterious to submerged macrophytes and spawning fish (Boulton, 2004; Wood and Armitage, 1997). It is thought that low-flow alleviation schemes may assist in recovering winterbourne ecology during a time of both increased human demand for water and reduced precipitation inputs due to climate change (Mainstone, 1999; Environment Agency, 2004).

Fisheries management, both for recreational and commercial purposes, has a number of impacts upon chalk streams. Weed cutting is undertaken to improve unobstructed angling, increase flow velocity (for flood management) and reduce fine sediment trapping (Dawson *et al.*, 1991; Aldridge, 2000). However, indiscriminate weed cutting equates to habitat removal, with the loss of macrophytes, freshwater mussels and common invertebrate species such as the Grannom caddisfly (*Brachycentrus subnubilus*: Pearson and Jones, 1978; Dawson *et al.*, 1991; Riley *et al.*, 2009). The removal of bankside tree to improve access may increase insolation leading to increased macrophyte growth (Larson



and Larson, 1996; Fletcher *et al.* 2000). Macrophytes provide shelter for fish and habitats for macroinvertebrates, which in turn increases the number of prey items available for salmonids (Dawson and Kern-Hansen, 1979; Riley *et al.*, 2009). Such a measure, as with all those previously mentioned, is attempting to maximise fish productivity; as to whether fish populations would be this high in an unmanaged, pre-human intervention, ‘natural’ chalk stream habitat is unclear.

Morphological modification of river form via bed level lowering and dredging for the purposes of flood control, navigation and drainage can have major implications for benthic organisms and their food chain dependents (Harvey and Wallerstein, 2009). Although historically such land management practices were common, contemporary changes in river depth are usually only undertaken as part of restoration projects (e.g. Millington and Sear, 2007). In some instances manmade chalk stream stretches are not restored, either because it is too expensive, their social amenity value is high, or, as is the case with the Brandy Stream in Hampshire, they have acquired ecological value over time (Riley, 2007; Davey *et al.*, 2009). Because of their low-energy nature, many modified chalk streams do not have the capacity to reassert their natural form (Sear *et al.*, 1999).

As well as exploitation for amenity, chalk streams are under increasing pressure due to catchment-scale land-use changes. In 2000, 49% of land within chalk stream catchments was used for arable farming, with only 27% as grassland and 13% as woodland (Environment Agency, 2004). Agricultural land contributes both dissolved (e.g. phosphates) and particulate pollutants (e.g. fine sediment) from diffuse sources (e.g. on the River Wensum in Norfolk; Natural England, 2010). In their study of the River Kennet catchment, Collins *et al.* (2012) suggest that unmetalled farm track surfaces contribute the greatest amount of sediment from agricultural land (55%), whilst agricultural topsoil contribute the lowest (4%).

Sufficient nitrates and phosphates from fertilizer can lead to algal blooms and subsequent eutrophication, particularly in slow flowing rivers, where biotic interactions can be

altered and, in extreme cases, deoxygenation can create dead zones (Neal *et al.*, 2000; Hanrahan *et al.*, 2003; Howden and Burt, 2009). Fine sediment inputs from agricultural activity (e.g. ploughing) can hinder macrophyte and macroinvertebrate growth, and smother fish eggs (Wood and Armitage, 1997; Greig *et al.*, 2005; Sear *et al.*, 2008; Kemp *et al.*, 2011). Organic inputs from defecating livestock can also deoxygenate river waters (bacterial decomposers use dissolved oxygen for respiration) and contribute nutrients that encourage photosynthetic autotroph growth (Hubbard *et al.*, 2004; Greig *et al.*, 2005).

Urbanisation has also impacted chalk stream ecosystems, with phosphorous inputs from sewage point sources posing a particular risk of eutrophication (Jarvie *et al.*, 2006a). Increased surface runoff from impermeable urban surface can occur in chalk stream catchments, although the effects are manifest in increased sediment inputs from urban sources rather than flooding; the underlying, porous chalk geology and groundwater flows often alleviate terrestrial flooding pressures. Consequently, chalk stream managers are usually more concerned about changes in water quality resulting from urban runoff than the threat posed to property and land through flooding.

The final major threat to chalk stream sustainability is neglect. With a long history of management by humans, many existing chalk stream environments require regular intervention to maintain their characteristics. In-stream weed cutting, sward height maintenance and coppicing may all be necessary; in their comprehensive review of England's wildlife sites and ecological network, Lawton *et al.* (2010) note how the removal of cattle from formerly flower-rich chalk grassland environments has led to habitat deterioration and scrub invasion. As such, even chalk stream environments of good ecological status need to be managed to maintain their qualities.

## 2.8. Summary

As discussed, chalk streams exhibit a definable, unique, relict geomorphology that helps facilitate an array of habitats and associated biota (Sear *et al.*, 1999; Smith *et al.*, 2003). Accounting for much of the landscape of south and south east England, chalk streams

consequently have significant cultural, economic and ecological value, both nationally and internationally (Mainstone, 1999; Environment Agency, 2004). However, attempts to retain these features are often hindered by the remnants of historic management practices that have occurred across several millennia, as well as contemporary demands upon chalk stream amenity (Mainstone, 1999). The condition and nature of many modern chalk streams is very much a function of human influence, with the construction of mills and the creation and maintenance of water meadows being characteristic traits (Langdon, 2004; Everard, 2005). Nonetheless, the value of chalk stream environments remains, and understanding the impact of specific pressures, such as grazing, upon chalk streams, is essential if these important environments are to be retained.

### **3. Cattle grazing**

#### **3.1. Introduction**

The domestication of cattle by humans dates back to the Neolithic period over five thousand years ago (Clutton-Brock, 1981; Bollongino *et al.*, 2006). Since then, cattle have become a global phenomenon, with the increasing demand for meat, milk and hides leading to a substantial increase in worldwide cattle numbers to approximately 1.5 billion (Wilson and Reeder, 2005; FAO, 2006; FAO, 2009); it is believed that over the next 50 years, the global cattle population will double to 3 billion (FAO, 2009). Such a large cattle population, combined with poor management practices, growing land-use pressures, and an increasing human population, has led to numerous environmental problems (FAO, 2009; Thornton, 2010). At the global level, cattle are suspected to have contributed significantly to climate change through methane emissions; whilst at the regional and local level there is evidence for cattle grazing-induced water pollution, land degradation and biodiversity loss (Johnson and Johnson, 1995; Harrison and Harris, 2002; 202)FAO, 2006; Ramos *et al.*, 2006).

For the purposes of this study, the discussion of cattle grazing is divided into three sections that relate specifically to chalk stream environments. The cattle history and statistics section provides necessary background information for those not familiar with the recent nature of the British cattle industry. The cattle grazing impacts section considers the geomorphological, hydrological and ecological consequences that result from the three main types of cattle grazing impact: herbivory, animal transit and excretion. The controls on cattle grazing section considers how animal psychology and physiology help determine the nature of cattle behaviour and subsequent impact. Together, these three sections provide a necessary overview of the drivers, mechanisms and consequences of cattle grazing.

### 3.2. Cattle history and statistics

In the UK, there are currently around 10 million cattle across some 75,000 premises, with the United Kingdom having the third largest cattle population of any EU Member State (163) (DEFRA, 2008; DEFRA, 2010a; The Secret Life of Cows, 2010). Approximately 5.5 million of these cattle are in England, with the highest concentration of dairy cattle in the South West region (DEFRA, 2010b). The most popular breed is Holstein, whilst female cattle outnumber male cattle by nearly three to one (DEFRA, 2010b). While the number of dairy cattle in England continues to decrease, as it has steadily over the last 25 years as a function of milk quotas and increased milk yields (the average annual milk yield per dairy cow has doubled since 1945), the number of beef cattle remains relatively constant (Clothier, 2009; DEFRA, 2010b: Figure 3.1).

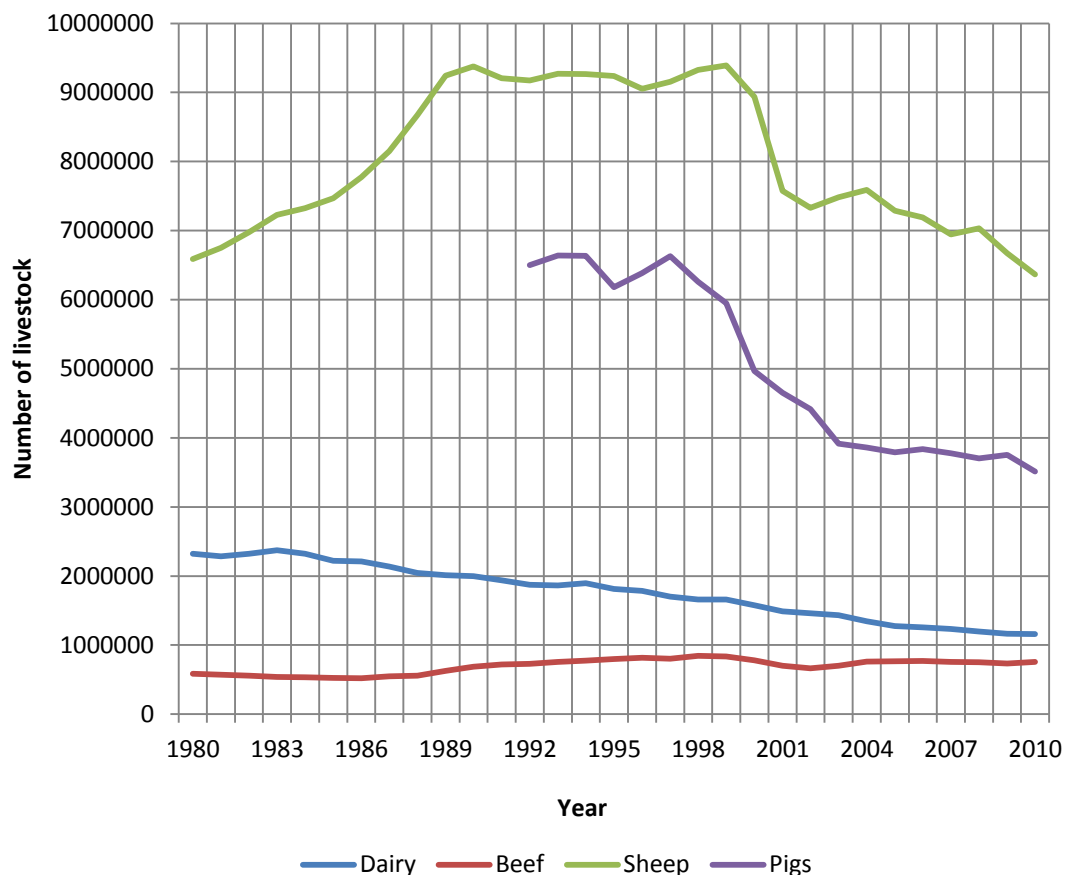


Figure 3.1. Changes in livestock numbers in England over the past 30 years. Note the relative decline of dairy cattle and the relative rise of beef cattle (DEFRA, 2010b).

## Cattle grazing

The net decline in the English cattle population and the proportional increase in the number of beef cattle reflect changes in the market forces influencing livestock farmers (Lowman, 2001). Specifically, increased consumer demand for premium, well-sourced, high mark-up beef products, and stable or falling profit margins for milk, has reduced the attractiveness of maintaining dairy rather than beef cattle (Lowman, 2001; Figure 3.2). It is envisaged this trend will continue into the second decade of the 21<sup>st</sup> century, with a 2.8% increase in the English population of the breeding beef herd from June 2009 to June 2010 (Lowman, 2001; DEFRA, 2010b: Figure 3.1).

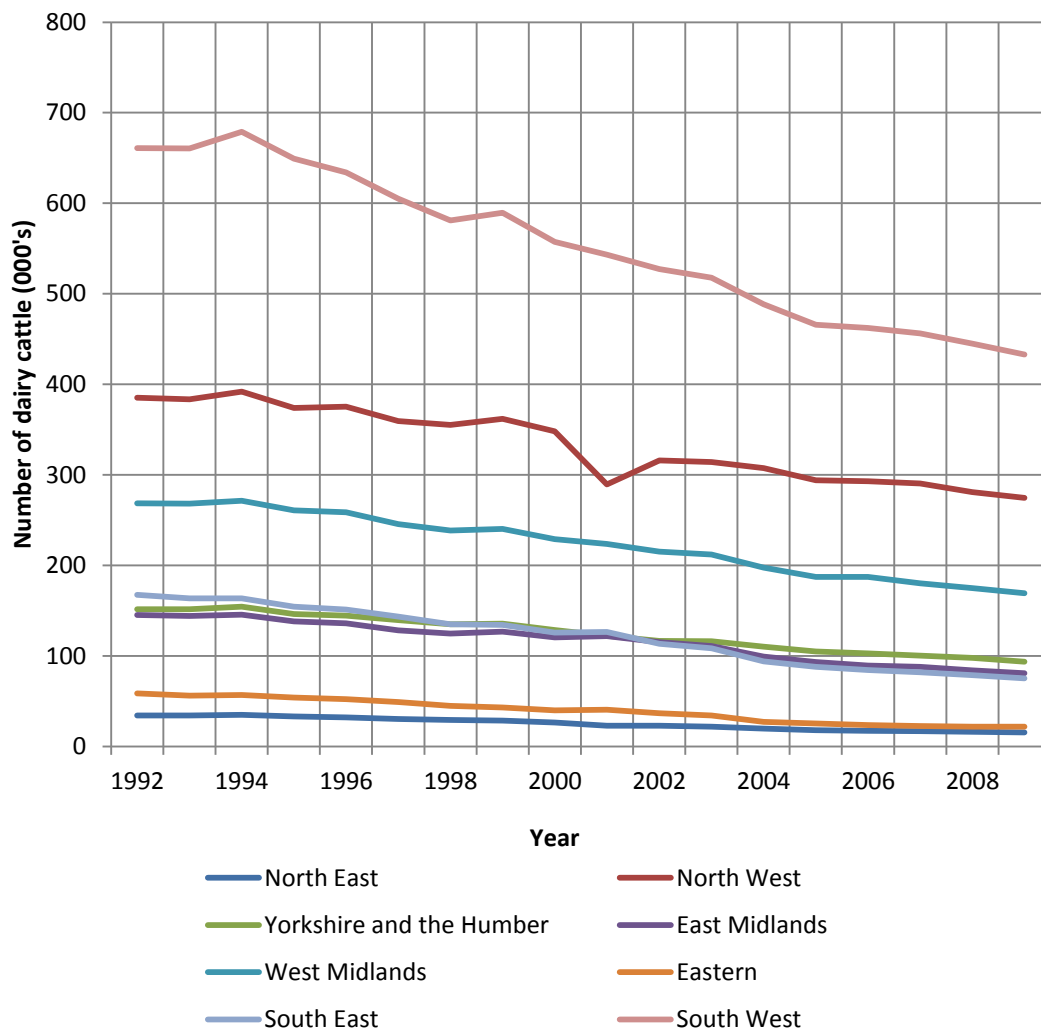


**Figure 3.2. Changes in dairy cattle numbers in different parts of England over the last 20 years. For all regions there is a downward trend (DEFRA, 2010b).**

## Cattle grazing

With respect to land usage, there are approximately 10,200,000 hectares of permanent grassland used for cattle grazing in UK, with over 4,000,000 hectares in England (DEFRA, 2010a, DEFRA, 2010b). The average stocking density of cattle on English permanent grassland has fallen over the course of the last decade, although numbers remain relatively high in the south west of England, with typical livestock units per hectare ranging from 2 to 2.5 (equivalent to approximately two dairy cows or four bulls per hectare); stocking densities in London and the South East are generally the lowest at approximately 1.8 livestock units per hectare (Clothier, 2009; Figure 3.3).

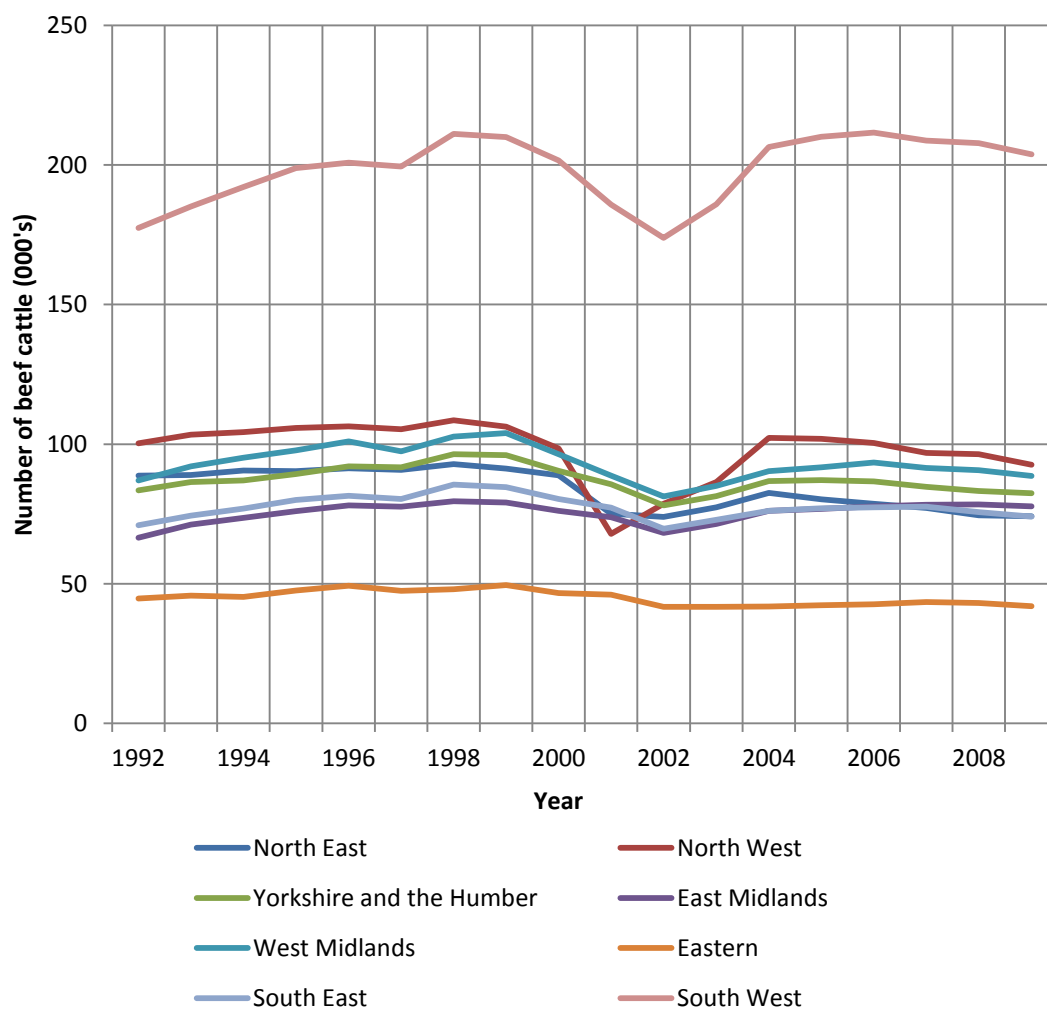


**Figure 3.3. Changes in beef cattle numbers in different parts of England over the last 20 years (DEFRA, 2010b).**

## *Cattle grazing*

In terms of land management, the overall consensus is that farmers and graziers are becoming increasingly aware of the potential environmental impacts of cattle. Clothier (2009) reports in the recent DEFRA report on dairy cattle that the number of dairy farms with fenced-off watercourses has increased from 46% in 2006 to 66% in 2009, whilst the number of dairy farmers removing cattle early or introducing cattle late, in an attempt to reduce cattle poaching (i.e.. river bank destabilisation and erosion), has risen from 70% in 2006 to 90% in 2009. By reducing the length of the grazing season (i.e the time cattle are kept at pasture), which typically spans from May until October inclusive in England, farmers hope to negate some of the negative environmental effects associated with cattle grazing (Clothier, 2009).

Although in some cases the scientific basis for action is empirically poor, based upon anecdotal evidence and possibly spurious observations, the desire for farmers to be environmentally conscientious is encouraging. In a 2008 survey of dairy farmers' attitudes to rearing cattle, approximately 70% of respondents agreed that caring for the environment was their greatest priority, whilst more than 95% of respondents agreed they want to be sensitive to the environmental impacts of farming (Clothier, 2009).

As to whether recent changes in farmers' river management practices are actually a function of an environmental or economic imperative, perhaps from Environmental Stewardship schemes or the sale of fishing licences and the maintenance of angler-friendly watercourses, is unclear. Irrespective of the cause, approaches to cattle farming have undoubtedly changed over the last decade (Robinson, 2007; Clothier, 2009).

### **3.3. Cattle grazing effects**

Within the fields of land management (e.g. Roath and Krueger, 1982), water quality management (e.g. Gary *et al.*, 1983), ecology (e.g. Hayes and Holl, 2003), geomorphology (e.g. Trimble, 1994) and pastoral agriculture (e.g. Drewry, 2006), there are a great number of studies concerned with the impacts of grazing. Different studies have considered different grazing species (e.g. Rook *et al.*, 2004), grazing intensities (e.g.



## *Cattle grazing*

Kruess and Tschardtke, 2002), research methodologies (e.g. Boitani and Fuller, 2000), response variables (e.g. Jones, 2000), temporal and spatial scales (e.g. Adler *et al.*, 2001; Oba *et al.*, 2003), and impacts (e.g. Proulx and Mazumder, 1998; Marty, 2005). Most of these studies have looked at large units in the rangelands of North America (e.g. Kauffman, 1984; Fleischner, 1994) and the dairy farms of Australasia (e.g. Ludwig *et al.*, 2001; Drewry and Paton, 2000); only a small selection have looked at non-livestock species (e.g. Fuller and Gill, 2001) and low grazing intensities (e.g. Fischer and Wipf, 2002). Consequently, the grazing impacts discussed below are largely known from studies involving high stocking densities of large herbivorous ungulates in semi-arid environments (Table 3.1; Figure 3.4). This represents a significant limitation in terms of the evidence base available to graziers managing cattle in English chalk stream catchments.

**Table 3.1 A sample of 25 studies that have considered the effects or behaviour of cattle within river systems. The location of these studies is displayed in Figure 3.4.**

| Reference                     | Location                                                                       | Cattle breed | Cattle type | Study type              | Summary findings                                                                                                                                                                                     |
|-------------------------------|--------------------------------------------------------------------------------|--------------|-------------|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Buckhouse and Gifford (1976)  | Cedar River, Iowa, USA                                                         | -            | -           | Effects – Water quality | No significant deleterious land-use effects resulting from cattle grazing were recorded. Faecal coliform concentrations due to allochthonous inputs from cattle did not pose a public health hazard. |
| Gary <i>et al.</i> (1983)     | Trout Creek, Manitou Experimental Forest, Colorado, USA                        | -            | -           | Effects – Water quality | Cattle grazing had minor effects upon in-stream water quality, with no significant differences in nitrogen and suspended solid content between rivers in grazed and ungrazed pasture.                |
| Kauffman <i>et al.</i> (1983) | Hall Ranch, Eastern Oregon Agriculture Research Centre, Wallowa Mountains, USA | -            | -           | Effects - Ecological    | Significant differences in riparian plant species composition, structure and productivity between grazed and ungrazed patches.                                                                       |
| Kreuper <i>et al.</i> (2003)  | San Pedro Riparian National                                                    | -            | -           | Effects - Ecological    | Increased density of riparian herbaceous plants following the cessation of cattle                                                                                                                    |

## Cattle grazing

|                                  |                                                       |   |                   |                      |                                                                                                                                                                                                               |
|----------------------------------|-------------------------------------------------------|---|-------------------|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                  | Conservation<br>Area, New<br>Mexico, USA              |   |                   |                      | grazing. Additionally, a statistically<br>significant increase in avian species diversity<br>following the cessation of cattle grazing.                                                                       |
| Knopf <i>et al.</i><br>(1988)    | Arapaho National<br>Wildlife Refuge,<br>Colorado, USA | - | -                 | Effects - Ecological | Vegetation and avifauna composition were<br>effected by cattle grazing, with the greatest<br>species diversity in areas subject to traditional<br>(winter) rather than contemporary (summer)<br>grazing.      |
| Taylor (1986)                    | Blitzen River,<br>Oregon, USA                         | - | -                 | Effects - Ecological | Cattle grazing in the riparian zone were<br>associated with reduced shrub height, volume<br>and abundance. Cattle grazing were also<br>associated with reduced bird species diversity<br>and abundance.       |
| Humphery and<br>Patterson (2000) | Strathroory Glen,<br>Scotland                         | - | -                 | Effects - Ecological | A decrease in riparian plant species diversity<br>in ungrazed reaches compared to static plant<br>species diversity in grazed reaches. Cattle can<br>be a useful tool for managing species-rich<br>grassland. |
| Pöyry <i>et al.</i><br>(2005)    | Somero, Finland                                       | - | Beef and<br>dairy | Effects - Ecological | Cattle grazing can be used to restore mesic<br>grasslands and subsequently moth and                                                                                                                           |

## Cattle grazing

|                                |                                                     |   |   |                      |                                                                                                                                                                                                                     |
|--------------------------------|-----------------------------------------------------|---|---|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                |                                                     |   |   |                      | butterfly species diversity.                                                                                                                                                                                        |
| Marty (2005)                   | Central Valley,<br>California, USA                  | - | - | Effects - Ecological | Continuous grazing maintained the prevalence of native species and prevented the invasion of exotics. Ungrazed areas exhibited lower macrophyte and aquatic invertebrate species richness compared to grazed areas. |
| Quinn <i>et al.</i><br>(1992)  | Mount Hamilton,<br>New Zealand                      | - | - | Effects - Ecological | Extensive and intensive grazing can affect the composition of benthic invertebrate communities through the removal of riparian shading and stream channel modification                                              |
| Braccia and<br>Voshell (2007)  | Blue Ridge<br>Mountain<br>streams, Virginia,<br>USA | - | - | Effects - Ecological | Benthic macroinvertebrates responded negatively to high intensity cattle grazing. Benthic macroinvertebrate response to cattle was less clear at intermediate grazing intensities.                                  |
| Ballard and<br>Krueger (2005b) | Oregon, USA                                         | - | - | Effects - Ecological | No difference in salmon populations between areas containing cattle and those without. Cattle spent <0.01% of their time within contact of a salmon redd.                                                           |
| Summers <i>et al.</i>          | River Piddle,                                       | - | - | Effects - Ecological | Cattle grazing negatively affected habitat use                                                                                                                                                                      |

## Cattle grazing

|                             |                                          |   |   |                                     |                                                                                                                                                                                               |
|-----------------------------|------------------------------------------|---|---|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (2005)                      | Dorset, UK                               |   |   |                                     | by trout in the summer and autumn, with reduced water depth and reduced shading. Salmon were unaffected in the same study.                                                                    |
| Harris and Harrison (2002)  | Dorset, UK                               | - | - | Effects - Ecological                | No difference in the total abundance of macroinvertebrates between grazed and ungrazed sites. Ungrazed sites have higher macroinvertebrate species diversity than grazed sites.               |
| Harner and Geluso (2012)    | Nebraska, USA                            | - | - | Effects - Ecological                | Cattle-induced differences in vegetation cover led to differences in caddisfly larvae densities between grazed and ungrazed plots, with greater larvae densities in ungrazed plots.           |
| Amy and Robertson (2001)    | Murrumbidgee River, Australia            | - | - | Effects – Ecological and geomorphic | A negative association between increased grazing intensity and riparian condition was observed. However, it is also suggested that cattle grazing could be used to improve riparian habitats. |
| Belsky <i>et al.</i> (1999) | A review of studies in the intermountain | - | - | Effects – Ecological and geomorphic | A quantitative review suggesting that cattle grazing is detrimental to water quality, stream channel morphology, and riparian and aquatic                                                     |

## Cattle grazing

|                               |                                       |           |           |                      |                                                                                                                                                                                                                                                                     |
|-------------------------------|---------------------------------------|-----------|-----------|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                               | west, USA                             |           |           |                      | organisms, with no positive environmental effects.                                                                                                                                                                                                                  |
| Mwendera <i>et al.</i> (1997) | Debre Zeit research station, Ethiopia | Zebu      | -         | Effects - Geomorphic | Increased surface runoff due to heavy (3.0 AUM ha <sup>-1</sup> ) and very heavy cattle grazing (4.2 AUM ha <sup>-1</sup> ) but no significant changes in surface runoff due to light (0.6 AUM ha <sup>-1</sup> ) and moderate (1.8 AUM ha <sup>-1</sup> ) grazing. |
| Clary and Kinney (2002)       | Stanley Creek, Idaho, USA             | Simulated | Simulated | Effects - Geomorphic | Simulated cattle activity demonstrated no change in the geomorphic characteristics of streambanks under moderate grazing. However, heavy grazing caused significant changes in bank angle, channel width, root biomass and bank retreat.                            |
| Marlow <i>et al.</i> (1987)   | Montana, USA                          | -         | -         | Effects - Geomorphic | The presence of cattle alone cannot explain seasonal changes in stream bank morphology, although cattle utilisation of the aquatic environment does cause stream bank alteration.                                                                                   |
| Clary (1999)                  | Stanley Creek, Idaho, USA             | -         | -         | Effects - Geomorphic | Increased stream bank stability, narrower channel and reduced width-depth ratios                                                                                                                                                                                    |

|                                    |                              |                                 |       |                                             |                                                                                                                                                                                                     |
|------------------------------------|------------------------------|---------------------------------|-------|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                    |                              |                                 |       |                                             | following the cessation of heavy grazing. These geomorphological conditions, along with ecologically desirable sward heights, were maintained even following light and moderate grazing.            |
| Sheffield <i>et al.</i> (1997)     | Virginia, USA                | Angus-Hereford/Br<br>ahma-Angus | -     | Effects - Geomorphic                        | A reduction in stream bank erosion and an improvement in river water quality following the installation of water-troughs and consequentially less in-stream cattle activity                         |
| Hart <i>et al.</i> (1993)          | Wyoming, USA                 | -                               | -     | Behaviour - Streams<br>Effects - Ecological | Cattle appear to spend more time near streams than in adjacent uplands. Cattle can increase seed burial and seedling emergence through hoof action.                                                 |
| Davies-Colley <i>et al.</i> (2004) | Wangapeka River, New Zealand |                                 | Dairy | Behaviour - Fords<br>Effects - Geomorphic   | Cattle defecated more frequently in the ford than elsewhere. When cattle crossed fords, in-stream turbidity, total nitrogen content and concentrations of faecal coliforms increased significantly. |
| Ballard and Krueger (2005a)        | Oregon, USA                  | -                               | -     | Behaviour - Streams                         | Cattle spent ~5% of their time on gravel bars and <1% of their time in the aquatic                                                                                                                  |

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environment. Cattle spent over half their time  
drinking in the aquatic habitat.

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It is also important to note that there is much contradictory evidence regarding the impacts of grazing (Table 3.1). Generally, the impacts of grazing may be presented in one of two main ways. Ecologists, geomorphologists and fisheries managers will present arguments that discuss the impacts of grazing upon ecosystems (e.g. Fleischner, 1994; Trimble, 1994; Knapp and Matthews, 1996). Contrastingly, farmers, rangeland owners and economists will often speak of grazing pressures in terms of livestock productivity (e.g. Holechek, 1988; Clason, 1995; Joblin, 2006). Resultantly, there is much rhetoric, with seemingly little middle-ground for informed discussion or compromise; fisheries managers often see *any* grazing as bad whilst livestock managers often overlook any ecological or geomorphic impact that *does not affect productivity*. One of the objectives of this document, in part, is to clarify our understanding of grazing impacts so as to better inform stakeholders.

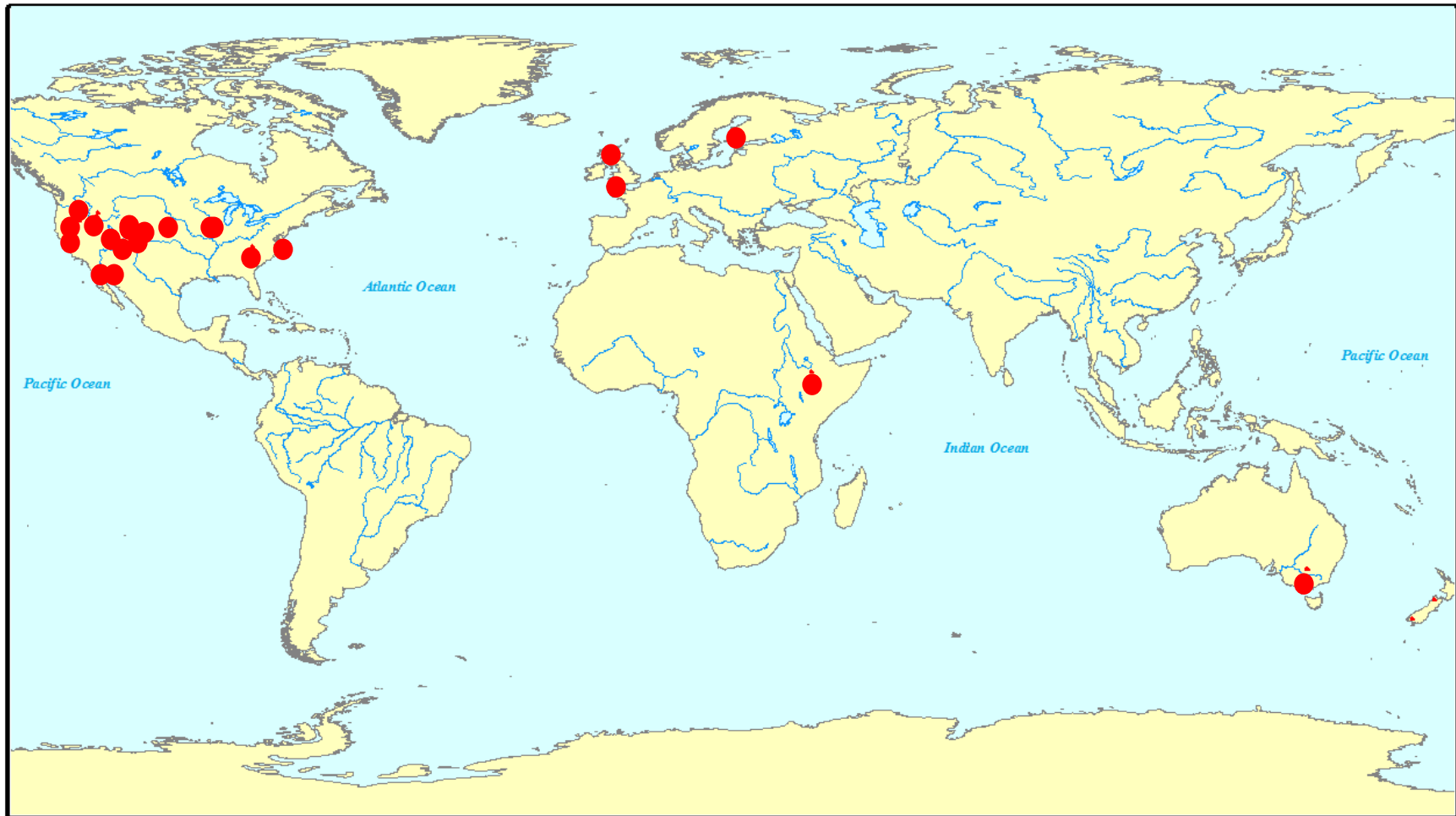


Figure 3.4. The global distribution of the 25 studies summarised in Table 3.1 as indicated by the red dots. Note the dominance of studies from North America.

What is also apparent is the relevance of grazing intensity in determining impact. In the literature the mostly widely used metric of grazing pressure is stocking density, which usually comes in the form of animal units per unit area per unit time (e.g. cows per hectare per month: Mendel and Trimble, 1995). Different animals are prescribed different animal or livestock units according to their potential impact upon the land (e.g. one pony = three cows = five sheep: Mitchell and Kirby, 1990). Often such categorisations are somewhat arbitrary, with no universally accepted measure of comparison between animal types (Mitchell and Kirby, 1990; Trimble and Mendel, 1995). Although it is clear that different animals do induce different impacts, broad groupings do not account for species-specific behaviour, antecedent environmental conditions, or the quantity and quality of forage available. Hence, classifying grazing intensity as light, moderate or heavy (e.g. Biondini *et al.*, 1998; Hart, 2001; Holechek *et al.*, 2003) is not necessarily informative, particularly in the absence of quantitative data regarding stocking density (Fleischner, 1994). These classifications appear to refer more to the perceived impact than to the intensity of pressure; thus most studies suggest light/moderate grazing pressure has minor impacts whilst heavy grazing pressure has significant impacts (e.g. Johnston *et al.*, 1971; Hart, 2001; Reeder and Schuman, 2002; Han *et al.*, 2008; Hanley *et al.*, 2009). Nonetheless, for the sake of clarity and consistency between researchers, these terms of grazing intensity will be explained and used in the subsequent text (we shall discuss later how grazing intensity could be better conceptualized).

Grazing impacts can be broadly characterised into three components: herbivory, animal transit and excretion (both defecation and urination). The effect, magnitude, duration and frequency of these impacts are discussed.

### **3.3.1. Herbivory**

At high grazing intensities the ramifications of herbivory are intuitive: reduced plant vitality and phytomass; increased plant mortality (Trimble and Mendel, 1995).

Less healthy or fewer plants offer reduced soil stability and increased soil erosion (aeolian and hydraulic) as plant stems and root systems are lost (Fleischner, 1994; Trimble and Mendel, 1995). This, in turn, reduces the effectiveness of sediment trapping

by plants, with a consequential increase in sediment availability (Belsky *et al.*, 1999). Increased sediment availability combined with increased surface runoff due to reduced rates of evapotranspiration and interception, can increase sediment yields to rivers (Kauffman and Krueger, 1984; O'Reagain *et al.*, 2005; Wheeler *et al.*, 2008). Reduced evapotranspiration and interception also affect the vegetation-level microclimate, with lower humidity recorded across heavily grazed landscapes than ungrazed landscapes (Hiernaux *et al.*, 1999).

In terms of a biotic response to extreme herbivory, vegetation community structure can be severely altered. Species diversity is often reduced, with changes in species composition also; from relatively fragile, native, flowering plants and grasses, to woody, grazing tolerant, invasive, forbs and shrubs (Pettit and Froend, 2001; Harris *et al.*, 2003; Vavra *et al.*, 2007). Tree seedlings are swiftly predated and as the number of reproductive trees decreases over time due to mortality, so does the rate of tree seedling recruitment (Vera, 2001). Over long timescales, the loss of tree seedlings and hence trees, can significantly reduce the shading of riparian areas (Vera, 2001). Reduced shading has numerous effects upon streams, including increased light availability (increased phytomass), increased water temperature (can be detrimental to salmonids), decreased thermal cover (can be detrimental to cattle) and decreased habitat availability (certain macroinvertebrate species may rely upon overhanging riparian vegetation: Kauffman and Krueger, 1984). Moreover, direct large woody debris inputs can be reduced; an absence of large woody debris, especially in chalk streams, greatly reduces habitat diversity and can hence impact upon biota (Sear and Arnell, 2006; Corenbilt *et al.*, 2007).

Heavy herbivory may also result in a heterogeneous spatial distribution of vegetation, particularly when grazing is initially introduced to a community, as animals selectively consume the most nutritious plants first (Schulz and Leininger, 1990; Ayantunde *et al.*, 1999; Adler *et al.*, 2001). A loss of floristic and structural diversity also affects fauna. Insects, small mammals and birds may be forced to migrate due to habitat or food resource loss; Jansen and Healey (2003) cite reduced frog species diversity and abundance along a floodplain river in Australia due to aquatic vegetation loss as a

consequence of herbivory by cattle. Reduced soil fertility and humidity make the remaining habitat even less suitable for ground-dwelling animals.

At intermediate or low levels of grazing the repercussions of herbivory are less straightforward. Although plant biomass is still lost at low grazing intensities, this loss may not result in a significant change to community structure or composition (Marty, 2005). Consequently, the geomorphic impacts of heavy herbivory, such as increased surface runoff and sediment yields, will not be as severe under a light or moderate stocking density (Dunford, 1954; Clary, 1999; Trimble and Mendel, 1995). Moreover, certain plant species with a history of exposure to herbivory may respond to phytomass loss by improving photosynthetic ability and leaf area, at least in the short-term (Hayashi *et al.*, 2007).

At the community level, light herbivory by large ungulates may enhance competition (and latterly diversity) through the predation of dominant species (e.g. the common nettle) that may otherwise establish a monoculture (Olf and Ritchie, 1998; Vera, 2001). Increased floristic diversity creates increased habitat diversity. Woodcock and Pywell (2009) note the importance of heterogeneity in sward height in determining invertebrate species richness within calcareous grasslands, whilst the diversity of flowering plants has been a long-established determinant of butterfly population composition in English chalklands (New, 1995). Indeed, a small number of studies have cited the potential benefits to ecological condition of light herbivory, both in arid environments (e.g. Taddese *et al.*, 2002; Holechek *et al.*, 2003) and northern, semi-natural grasslands (e.g. Pykälä, 2003). As eluded to recently by Soder *et al.* (2009), much more is to be learnt regarding the controls on, and effects of, grazing cattle in temperate pasture.

### **3.3.2. Animal transit**

The movement of animals can have numerous geomorphic impacts, often referred to as poaching. Large, powerful hooves can exert substantial force, reshaping and compacting soil to reduce infiltration rates (Warren *et al.*, 1986; Sharrow, 2007). Soil susceptibility to wind and water erosion is increased, whilst increased soil bulk density, reduced

### *Cattle grazing*

permeability and reduced hydraulic conductivity, resulting from trampling, can increase surface runoff and modulate subsurface flows (Trimble and Mendel, 1995; Mwendera *et al.*, 1997; Castellano and Valone, 2007; Wheeler *et al.*, 2008). The changes could lead to the formation of gullies, increase sediment yields, reduce flood lag-times, increase the magnitude and frequency of flooding, and generally alter the river streamflow regime (Trimble and Mendel, 1995). Cattle trails (pathways created by cattle that animals will preferentially use to move through the terrestrial landscape) can also funnel surface runoff and cause soil displacement (Trimble and Mendel, 1995; Wheeler *et al.*, 2008; Figure 3.5).



**Figure 3.5. A cattle trail on the floodplain of the River Meon at Droxford. Note cattle grazing off of the cattle trail in the background; cattle trails are pathways for movement across the landscape and cattle do not generally graze in areas immediate proximate to cattle trails.**

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With respect to hillslope processes, cattle agency can enhance surface runoff and soil erosion through compaction, contributing fine sediment and organic inputs that are deleterious to river water quality (Mwendera *et al.*, 1997; Belsky *et al.*, 1999; Wheeler *et al.*, 2008). In his long-term study of the biotic and hydrological responses of several Colorado watersheds to cattle grazing, Lusby (1970) found that ungrazed sub-catchments experience 30% less runoff and 45% less sediment yield than grazed sub-catchments. More recent studies in England and Wales (Hess *et al.*, 2010), Australasia (Cournane *et al.*, 2011) and Europe (Ramos *et al.*, 2006) have shown how these potential effects of animal transit manifest themselves in several different environments.

If animal movement occurs at a river bankside, particularly during times of high soil moisture content and high streamflow, bank slumping or collapse may result (Kauffman and Krueger, 1984; Marlow *et al.*, 1987; Clary, 1999; Magner *et al.*, 2008). Repetitive animal egress and ingress across rivers can also create cow ramps; preferred pathways via which cattle can access waterways (Trimble, 1994; Figure 3.6)





**Figure 3.6.** An example of a cow ramp on the River Meon at Droxford. Note the suspended sediment plumes visible in the middle-ground; these are a consequence of recent cattle activity on the cow ramp.



Cow ramps, once established, can be self-sustaining geomorphic features; increased turbulence during bankfull flows and the concentration of surface runoff act as positive feedback mechanisms (652)Trimble and Mendel, 1995).The net effect of these geomorphic impacts is that over sufficient time periods, animal activity can change local cross-sectional channel form (Kauffman *et al.*, 1983; Trimble, 1994); Clary (1999) notes that heavy grazing can reduce bed substrate cohesion and induce channel narrowing.

Animal transit can also have direct effects upon biotic components of an ecosystem. Vegetation can experience injury and hence reduced mortality because of cattle trampling (Trimble and Mendel, 1995; Mwendera *et al.*, 1997). Trampling can also reduce variability within the soil surface microtopography and leaf litter habitat availability, which may limit the number of ground foragers and detritivores (Yates *et al.*, 2000). At the soil surface and subterranean level, endopedofauna may be absent in soils subject to compaction by cattle (Cluzeau *et al.*, 1992), with reduced soil fertility a possible consequence (Murphy *et al.*, 1995; Edwards, 2004).

It should be noted that within the literature there are several alternative, and less-widely accepted but equally logical, possibly beneficial consequences of animal transit. A surprising number of relatively obscure, but highly important studies have been conducted into the effects of animal transit on British waterways, with many identifying positive cattle impacts upon biodiversity (e.g. Dolman, 1993; Biggs *et al.*, 1994; Summers, 1994). Drake's (1995) comparison of invertebrate diversity between fenced and unfenced sites on the River Itchen identified a greater variety of riparian insects occurring at those locations with cattle access than without; Drake (1995) suggests that lightly poached, unfenced river reaches provide a better habitat for insects than unpoached, fenced river reaches. Meanwhile, Sanderson's (2007) study of vascular plant diversity across fenced and unfenced riparian margins at Winnall Moors Nature Reserve, also on the chalk stream Itchen in Hampshire, shows that higher-order riparian macrophytes can also benefit from cattle poaching.

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Studies from other parts of the world appear to support the notion of net positive impacts from cattle movement. Roundy *et al.* (1992) and Hiernaux *et al.* (1999) both suggest that in arid environments, animal movement may actually break up hard soil surface crusts, thereby increasing permeability, soil water content and ground level humidity.

Furthermore, in a study by Curry *et al.* (2008) conducted in Ireland, even heavy grazing appeared to have no adverse short-term effect upon earthworm populations. Curry *et al.* (2008) put forward that any negative trampling effects caused at high stocking densities are offset by the benefits of increased organic inputs from cattle excretion and plant death.

It has also been shown that cattle do not necessarily act as significant geomorphic agents in certain circumstances. Lucas *et al.* (2009) observed no large-scale changes in streambank morphology resulting from cattle access in their evaluation of different grazing intensities across two montane riparian areas in western New Mexico; attributing the recorded small-scale morphological changes to natural processes. Similarly, Marlow *et al.* (1987) demonstrated in their four year study that soil moisture content was the greatest control on bank stability, and not geomorphic agency due to cattle. Clary (1999) goes further, having recorded improved streambank stability under light and moderate late-spring grazing regimes following the cessation of a heavy grazing regime, whilst Dunford (1954) observed that moderate grazing did not lead to a substantial increase in soil erosion across pine grassland.

#### **3.3.3. Excretion**

Excretion in the form of urine and faeces from animals can have several impacts within an ecosystem. The severity of impact, as with herbivory and animal transit, is often a function of stocking density. The animal species, the availability of food and the environmental conditions also need to be considered.

The most widely documented consequence of excretion by animals is the recycling, movement and output of organic matter into soil and river systems (Hooda *et al.*, 2000; Dahlin *et al.*, 2005). Intuitively, the amount of faeces and urine an animal produces is

determined by the amount they eat and drink. Consumption is largely determined by size, age and condition, and hence so is excretion; Aland *et al.* (2002) note how heifers defecate less frequently than adult female cows, which is logical given the relative demands on their bodies. Theoretically, food availability also controls excretion, although in reality animals will move from locations in which there is limited or low-nutrient foraging (Seagle and McNaughton, 1992; Utsumi *et al.*, 2009). In a study by Oudshoorn *et al.* (2008), cows subject to time limited-grazing of four hours produced approximately the same volume of excrement as those allowed to graze for nine hours; the cows who had less time at pasture compensated for this by eating (and hence excreting) more.

Aside from the amount of faeces and urine, the composition is also important. Different animals will produce excrement with different concentrations of nutrients and toxins according to their diet and physiology. For example, Le *et al.* (2008) discovered that pigs, whose diet was dominated by fermentable carbohydrates from barley, produced more ammonia per unit excrement than pigs whose diet was dominated by crude protein from wheat. Similarly, sheep and goats that eat plants containing high levels of condensed tannins, such as the birdsfoot trefoil (*Lotus corniculatus*), are likely to produce urine with relatively more nitrogen, and faeces with relatively less nitrogen, when compared to other plants (Waghorn, 2008). Other by-products of excretion that may be effected by diet include microbial faecal bacteria, pH, methane emissions and phosphorous concentration (Baidoo *et al.*, 2003; Mikkelsen *et al.*, 2003; Dämmgen and Hutchings, 2008; Le *et al.*, 2008; Waghorn, 2008).

Several studies have considered the characteristics of faeces from cattle, for the purposes of environmental management, and in relation to water quality and human health (e.g. McDowell, 2006; Johnson *et al.*, 2008; Litskas *et al.*, 2010). In addition, Hubbard *et al.* (2004) provide a useful quantitative assessment of the rates of faeces production for cattle; dairy cattle produce, on average, 86kg of manure a day, compared to 58kg for beef cattle. Of these volumes, the content of total nitrogen is approximately 0.45kg for dairy and 0.34 for beef, whilst the total phosphorus content averages at 0.093kg (Hubbard *et al.*, 2004). Approximate values for other cattle faeces characteristics, such as the five day

biochemical oxygen demand, and faecal coliform abundance, are also known (Hubbard *et al.*, 2004).

| Study                        | Selected findings                          |
|------------------------------|--------------------------------------------|
| Barnett (1994)               | Phosphate as 0.67% of cattle faeces weight |
| Smith and Frost (2000)       | Nitrogen as 0.50% of cattle faeces weight  |
| Hubbard <i>et al.</i> (2004) | Potassium as 0.36% of cattle faeces weight |

**Table 3.2. A selection of findings from papers discussing cattle faeces composition. A more comprehensive, but unintuitive, list can be found in Table 1 of the paper *Water Quality and the Grazing Animal* by Hubbard *et al.* (2004).**

Sources of excretion pollution can be either diffuse or point. Several studies have identified excretion point sources or ‘hotspots’; non-uniformly distributed locations where certain species of livestock will preferentially and repeatedly urinate and defecate (Oudshoorn *et al.*, 2008). Although the sequestration of these pollution point sources into a river channel during flooding can have catastrophic effects upon biota, land and river managers are often more concerned with diffuse excretion pollution sources, whose impacts are relatively difficult to quantify (Cheng *et al.*, 2007; Bowes *et al.*, 2008). Diffuse organic matter enters the river system through run-off, either from stochastic excretion (particularly urine) or from slurry (animal faeces mixed with water and spread across land to act as a fertiliser: Núñez-Delgado *et al.*, 2002; Vinten *et al.*, 2008). In both instances, diffuse source pollution can alter biotic interactions within waterways (Hooda *et al.*, 2000).

In lotic systems, particularly those that have slow flows and shallow cross-sections, nutrient enrichment due to the input of organic matter from either point or diffuse sources can stimulate algal blooms and induce eutrophication (Withers and Lord, 2002; Garnier *et al.*, 2005; Bowes *et al.*, 2008). Eutrophication, alongside the decomposition of allochthonous faecal and urinal organic material from animals, can deplete dissolved oxygen content within a river and lead to fish, invertebrate and macrophyte mortality (Sharpley, 1999; Singh *et al.*, 2008). Moreover, eutrophic water abstracted for human

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consumption can contain cyanobacteria, amongst other algae, whose ingestion can cause illness and even death in animals and people (Howard *et al.*, 1996).

In the terrestrial environment the consequences of excessive cattle excretion are rarely as catastrophic. Nonetheless, there is a body of literature citing negative impacts. Loydi and Zalba (2009) demonstrate in their study of feral horse dung in Argentina that deposits of faeces can act as invasive windows for alien plant species, whilst Oliver *et al.* (2010) note the potential health risk to humans posed by accumulations of *E. coli* from cattle dung in the terrestrial environment.

The counter argument to excessive loading from animal excrement is that in some instances, nutrient recycling and redistribution may benefit an ecosystem. Indeed, Dahlin *et al.* (2005) note that low intensity grazing may enhance biodiversity in nutrient-poor grasslands by improving nutrient recycling and excrement availability. Moreover, Persson *et al.* (2000) highlight the importance of moose urine for plant and fungi growth in Scandinavian boreal forests. In the steep sloped East African Highlands, the accumulation of cattle dung and urine has been shown to enhance overall plant biomass and species richness (Taddese *et al.*, 2002). Hence, nutrient inputs from animal excretion, in these environments at least, can have positive impacts; the effects of cattle are environment specific.

As well as nutrients, excrement, and faeces in particular, can contain potentially harmful bacteria and pathogens. Faecal coliform bacteria (e.g. *Escherichia coli*) found in slurry and faeces can enter rivers through runoff, by direct deposition, or as a consequence of flooding (Nagels *et al.*, 2002; Avery *et al.*, 2004; Rufete *et al.*, 2006; Collins *et al.*, 2007). These bacteria, alongside *Campylobacter* such as *C. jejuni*, are renowned for degrading water quality and having deleterious effects upon humans and other organisms (Ryan *et al.*, 2004; Collins *et al.*, 2007). There can be other contaminants also; Matthiessen *et al.* (2006) identified the role that steroid hormone contamination from livestock excrement (sheep and cattle) played in modifying endocrine activity within fish in headwaters across England.

### **3.3.4. Summary**

There are three broad effects of cattle grazing: herbivory, the predation of plants; animal transit, the mechanical disruption of soils, sediments and organisms; and excretion, the production of cattle faeces and urine. Combined or in isolation, these effects can significantly alter the ecology and geomorphology of terrestrial environments, as well as the hydrology and water quality of aquatic environments.

In most instances cattle have a deleterious effect upon the ecology, geomorphology and water quality of environments in which they are kept. Nonetheless there are clear caveats relating to the specific circumstances of cattle grazing that mean in certain cases cattle can have an overall positive effect upon their environment. The magnitude, scale and direction of grazing effects are a function of species, stocking density, forage availability and landscape conditions, amongst other variables. The environment specific nature of these effects, as illustrated by the diversity of conclusions reached in the studies conducted previously, highlights the need for research in thus far understudied locations. Owing to their unique characteristics and landscape history, the relict chalk stream environments of southern England represent an area where the net effects of cattle grazing may not necessarily be detrimental.

### **3.4. Controls on cattle grazing**

The most basic needs of all animals, including cattle, are food, shelter and water (Litvaitis, 2000). As well as behaving to fulfil these needs, animals may also behave according to a number of internal and external influences. Environmental conditions, society, hierarchy, altruism, competition, resource quality, resource availability, animal condition, human interaction and predation risk are just some of the variables that influence animal behaviour (Hughes, 1990; Boitani and Fuller, 2000). Understanding how and why these factors induce different behaviours is fundamental to ethology; an ever growing discipline that provides a number of qualitative and quantitative models to explain animal tendencies (Hughes, 1990; Boitani and Fuller, 2000).

### **3.4.1. Qualitative ethology: Tinbergen's four questions**

Tinbergen's four questions represent a qualitative framework within which all animal behaviours can be explained on four levels: function (adaptation), phylogeny (evolution), causation, and development (ontogeny: Tinbergen, 1951; Alcock, 2009).

**Function** refers to the element of animal behaviour that modifies the probability of the animal surviving and reproducing (Tinbergen, 1951). If we take the behaviour of feeding as an example, the function for which this is performed is to acquire energy and nutrients, which will ultimately keep the animal alive, healthy and reproductive. The function of fleeing a predator, as another example, is intuitive; avoiding predation allows the animal to live.

**Phylogeny**, or the evolutionary relatedness of different species, refers to the element of animal behaviour that is derived from biological evolution, and that is comparable to behaviour seen in other species (Tinbergen, 1951; Gould, 1977). In the eating example, this is behaviour that began at the beginning of evolutionary history and one that is apparent in nearly all animals. In the flight example, it should be found that all animals exhibiting this behaviour share evolutionary histories; these animals may have physical similarities that encourage fleeing rather than, for example, using camouflage to avoid predators.

**Causation** refers to the stimuli that illicit a behavioural response (Tinbergen, 1951). Eating is caused by hunger and the reason animals experience hunger is because they require energy to live and reproduce. Fleeing a predator is often caused by sensing (i.e. hearing, smelling, feeling, seeing) the predators presence, and the act of fleeing keeps the animal alive. This causation effect relates loosely to another component of ethological theory; fixed action patterns (Tinbergen, 1951; Alcock, 2009). Fixed action patterns refer to those instinctive, often elaborate and complex reactions exhibited by animals subject to a particular sign stimulus. These reactions are argued to be indivisible and predictable,

accounting for a large proportion of animal behaviour between animals, especially in the wild (Tinbergen, 1951; Alcock, 2009).

The final question, **development**, considers behaviours that are a consequence of changes over time or behaviours that are learnt (Tinbergen, 1951; Gould, 1977). In the eating example, animals will eat different foods throughout different life stages and this leads to different behaviour (e.g. mammals suckle milk from their mother when young but will find and eat their own food when mature). Moreover, animals may learn either through experience or observation, that certain foods are more nutritious than others, and their behaviour may reflect this. In the animals fleeing predators' example, juveniles may be unequipped to successfully avoid predation by fleeing when young, and hence may not display this behaviour. However, as these animals grow they develop the physical traits that enable them to run away from predators, as well as the experience that modifies this behaviour, perhaps refining it.

### **3.4.2. Quantitative ethology: Rate maximisation**

Although Tinbergen's four questions provide an important conceptual framework that permits the understanding of generic animal behaviour, they are ill-suited to quantitative ethology (Jensen, 2009). For this, various statistical models exist, many of which are based upon assumptions regarding animal behaviour (Colgan, 1978; Hughes, 1990; Boitani and Fuller, 2000). Models of rate maximisation, for example, assume that animals are as efficient as possible in their activities in accordance with their need to survive and reproduce (Real, 1990). One such model especially relevant to this study is the optimal foraging theory (OFT: MacArthur and Pianka, 1966; Schoener, 1971).

At the most basic level, the OFT assumes that all predators (including ungulate grazers) will maximise their energy intake per unit time when foraging, and that this rate maximisation will maximise fitness (Schoener, 1971; Hughes, 1990). Of the two interpretations of this model, the patch use paradigm (also containing the marginal value theorem: e.g. Charnov, 1976), rather than the prey choice paradigm (e.g. Houston *et al.*, 1980), is best suited to analysing cattle behaviour.



The patch use optimal foraging model considers how much time a predator spends within a given area based upon the profitability of the food available within that area. The energy intake within a given patch decreases with time as the forager removes the best food. The model shows that an animal will move from one patch to another once the energy intake per unit time decreases below a rate which is obtainable at a different patch. Mathematically, this is given by:

$$\gamma(t) = G(t) / (t + \tau)$$

Where  $\gamma(t)$  refers to the overall rate of gain,  $G(t)$  refers to the amount of energy gained,  $t$  is the time spent in a patch and  $\tau$  is the time taken to move between patches. If  $\gamma^*$  represents the maximum rate achievable in any patch, then  $\gamma$  is maximised by the animal leaving a patch when  $\gamma(t)$  falls to  $\gamma^*$  (Charnov, 1976).

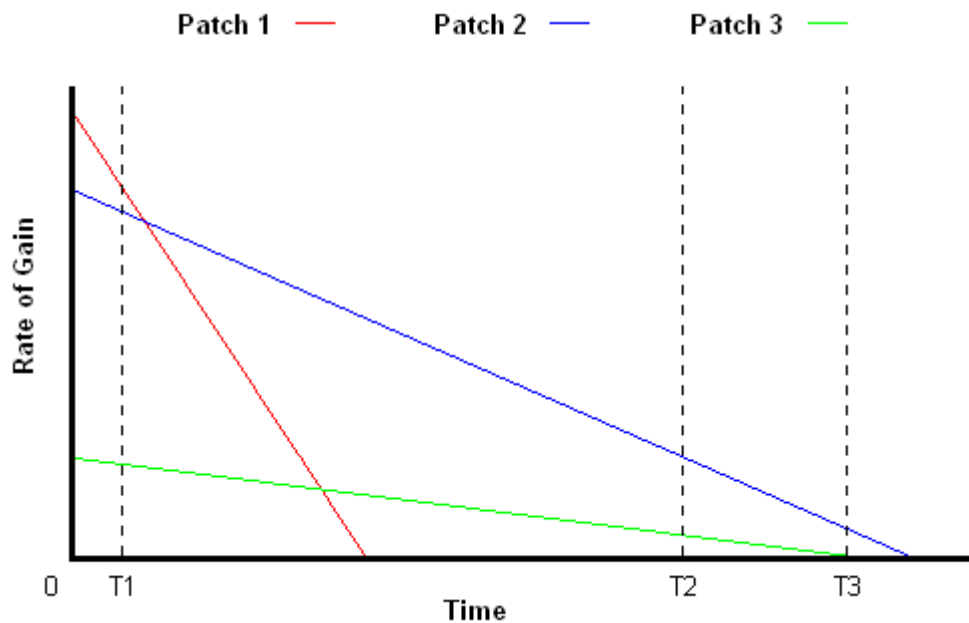


Figure 3.7 A graphical adaptation of the optimal foraging theory (adapted from Charnov, 1976).

In Figure 3.7 cattle will graze at Patch 1 from time 0 until time T1, at which point cattle will move to Patch 2 where the decrease in the rate of gain is more gradual. Cattle will

then graze at Patch 2 from time 0 until time T2, when cattle will move to Patch 3, where they will graze from time 0 to time T3.

Throughout, the amount of time spent within a patch, and the time at which cattle move between patches, is determined by the need to maximise the rate of gain (111)). Although theoretically idealised, in reality animal behaviour is somewhat less predictable, and there have been numerous amendments to the OFT since its conception.

One parallel theory that is particularly relevant to grazing animals is the digestive rate model (DRM), which bases optimisation upon the rate maximisation of digestion rather than the rate maximisation of foraging. The DRM suggests that animals will choose prey on the basis of their digestibility; the consumption of indigestible material leads to sub-optimal energy intake as it occupies space within the digestive tract that could otherwise be taken by digestible material (Illius and Gordon, 1990; Van Gils *et al.*, 2005).

Therefore, prey with a high content of relatively indigestible materials (e.g. fibre, chitin, bones, and shells) will be foregone in favour of those with the highest digestive energy content (Verlinden and Wiley, 1989). This may be particularly applicable to large domestic mammalian herbivores in temperate environments, where the food resource is abundant and varies little in quality between locations (Hirakawa, 1997). In such situations, the DRM suggests that the limiting factor in diet selection is the digestible energy content of prey items; not the food ingestion rate (Hirakawa, 1997).

### **3.4.3. Applied ethology: cattle behaviour**

In domestic animals, influences of behaviour often manifest themselves in different ways to animals that are in the natural world; predation risk, for example, is non-existent, whilst human influence is considerable (Lott and Hart, 1979; Houpt and Wolski, 1982). Moreover, large mammalian herbivores, and cattle specifically, have different morphological, physiological and environmental constraints on behaviour compared to, for example, carnivorous insects (Hughes, 1990). Consequently, the aforementioned models of animal behaviour require refinement when applied to cattle, and this is discussed below.

Cattle shape, size, age, anatomy and psychology go a long way in explaining their behaviour (Kelley, 1959; Currie, 1992; Porter and Stone, 2008). Side-mounted eyes provide a 330° panoramic view that may have developed over evolutionary history as a means of improving predator awareness; distress can be caused to domestic cattle by handlers or other people emerging from the blind-spot directly behind the animal (Phillips, 1993; Lomas *et al.*, 1998; Houpt, 2010). Their vision in long wavelengths (red-yellow) is better than in short wavelengths (green-blue) and they lack the ability to quickly focus upon objects, as well as suffering from poor depth perception (Phillips, 1993; Grandin, 2007). Consequently, it is thought that cattle use other senses such as taste and touch to choose prey items; sight simply divides the world into food and non-food (Phillips, 1993). Moreover, cattle may refuse to walk over shadowy or high contrast surfaces if it is unclear as to whether the surface is solid or otherwise (e.g. cattle grids: Grandin, 1980; Houpt, 2010).

With respect to grazing, although studies have shown that livestock behaviour broadly conforms to the patch use optimal foraging theory (e.g. 662)Utsumi *et al.*, 2009), there are several constraints (Pyke *et al.*, 1977). Most dairy cattle will spend approximately eight hours a day grazing, whilst beef cattle may spend nine (Phillips, 1993; Jensen, 2009). Time spent grazing will increase with reduced foraging quality and increased herd size, but will be reduced in adverse weather conditions and in older animals (523)Phillips, 1993). Older animals have not only the experience to better determine the most nutritious plants, but also larger body size, which correlates to a greater gut capacity and hence more efficient digestion, particularly of fibrous materials (Demment and Van Soest, 1985; Broom and Fraser, 2007).

In terms of patch and diet selection, cattle behaviour is determined by a mixture of prospective and retrospective perceptions of the available forage (Figure 3.8).

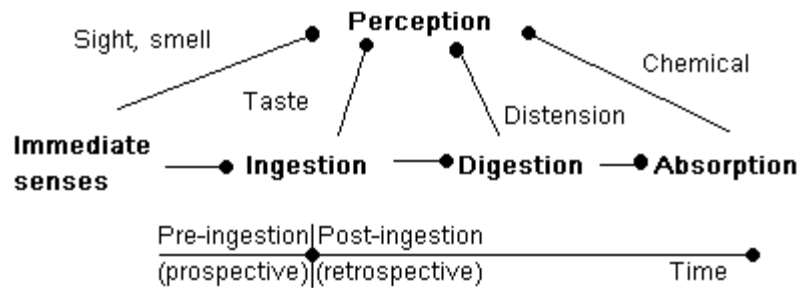


**Figure 3.8 A flow diagram showing the various stages and components that determine grazing behaviour in cattle (adapted from Illius and Gordon, 1990).**

Although it is known that taller sward heights are generally preferred (e.g. Illus and Gordon, 1990) and that new plant shoots are eaten ahead of mature vegetation (e.g. Jerling and Anderson, 1982), it is not thought that smell, taste or touch are especially important in controlling micro-scale cattle grazing; these senses may simply point the animal in the correct direction (Houston *et al.*, 1980; Milne, 1991). Instead, sight, retrospective knowledge regarding palatability, nutrient content and toxicity may inform the animal of the suitability of the vegetation, as has been recorded in sheep (Milne, 1991; Edwards *et al.*, 1996). Cattle may retain this information and use it to better inform future and on-going grazing choices, although the power of memory in grazing choice should not be overstated (Laca, 1998). Experiments have shown that livestock will periodically leave areas of good foraging and return to comparatively poor vegetation patches, even with prior knowledge and experience of the taste and nutrition accrued from plants within the poor vegetation patches (Hughes, 1990). Hence, although cattle adhere to the optimal foraging theory insofar as they try to maximise their energy intake whilst grazing, their ‘suck it and see’ grazing strategy is not 100% efficient (Hosoi *et al.*, 1995). As such, whilst strict use of the OFT may not provide a precise quantitative predictor of grazing behaviour across a spatially heterogeneous vegetation landscape, the OFT remains useful as an imprecise model of the probable time spent grazing across different patches; this has been demonstrated in cattle (e.g. Senft *et al.*, 1985; Illius *et al.*, 1987) and sheep (e.g. Clark *et al.*, 1982)

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Time spent grazing helps determine time spent ruminating (chewing the cud). The R:G ratio, which divides the time spent ruminating by the time spent grazing, is a useful means of identifying whether the pasture available to cattle is suitable (McCullough *et al.*, 1953). If the available forage is good and easily digested then the ratio will be relatively low (e.g. Hereford cows in Southern New Mexico with an R:G ratio of 0.64: Herbel and Nelson, 1966). If the available forage is poor and nutrient deficient then the ratio will be relatively high (e.g. Maasai cattle in Kenya with an R:G ratio of up to 1.9 during the dry season: Semeyne, 1988). In lowland Britain with average pasture an R:G ratio of 0.75 can be expected; i.e. if eight hours are spent grazing, approximately six hours will be spent ruminating (Phillips, 1993).

Another behaviour seen regularly in cattle is excretion. Unlike rumination, time spent grazing does not affect the frequency or time spent urinating and defecating (Oudshoorn *et al.*, 2008). Nonetheless, there is no definitive frequency with which cows are known to excrete. 254)Hafez and Bouissou (1975) suggest dairy cows defecate between 12 and 18 times a day, which broadly agrees with Aland *et al.* (2002), whose cows defecated 16 times per 24 hours and urinated on average nine times per 24 hours. However, a study of 60 Holstein dairy cattle by Oudshoorn *et al.* (2008) suggests cows excrete far less frequently, urinating once every four hours and defecating once every three hours. Irrespective of differing excretion frequencies, the overall amount of time spent excreting is low when compared to other cattle behaviour.

A behaviour that takes up a far greater amount of time than excretion is sleeping. Meddis (1975) suggests that the average cow sleeps for approximately seven hours a day, with sternal recumbancy the preferred position for rest (Broom and Fraser, 2007). Others argue that cattle always retain consciousness whilst sleeping and may exhibit rapid eye movement (REM) to account for this (Merrick and Scharp, 1971). Ruckebush (1972) found that mature cattle may sleep for only four hours every day, and spend eight hours a day in near perpetual drowsiness, with up to 50, two to eight minute periods of REM sleep accounting for much of the rest acquired by cattle (Hänninen *et al.*, 2008). Additionally, cattle are able to ruminate during non-REM sleep, and may sleep whilst

standing if they are unable to lie down (Arave and Albright, 1981; Broom and Fraser, 2007). In all instances, sleep and rest are important components of maintaining physiological and psychological well-being in cattle, and a significant proportion of their behaviour should fall within this category (Albright, 1993; Broom and Fraser, 2007).

The remainder of the cattle day is taken up by drinking, social activities and other non-specific behaviour, such as grooming. The volume of water drunk, and the amount of time spent drinking, can vary substantially depending on the situation. Variations in water quality, animal type, environmental conditions and forage intake water content mean that young cattle in temperate Canadian grasslands may require only 15 litres of water a day, compared to the 140 litres required by adult dairy cows grazing Australasian saltbush in the height of summer (Castle, 1972; Markwick, 2007; McKague, 2007). Equally, although Schake and Riggs (1969) suggest that lactating beef cattle require watering for 10-15 minutes a day, which agrees with Sneva (1970: cattle need to drink for 17 minutes a day), Wagnon (1963), whose study was conducted in California, suggests cattle need only drink for three to six minutes a day.

Social activities within cattle may include leading, subordination, aggression, displays of territoriality, grooming and sex, and the time allocated to each depends on the age, size, species, gender and well-being of the cattle within the herd, as well as the environmental conditions in which they are kept (space, resource availability, etc: Arave and Albright, 1981; Phillips, 1993; Broom and Fraser, 2007). Self-grooming may also be practiced by some cattle, although for no longer than a few minutes each day Hafez and Bouissou, 1975).

### **3.4.4. Applied ethology: cattle behaviour and landscape**

A range of studies have been conducted into the role of landscape in determining cattle distribution and behaviour (Barrett, 1982; Hart *et al.*, 1991; Howery *et al.*, 1998).

Vegetation composition, water distribution, relative humidity and shade availability (Figure 3.9) are examples of landscape-determined factors that influence cattle activity (Roath and Krueger, 1982; Armstrong, 1994; Kendall *et al.*, 2007; Legrand *et al.*, 2011).



Figure 3.9. Cattle under the shade of a horse-chestnut tree near the River Meon at Droxford.

#### 3.4.5. Applied ethology: cattle behaviour in rivers

Although there are several studies that have considered the behaviour of cattle within the terrestrial riparian environment (e.g. for shading: 95)Cabrera *et al.* [2007]; for drinking water: Godwin and Miner [1996] and Bagshaw *et al.* [2008]; for improved foraging: Kauffman and Krueger [1984]), the existing literature on cattle behaviour within the aquatic environment is limited. Of the sparse information that does exist (Table 3.3), nearly all observations of in stream cattle behaviour have been taken as part of studies not directly concerned with cattle activity within the aquatic environment (e.g. Pultney, 1798). Of the small number of studies dealing with in-stream cattle activity, only a few focus upon the nature, causes and duration of animal behaviour rather than its consequences; the work of Schmutzer *et al.* (2008) is a good example of a study whose conclusions contribute usefully to understanding the impact of cattle within the aquatic

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environment, but offers little to improve our understanding of how, when and why cattle utilise watercourses.

| Search term(s)                               | Number of publications | Country breakdown                            |
|----------------------------------------------|------------------------|----------------------------------------------|
| ‘cattle’                                     | 697,867                | USA (14%): UK (8 <sup>th</sup> )             |
| ‘cattle’, ‘grazing’                          | 30, 851                | USA (25%): UK (5 <sup>th</sup> )             |
| ‘cattle’, ‘behaviour’                        | 26,789                 | USA (9%): UK (3 <sup>rd</sup> )              |
| ‘cattle’, ‘grazing’, ‘effect’                | 12,754                 | USA (13%): UK (4 <sup>th</sup> )             |
| ‘cattle’, ‘grazing’,<br>‘impact’             | 1,403                  | USA (31%): UK (5 <sup>th</sup> )             |
| ‘cattle’, ‘groundwater’                      | 390                    | USA (29%): UK (8 <sup>th</sup> )             |
| ‘cattle’, ‘grazing’, ‘river’                 | 355                    | USA (25%): UK (5 <sup>th</sup> )             |
| ‘cattle’, ‘grazing’,<br>‘stream’             | 245                    | USA (59%): UK (6 <sup>th</sup> )             |
| ‘cattle’, ‘grazing’,<br>‘sediment’, ‘impact’ | 67                     | USA (39%): UK (7 <sup>th</sup> )             |
| ‘cattle’, ‘grazing’, ‘river’,<br>‘behaviour’ | 34                     | USA (26%): UK (12 <sup>th</sup> )            |
| ‘cattle’, ‘chalk’, ‘river’                   | 4                      | The Netherlands (75%): UK (2 <sup>nd</sup> ) |

**Table 3.3. The number of academic publications found following a Web of Knowledge search using different terms (Lemmatization: ON; publications after 1950). The country in which the majority of studies have been conducted is provided, alongside the percentage of studies from that country. The number of studies conducted in the United Kingdom (UK) is given as a rank e.g. of all the countries in the world, the UK has the 8<sup>th</sup> greatest number of studies containing the search term ‘cattle’.**

One study that does provide a useful quantitative assessment of cattle behaviour in and around rivers is documented in Ballard and Krueger (2005a) and Ballard and Krueger (2005b), two papers in the *Journal of Rangeland Ecology and Management* that chronicle a two year study into cattle-salmon interactions in North-eastern Oregon.

The first paper, Ballard and Krueger (2005a), provides quantitative data regarding the time spent by cattle in both the terrestrial and aquatic environment during the 18 day



## *Cattle grazing*

period over which they were observed. Moreover, the paper details quantitatively the amount of time cattle were engaged in different activities or behaviour. Ballard and Krueger (2005a) witnessed that cattle spent less than 1% of their time within the aquatic environment, and that only 12% of this time was spent foraging or grazing i.e. during the total period of observation cattle spent just over 0.1% of their time eating vegetation within the aquatic environment. Of the remaining time spent in-stream, over half was spent drinking and only a fraction of a percentile was spent defecating; total direct in-stream manure inputs were approximately 2% of the total manure produced by the animals.

The second paper, Ballard and Krueger (2005b), addresses cattle-salmon redd interactions. In the same 18 day investigation discussed previously, the frequency of cattle contact with salmon redds was recorded; 84% of the time cattle were over 3m away from active salmon redds and the total contact time between cattle and salmon redds was less than 0.01% of the total time of observation. Furthermore, although it is known that disturbance to salmon redds can reduce egg viability, the limited in-stream activity of the cattle observed in Ballard and Krueger (2005b) study had no apparent effect on salmon populations, with all salmon fully spawning throughout the study years.

The study described in the two previous paragraphs stands alone within the applied ethology literature in two main respects. Firstly, the comprehensive monitoring of in-stream cattle behaviour in a quantitative and categorical manner is seldom recorded elsewhere. Secondly, whilst many studies cite the negative effects of cattle when in rivers (e.g. Davies-Colley *et al.*, 2004; Bagshaw *et al.*, 2008), this investigation contests that not only do cattle spend less than 1% of their time in the aquatic environment, given the choice, but that their activities during this time have no discernible impact upon salmon; often the most economically important fish in the rivers in which they occur (O'Connor, 1984; Butler *et al.*, 2009).

Unfortunately Ballard and Krueger (2005b) do not elaborate on the wider geomorphic (e.g. bank destabilisation: Trimble and Mendel, 1995) or biological (e.g. nutrient inputs

from faeces; Hubbard *et al.*, 2004) consequences of in-stream cattle activity over the course of their study.

#### **3.4.6. Applied ethology: cattle behaviour in chalk streams**

Although generic statements can be found with respect to trampling, siltation effects and herbivory, there is a dearth of quantitative studies into cattle behaviour in and around chalk streams (Table 3.3). Moreover, nearly everything that is written is concerned with bankside and riparian activity, rather than in-stream behaviour. Of the literature directly concerned with in-stream cattle grazing in chalk streams, there is no clear consensus.

Historic work by Pultney (1798) suggests that cattle in the River Avon used to eat water crowfoot (*R. flutians*) in preference of other vegetation. Johnson and Sowerby (1862) support this, noting that local people used to remove common water crowfoot (*R. aquatalis*) from the Hampshire Avon and use it as cattle fodder. A more recent study by Preston *et al.* (2001) suggests cattle also eat stream water crowfoot (*R. penicillatus*).

Curiously, it is widely held that many *Ranunculus* species can be poisonous to livestock and humans, with symptoms of poisoning in dairy cows including red-tinted or bitter tasting milk, colic diarrhoea and, in extreme cases, death (Long, 1924; Clapham *et al.*, 1957; Mabberley, 2008). Although Long, 1924, pp.10) describes *R. aquatalis* as ‘quite harmless’ to cattle, it is unclear as to its exact effect. Other aquatic *Ranunculus* species occurring in chalk streams, such as the three-lobed water crowfoot (*R. tripartitus*), are thought not to be eaten by cattle, with the Devon Wildlife Trust suggesting that the presence of livestock may actually enhance the survival rate of *R. tripartitus* (Devon Wildlife Trust, 2008). This is supported by evidence from Pavlu *et al.* (2008), whose work found that introducing grazing to unmanaged, semi-natural grasslands resulted in an increase in the abundance of *Ranunculus* species.

As well as it being unclear as to whether cattle do or do not eat the ecologically valuable vegetation found within chalk streams, it is not known whether cattle display the same non-herbivory behaviours in chalk streams as recorded elsewhere. In the dry continental

climate of northeast Oregon (e.g. Ballard and Krueger, 2005a) or semi-arid New Zealand (e.g. Davies-Colley *et al.*, 2004), the need for cattle to use rivers for drinking or thermal cover is obvious; it is less obvious whether these needs are so pressing in temperate England.

### **3.5. Summary**

As discussed, excessive cattle grazing can induce negative ecological and geomorphological impacts, whilst well-managed cattle grazing may in specific cases engender benefits. Nonetheless, it remains clear that the majority of studies identify cattle as significant geomorphological and ecological agents in the landscape. Although our existing knowledge base is somewhat biased, with the literature dominated by studies from North America and Australasia, too few investigations considering below threshold or non-critical grazing intensities, and particular stakeholders championing particular perspectives, the overriding finding is that cattle generally degrade their environment, whether aquatic, riparian or terrestrial.

With respect to cattle grazing behaviour, it is clear that animal activity is a function of landscape and non-landscape controls. Evidence for this comes from both qualitative and quantitative theoretical behavioural models, and empirical studies. However, although much has been written about cattle behaviour within the terrestrial and even the riparian environment, there is a dearth of studies concerned with in-stream cattle activity. Furthermore, there is relatively little scientific evidence explaining cattle impact and behaviour in the chalk stream environment. Whilst this thesis will study the behaviour of cattle grazing in lowland chalk streams, further research into general cattle-waterbody interactions will be necessary in the future.

## 4. Study theory and hypotheses

### 4.1. Introduction

Despite the aforementioned gaps in our knowledge with respect to the impacts of cattle grazing upon chalk streams, it is possible to speculate as to what might occur across our experiments. Here a number of theories, hypotheses and conceptual models based both upon existing ideas and original thinking are put forward.

### 4.2. Behaviour and the landscape

With reference to ingress and egress from the river channel, it is hypothesised that the landscape will present a number of natural barriers that deter or prevent cattle access at certain points. The barriers are likely to be geomorphological (e.g. bank height, bank angle, bank stability, channel depth, surface roughness, etc) and hydrological (e.g. water velocity, water height, in-stream turbulence, etc: Figure 4.1). As a consequence of this, and as seen in anecdotal evidence of cattle access along the River Meon, it is thought ‘hotspots’ or preferential areas of cattle activity are likely to develop.

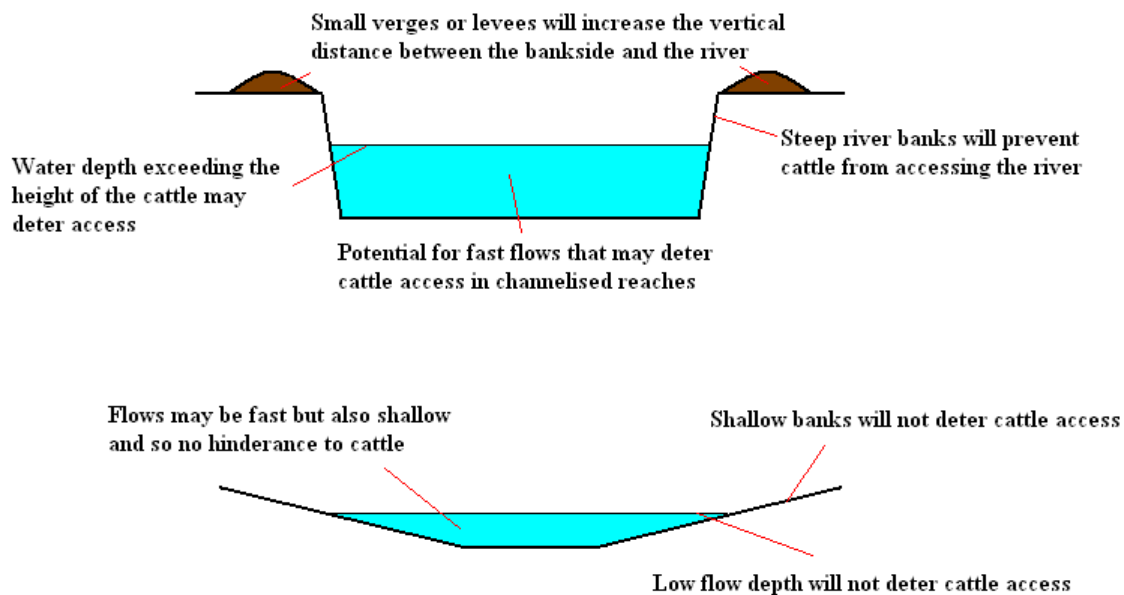


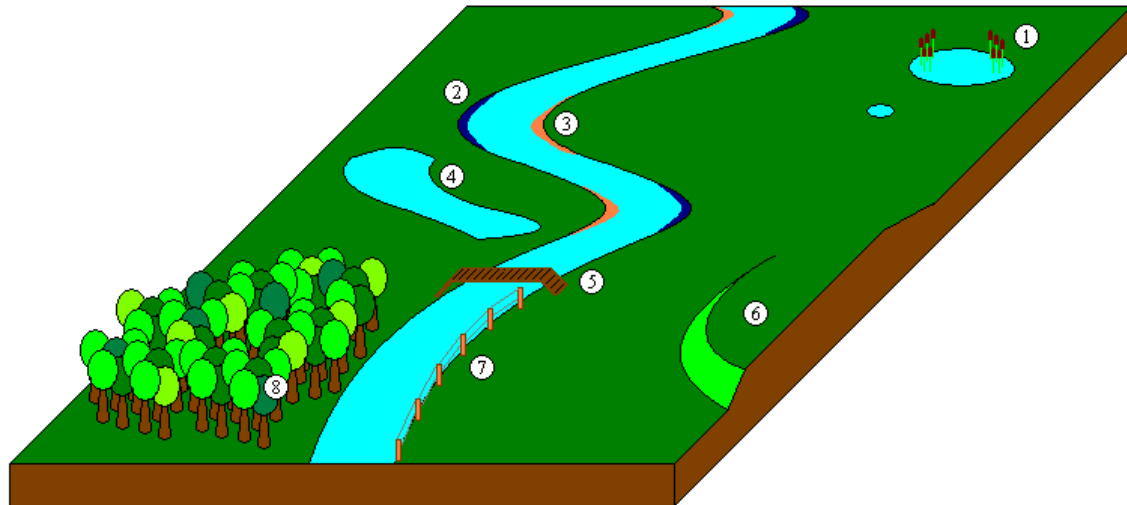
Figure 4.1. Natural barriers to river utilisation by cattle.

In addition to natural physical barriers influencing cattle activity, it is likely that manmade structures will affect behaviour (Harrington and Conover, 2006; Tomkins and O'Reagain, 2007). Barbed wire and electric fences have often been used as a means of controlling cattle access to rivers and environmentally sensitive areas (Boone and Hobbs, 2004; Somers and Hayward, 2012). However, it is unclear as to how the presence of such structures influences behaviour beyond preventing access; cattle may avoid fences entirely, use the adjacent area up until a point, or selectively spend time in fence-adjacent areas, perhaps out of curiosity. Bridges for vehicles, pedestrians and cattle crossings will also influence behaviour, with cattle using such features to access different parts of the landscape (Davies-Colley *et al.*, 2004). In cold weather, cattle may use such crossing points preferentially to avoid heat loss induced by crossing a ford. In the summer, this behaviour may be reversed, with cattle potentially accessing the river at any shallow point either as a means of crossing or for thermal regulation (Bond *et al.*, 2012).

Vegetation community composition will also affect behaviour (see section 3.4). Understanding precisely how behavioural mechanisms, such as optimal foraging and rate maximisation, will manifest themselves in a chalk stream landscape requires an understanding of the typical vegetation productivity and distribution within such environments (Pyke *et al.*, 1977). For example, relict channels or historic drainage ditches beyond the riparian margin may create muddy, waterlogged habitats that support wetland plant species such as marsh yellow-crest (*Rorippa amphibian*) and celery-leaved buttercup (*Ranunculus sceleratus*; Mainstone, 1999). However, *Ranunculus sceleratus* is thought to be poisonous to cattle (Cooper and Johnson, 1984), whilst many wetland species, such as *Rorippa amphibian*, have relatively low productivity when compared to plant species occurring in drier areas, such as great willow herb (*Epilobium hirsutum*). Add into this the complexity of the riparian vegetation community, which generally contains a higher foraging volume of more palatable plants (Platts and Nelson, 1985), and it becomes increasingly difficult to predict precisely how grazing controls will influence behaviour

Non-grazing controls will also be at work. Wooded areas, whether riparian or otherwise, will provide cattle with thermal cover during summer months (Armstrong, 1994; Kendall *et al.*, 2007: Figure 4.2). During the early spring and late autumn these same areas will retain heat better than the surrounding environment. However, whether cattle will use these areas is unclear; the temperature regulation benefits accrued maybe offset by the poor forage available in sub-canopy environments. Cattle may graze in the open landscape and return to wooded areas to rest, ruminate or sleep.

The need to drink is also a control upon behaviour (Figure 4.2). Fensham and Fairfax (2008) demonstrated in their study of cattle activity across Australian arid lands that large herbivores spent a minimal amount of time in areas without a drinking source. In the chalk stream environment, standing water, water meadow drains and relict channels all provide sources of water away from the main channel. It is unclear as to where cattle will drink from, although it may be reasonable to assume they would prefer clear, fast flowing water from the main channel rather than potentially turbid, slowing moving or stagnant water from floodplain pools and ditches (Willms *et al.*, 2002).



1. Riparian ponds may be used by cattle for drinking
2. Unstable banks and deep water on the outside of meander bends will deter cattle
3. Low gradient banks and shallow water on the inside of meander bends will encourage cattle
4. Relict channels may be used by cattle for drinking
5. Human structures will influence behaviour; cattle may use bridges and fords to cross rivers
6. Areas of above average elevation may have better drainage and hence plant growth, encouraging usage by cattle
7. Fences will prevent cattle accessing the river or corral them into certain areas or crossing points
8. Trees may be used by cattle for shading in the summer and insulation in the winter; trees may be avoided due to the low quality forage found beneath their canopies

**Figure 4.2** Areas likely to be used by cattle in a typical chalk stream landscape.

#### **4.2.1. Drivers of cattle-river interactions**

There are a number of theoretical reasons as to why cattle would utilise the aquatic environment. Cattle may enter rivers to drink water. It is possible that the clear, cool, fast flowing water found in chalk streams is preferred by cattle; turbid, warm, stagnant or slow flowing water found within relict channels, ditches and water troughs may be less appealing (Willms *et al.*, 2002).

Cattle may also enter rivers to graze aquatic or riparian vegetation, either because such vegetation has greater nutritional value than that in the terrestrial environment, or because terrestrial vegetation sources have been exhausted (Platts and Nelson, 1985); as per the optimal foraging theory (Clutton-Brock, 1981). Equally, cattle may enter the river to access parts of riparian trees that can only be browsed in-stream; chalk streams often

have riparian trees lining parts of their banks and significant parts of such trees may be accessed by standing in the aquatic environment.

River access by cattle could also be for thermoregulation (Armstrong, 1994; Kendall *et al.*, 2007; Legrand *et al.*, 2011). Cattle may bathe or stand in the lotic environment to lower their body temperature. Such activity would most likely manifest during the summer months, although an absence of trees and other shading elements within the landscape would improve the likelihood of this behaviour at other times (Legrand *et al.*, 2011).

In-stream activity could also be a function of the need to access parts of the landscape that are only accessible by crossing the river. The probability of this behaviour is a function of many of the landscape elements previously discussed. In particular, the river planform will be important; cattle are more likely to want to cross the river if the landscape is split into equal parts by the river channel than if the river channel runs along one side of the accessible landscape (Wallis de Vries and Schippers, 1994).

There may be other less intuitive drivers of cattle-river interactions. Some of these may be identified through observation whilst others may remain unknown even with research; any number of stochastic physiological and psychological factors could influence behaviour (Murphey *et al.*, 1995; Bagshaw, 2001; Hunt *et al.*, 2007).

Equally, cattle may access rivers indiscriminately. Despite the obvious differences in physical characteristics between the terrestrial and aquatic environments, cattle may see rivers as simply another part of the landscape. Although the evolutionary history of ungulate herbivores and the association of rivers with death due to predation and drowning (Oakleaf *et al.* 2003; Beschta and Ripple, 2011), amongst other factors (e.g. humidity: Gillen *et al.* 1985), makes this unlikely, it remains a possibility.

Ultimately cattle-river interactions will be a function of both stochastic and deterministic drivers. There are internal mechanisms such as overheating and thirst that will force cattle to utilise rivers to survive (Willms *et al.*, 2002; Legrand *et al.* 2011). There are also



external mechanisms that are not necessarily predictable and that do not necessarily produce a consistent outcome but which lead to cattle access to rivers, such as the distribution of forage across the landscape (Marion *et al.*, 2005). Both types of mechanism are important according to the existing literature (deterministic e.g. Parsons *et al.* 2001; and stochastic e.g. Guo *et al.*, 2009); the quantitative and qualitative analysis in subsequent chapters is conducted with this view.

#### **4.2.2. Cattle-made landforms**

##### *4.2.2.1. The theoretical basis for the formation of cattle-made landforms*

The force exerted by cattle as they move through the landscape results in soil compaction and displacement, as well as river bank shearing and destabilisation (Trimble and Mendel, 1995). In order to be geomorphic agents in this way, cattle must generate and apply forces greater than those the landscape can withstand. A basic calculation of the force exerted by a cow considers the mass of the animal and its acceleration due to gravity:

$$F = mg$$

Where  $F$  equals force,  $m$  is the mass of the cow and  $g$  is acceleration due to gravity. Given that a domestic cow typically weighs approximately 500kg, it can be calculated that a static animal will exert around 5000N of force. The pressure generated by such a force can be calculated:

$$P = F/A$$

Where  $P$  equals pressure (stress),  $F$  is force and  $A$  is the area over which the force is applied. In a static, standing cow the force will be spread across the basal area of four feet, with a contact area per foot of approximately  $10\text{cm}^2$ . Resultantly, the total vertical stress exerted may be  $1.25 \times 10^6\text{Pa}$ ; Scholefield and Hall (1986) suggest a pressure of  $0.25 \times 10^6\text{Pa}$  in their study, as derived from their use of a mechanical simulator and measurements of resultant soil deformation.

In practice, cattle only spend a fraction of their time standing statically (Ganskopp and Bonhert, 2009; Guo *et al.*, 2009). The majority of geomorphic agency by cattle involves movement and dynamic forces (Trimble and Mendel, 1995). Consequently in most scenarios the acceleration due to gravity component is replaced by acceleration due to movement, with force given as:

$$F = ma$$

Where F is force, m is the mass of the cow and a is acceleration due to movement. Recent work by Tanida *et al.* (2011) suggests that cattle acceleration in the vertical dimension can be greater than  $40\text{ms}^{-2}$ , and over  $150\text{ms}^{-2}$  in the lateral dimension. If these accelerations are taken to be correct, the vertical pressure (stress) created by a cow placing its weight on to a horizontal surface on one hoof could be as high  $10^7\text{Pa}$ , and the lateral pressure (shear stress) could be  $10^8\text{Pa}$ .

The ramifications of applying such a pressure will vary according to soil properties and conditions. In chalk stream environments, where soft peat soils characterise the floodplain, the potential for shearing, compaction and soil displacement in the terrestrial environment is high. Accordingly, terrestrial cattle-made landforms such as cattle trails and cow ramps (Trimble, 1994) should develop within chalk stream environments containing cattle.

In-stream consequences of pressure resulting from cattle movement are less clear. The force applied will be dampened by the dissipation of energy through water and reduced acceleration in the aquatic environment. Moreover, in-stream sediments are distinct from terrestrial soils, both in their composition and response to forcing; chalk streams are often characterised by armoured gravel beds whose coarse, concreted sediments are difficult to mobilise (Mainstone, 1999).

#### *4.2.2.2. Factors determining the location of cattle-made landforms*

The controls on the development of landforms created by cattle are not known, but can be reasonably hypothesised. Telezhenko *et al.* (2007) and Platz *et al.* (2008) note that housed cattle preferentially select, and incur health benefits from using, soft, non-slippery surfaces when walking. However, it has also been observed by Phillips and Morris (2001) that cattle walk relatively slowly when moving through deep (12.5cm) excreta, likely due to the additional resistive forces encountered.

These generic controls on cattle locomotion will help determine the distribution of cattle-made landforms. The two features known to form as a function of geomorphic agency by cattle are cattle trails and cow ramps (Trimble, 1994; Trimble and Mendel, 1995); where these landforms might develop in an archetypal chalk stream environment is discussed.

#### *4.2.2.3. Cattle trails*

Cattle trails are created by the repeated force exerted by cattle along paths that they preferentially use. They vary in length, depth and width according to usage and local environmental conditions (see section for a detailed description; Trimble, 1994).

Cattle should theoretically create trails along pathways that not only connect different parts of the landscape through which they travel, but that also use the path of most efficient resistance (Figure 4.3; Phillips, 2002). Specifically, cattle should be expected to choose surfaces with moderate roughness, firm topsoil and limited organic matter (Phillips and Morris, 2003). In addition cattle trails may be more likely to form under shade and in areas with protection from the wind (Mader *et al.*, 1999), whilst they may be absent near electric fencing (Hoare, 1992; McKillop and Silby, 1998).

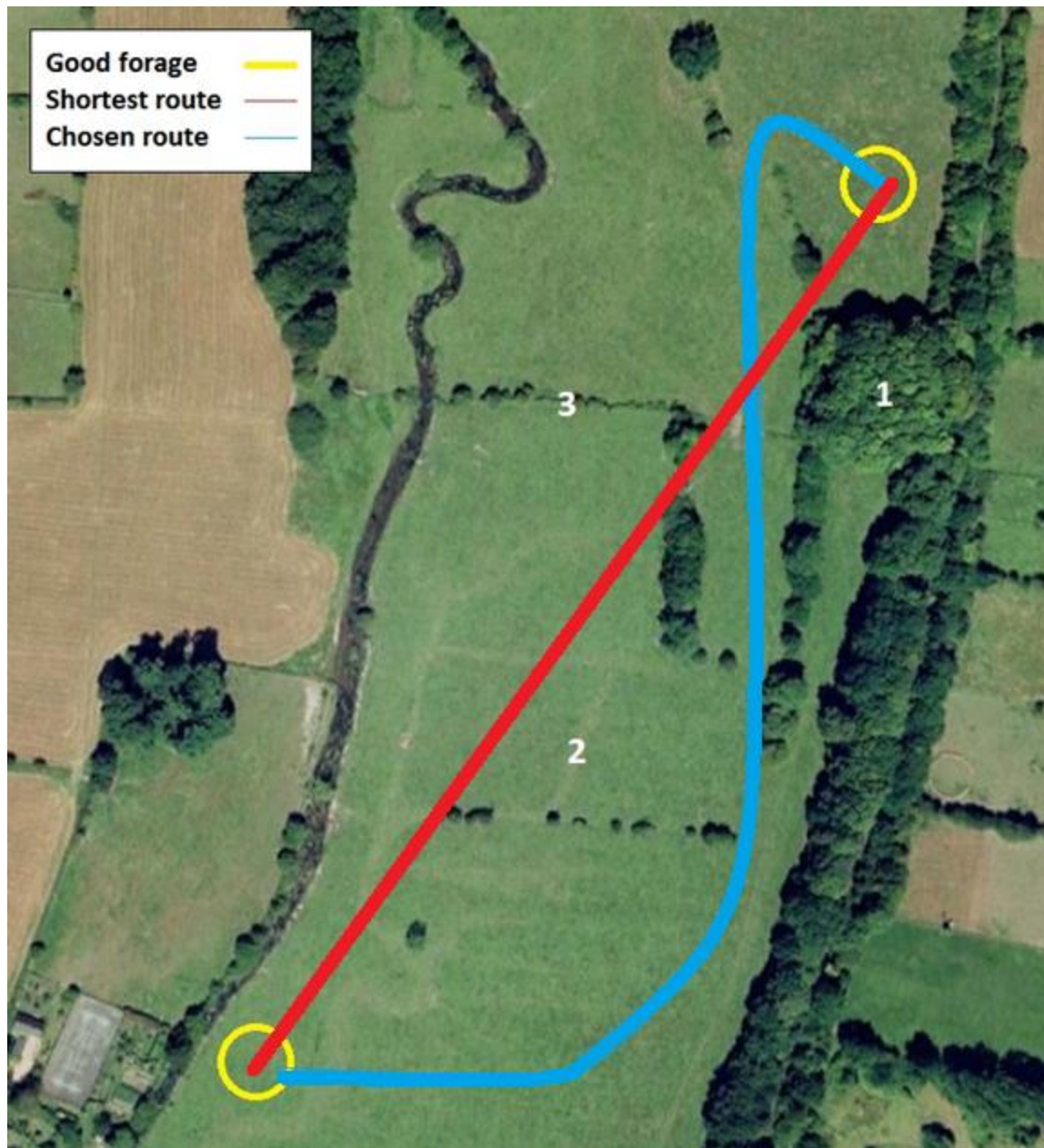


**Figure 4.3. The River Meon at Droxford (a chalk stream). Cattle trails will not necessary develop along the shortest route between two points of interest. 1. A high density of deciduous trees leads to high organic soil content following leaf-fall, and cattle avoid these soft soils. 2. A relict, waterlogged drainage ditch with deep, soft soils may deter cattle. 3. Fencing or hedgerows may act as a physical barrier to cattle trail formation (Google Inc., 2012).**

Additionally, physical barriers, whether natural or man-made, will inhibit cattle movement. Trees will be walked around, whilst fences will restrict and potentially channel cattle into certain locations. Tall, dense grass may be avoided, and trails are

unlikely to bisect areas of steep relief. Areas that are topographically variable (e.g. hummocks, relict drainage ditches) are likely to be bypassed, as should man-made features such as pylons and disused water meadow structures (e.g. bridges).

#### *4.2.2.4. Cow ramps*

Additional factors will influence the development of river access features. It is known that cattle have poor depth perception (Phillips, 1993; Grandin, 2007), and hence they should avoid entering the river where its depth is not perceptible; either genuinely deep areas, areas with a low Secchi depth due to turbidity, or areas where cattle cannot clearly see the water's surface (e.g. due to shading from trees or reflection from light).

It is also probable that cattle will avoid entering the river where its banks are steepest; such locations may be difficult to traverse, whether entering or exiting the aquatic environment (Mueggler, 1965; Cook, 1966); even where river banks are relatively shallow, if the material composition is not conducive to cattle locomotion (e.g. deep, silty berms) then these locations may be avoided (Phillips, 2002). Theoretically the chosen places for cattle crossing in chalk streams should be riffles (shallow with firm gravel bed substrate), and the locations avoided by cattle should be pools (deep with soft silt deposits) or sections of river with steep banks.

Riparian trees will also play a factor in the spatial distribution of cow ramps (Trimble, 1994). Tree roots, which are difficult for cattle to traverse, may present an obstacle to cattle access; soil that would otherwise be poached by cattle activity will be retained (Adams, 1975).

As with cattle trails, the location of cow ramps will also be determined by the availability of forage and the location of landscape features important to cattle. Cattle should not make access features between unused landscape elements, and it could be assumed that cattle will choose the shortest and most convenient crossing point between forage areas if given the choice between geomorphologically and hydrologically similar locations.

Finally, man-made structures will effect cow ramp location. Cow ramps will only develop in unfenced areas, and if river access is restricted then cow ramps may develop in sub-optimal areas for crossing.

All of these different factors will come together to determine the location of cow ramps (Figure 4.4)

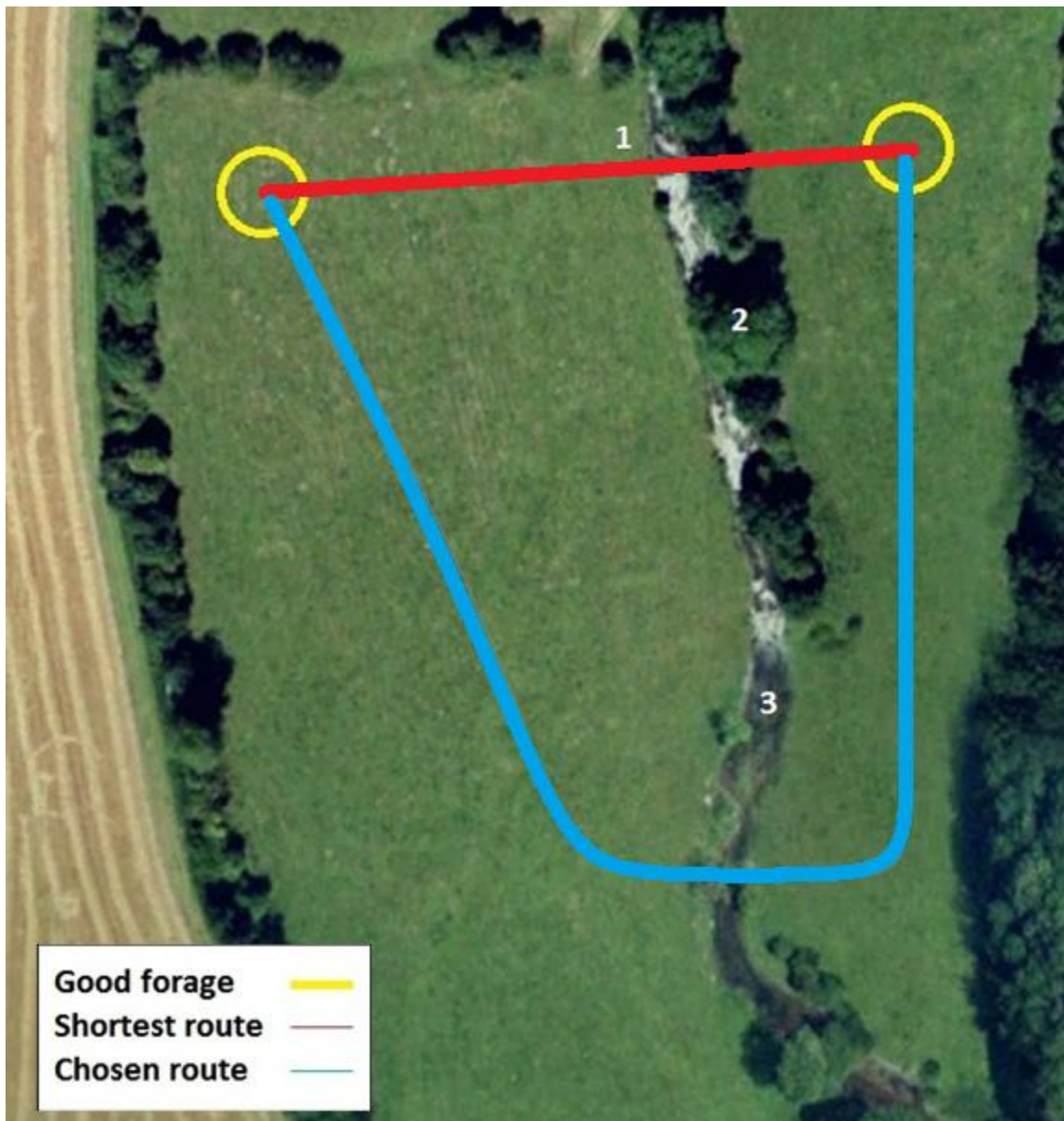


**Figure 4.4.** The River Meon at Droxford (a chalk stream). Cow ramps will not necessarily form on the river banks along the shortest route between two points of interest. 1. Fencing on the east side of the river prevent cattle from creating a cow ramp here. 2. Dense riparian vegetation and trees

**prevent cattle access and cow ramp formation. 3. Pools are too deep for cattle to cross and cow ramps do not form on pool-adjacent river banks (Google Inc., 2012).**

### **4.3. Cattle grazing effects and the landscape**

If there is a general bias in the literature it is towards the overall negative impact of cattle in and around rivers (see Belsky *et al.*, 1999, in which no positive effects of cattle grazing in riparian zones were found). However, and despite a few notable papers (e.g. Kauffman and Krueger, 1984; Milchunas *et al.*, 1988; Trimble and Mendel, 1995), there has been no attempt to collate the existing knowledge into a conceptual model of grazing impacts upon rivers. Figure 4.5 shows how the three outcomes of grazing impact might manifest themselves in the riverine environment.



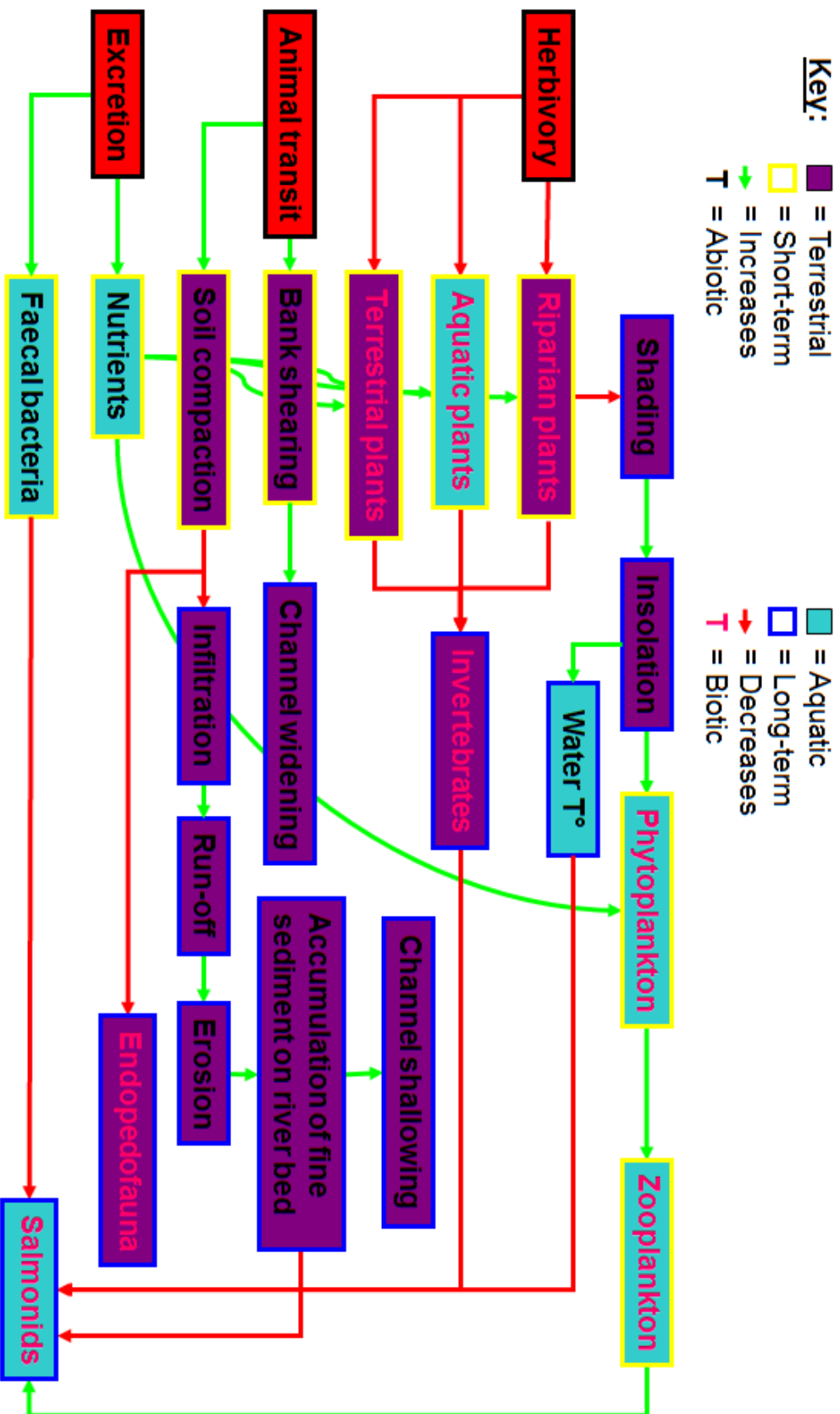


Figure 4.5. A conceptual model of excessive cattle grazing in streams. The three drivers (herbivory, animal transit and excretion) are to the left in red boxes. Short-term impacts may occur between 0–2 years. Long-term impacts may take several years to manifest. The rapidity of impact onset is a function of numerous factors, including grazing intensity and environmental conditions. This model represents the effects of excessive, rather than moderate or light cattle grazing.



Although somewhat simplified, the above model does provide a basic series of steps that explains how rivers subject to excessive grazing can change over time. What the model does not consider is how a river might change given a moderate or low grazing pressure. Nonetheless, there are several theoretical models within the discipline of ecology that suggest cattle activity may enhance aquatic and riparian biodiversity.

The predation hypothesis developed by Paine (1966) identifies the increase in prey diversity that results from predators preventing the monopolization of one species. Dominant species often competitively exclude less-dominant species and the removal of these dominant species improves resource availability and competitiveness between less-dominant species (Paine, 1966; McCauley and Briand, 1979).

Although useful and generally applicable, the predation hypothesis was superseded in ecological theory by the now widely cited intermediate disturbance hypothesis (Grime, 1973; Connell, 1978; Wilkinson, 1999). The hypothesis suggests that biodiversity within a community is maximized in the presence of occasional, although neither too frequent nor too seldom, disturbance (Connell, 1978). At low levels of disturbance, communities can become homogeneous and devoid of structure as competitive exclusion by dominant species can create a monoculture. At high levels of disturbance, environmental stress can be so severe that only the most resistant and resilient species can survive. Evidence for this can be seen in numerous environments, including lotic systems (e.g. Ward and Stanford, 1983; Pollock *et al.*, 1998; Everall *et al.*, 2012), and the theory can be applied to cattle grazing in chalk streams also (Figure 4.6).

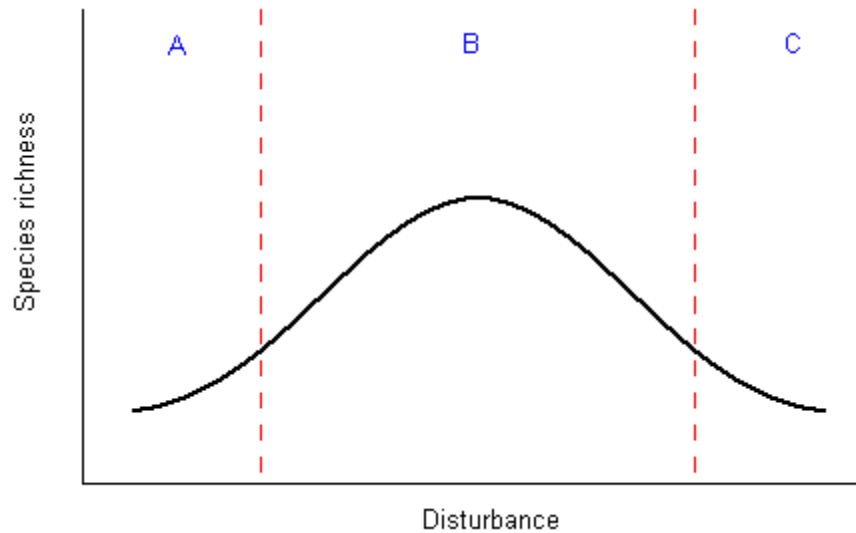


**Figure 4.6** A graphical representation of the intermediate disturbance hypothesis. In chalk streams, section A represents unmanaged sites, infrequently cut, uniform riparian swards, and riverside vegetation beyond fenced margins. Section C represents excessively grazed locations, those rivers subject to frequent sediment inputs due to weed cutting or other causes, and overly fished locations. Section B represents a theoretical location where species richness is optimised, possibly due to moderate cattle activity.

The intermediate disturbance hypothesis, when considered in these terms, provides the basis for a different conceptual model of the interactions between grazing pressure and impact in which diversity rather than destruction may result.

In reality, and as highlighted by Huston (1979) in the Huston model, as well as others (Bornette and Amoros, 1996; Thorp *et al.*, 2006) natural ecosystems are more complex than appreciated by the intermediate disturbance hypothesis. Specifically, understanding the frequency and magnitude of disturbance, as well as the recovery rates of prey populations, is important (Huston, 1979). There may be significant differences in the response of a community to high frequency, low magnitude forcing compared to low frequency, high magnitude forcing. Moreover, different species may exhibit different responses based upon their evolutionary exposure to pressure, which may have equipped certain species with morphological and genetic adaptations that make them more resilient and resistant. Indeed, Milchunas *et al.* (1988) put forward an interesting theory that argues plant species adapted to tolerate water stress, with basal meristems, high shoot

density and deciduous shoots, etc, are well placed to tolerate similar pressures, such as grazing.

All of these factors are likely to cause deviation between the predictions of our existing qualitative models and the observed reality. Nonetheless, there are a number of theoretical ways in which cattle activity specifically could enhance biodiversity within chalk stream systems, and they stem from the three impacts of cattle grazing: herbivory, excretion and animal transit.

#### **4.3.1. Herbivory**

The principle way in which herbivory could improve biodiversity is by inducing plant mortality in homogeneous vegetation communities. Improved light availability due to reduced sward height, reduced competition for resources due to plant mortality, and the removal of invasive or alien species are the mechanisms through which this could occur. Areas previously dominated by one or two species may experience changes in community structure and composition that allow for the establishment of less competitive but equally ecologically valuable species. Evidence for these mechanisms has already been recorded in species-rich and species-poor grassland in England (Tallowin *et al.*, 2007), the Ethiopian highlands (Mwendera *et al.*, 1997), vernal pools in California (Marty, 2005) and semi-natural grassland in southern Finland (Pykälä, 2003; Pykälä, 2005).

It is also possible that cattle may eat in stream plants such as *Ranunculus*, although, as previously mentioned, some such plants may be poisonous to livestock (Long, 1924). Moreover, cattle may not feel comfortable submerging their heads in water for prolonged periods and so may graze from the surface rather than removing macrophytes by the root. If cattle can and do eat in stream macrophytes then this may help prevent excessive plant growth, which may otherwise require management by weed cutting. Weed cutting, whilst effective in reducing flood risk and improving fishing conditions in the short-term, is expensive, and can lead to homogenized macrophyte communities (Haslam, 1978;

Baatrup-Pedersen and Riis, 2004). Allowing cattle access could potentially maintain a stable level of in stream macrophyte density whilst retaining community diversity.

#### **4.3.2. Animal transit**

In terms of animal transit, and as geomorphic agents, cattle have the potential to create a range of different landscape features that would not develop in their absence (Trimble and Mendel, 1995). For example, sustained, light poaching at the river bank will eventually lead to lower, shallower banks as bank material is moved mechanically by cattle (Trimble, 1994). As well as improving connectivity between the main channel and the floodplain by lowering bank height, this cattle activity has the potential to develop new habitats with slow, low flows. Indeed, focused cattle activity anywhere across a chalkland floodplain could create wetland habitat, with soft, sodden, peaty soils offering little mechanical resistance. Such habitats would encourage the establishment of typical wetland plants, including water speedwell (*Veronica anagallis-aquatica*) and whorl grass (*Catabrosa aquatica*: Mainstone, 1999).

In stream cattle transit may also incur benefits. Siltation can deoxygenate spawning gravels and reduce the rate of survival to emergence (Acornley and Sear, 1999; Armstrong *et al.*, 2003). The disruption of concreted and armoured gravel substrate by cattle hooves may help in the mobilization and removal of trapped fine sediment particles, thereby reducing egg mortality (Greig *et al.*, 2005; Greig *et al.*, 2007). Furthermore, more easily mobilized gravels may reduce the energy expenditure requirements of salmonids when creating redds, potentially improving the likelihood of individuals returning to spawn again in future years (Montgomery *et al.*, 1996; Kemp, 2011). Fine sediment suspended due to cattle activity may travel downstream and deposit in areas of slow flow, such as pools, or shallow vegetated berms created by cattle poaching. These habitats in turn facilitate further biodiversity; brook lamprey use areas of siltation as a nursery habitat (Maitland, 2003), whilst the submerged macrophytes present in such areas provide cover for adult bullhead (Tomlinson and Perrow, 2003).

#### 4.3.3. Excretion

In the terrestrial environment, sites of cattle excretion, or excretion hotspots, are likely to encourage spatial heterogeneity in vegetation community composition (Malo and Suarez, 1995; Augustine and Frank, 2001).

Firstly, seeds from particular plant species may occur more frequently in dung than otherwise; dung produced by cattle in alvar limestone grassland in Sweden is dominated by the seeds of *Arenaria serpyllifolia* (Thyme-leaved sandwort: Dai, 2000). Several plant species use endozoochory as a means of seed distribution and zones of excretion are likely to develop characteristic communities as a consequence (Malo and Suarez, 1995; Traveset *et al.*, 2007; Vavra *et al.*, 2007).

Secondly, cattle excrement, whether faecal or urinary, contributes organic matter and nutrients to the environment. In particular, excretion from cattle is a source of nitrogen and phosphorous that in high enough concentrations can promote plant growth and improve forage yield (Norman and Green, 1958; Lantinga *et al.*, 1987). Consequently, areas containing excrement are likely to experience relatively rapid growth and increased competition compared to unfertilized areas, contributing to spatial heterogeneity in vegetation community structure.

Thirdly, the presence of dung, particularly in hotspots, may deter cattle from grazing in these areas due to dung composition and odour (Dohi *et al.*, 1991; Bosker *et al.*, 2002; Oudshoorn *et al.*, 2008). This in turn could allow for the establishment of different plant species: Loydi and Zalba (2009) note how the grazing intolerant grass *Nassella clarazii* thrives in areas of horse dung because local horses avoid grazing these areas.

Beyond vegetative growth, animal dung can support communities of fungi, worms, flies, nematodes, springtails, other endopedofauna, and detritivores (Greenham, 1972; Persson *et al.*, 2000; Curry *et al.* 2008). The largest group of creatures that exploit this niche are the dung beetles (*Aphodiinae* spp.; *Scarabaeinae* spp.), the diversity and abundance of

which can improve in areas subject to grazing (Verdú *et al.*, 2007). These insects in turn perform numerous beneficial ecosystem functions; Nichols *et al.*, (2008) note the role played by dung beetles in recycling nutrients, enhancing plant growth, bioturbation, parasite control, secondary seed dispersal, pollination, trophic regulation, and acting as prey items. In England, English Nature (2001) recognizes the importance of cattle dung in attracting the rare *Cosmetopus dentimanus* fly.

#### **4.4. Ecological windows, cattle impact and chalk stream environments**

The previously discussed theories and hypotheses must be considered within the context of ecological windows (windows of opportunity: Francois, 1998; Stone *et al.* 1999; DeGasperis and Motzkin, 2007), the seasonality of the chalk stream ecosystem, and the management of cattle.

Although land owners may graze livestock any time of the year, the grazing season is focused between May and October (Hester *et al.*, 1996; Newton *et al.*, 2009). Extensions beyond this period are uncommon in English chalk stream environments, but will vary annually according to the antecedent environmental conditions and subsequent sward growth. Where cattle are kept principally for land management, rather than monetary gain, the period of cattle exposure may only be a few months during the peak of summer (Flora Locale, 2009). Hence, aside from lagged and indirect effects, the direct, in-stream and riparian impacts of cattle can only result when the cattle are present.

Logically therefore, only the fauna and flora whose lifecycles coincide with the grazing season will be directly impacted by cattle. Given the seasonality in the presence of the organisms that typically inhabit chalk stream environments, this means that several species may be unaffected by the activity of cattle in streams.

For example, fish species from the salmonidae family (Atlantic salmon: *Salmo salar*; brown/sea trout: *Salmo trutta*) generally spawn during the winter months, and specifically the months of December and January in English chalk streams (Acornley and Sear, 1999; Greig *et al.*, 2007). Of all their life-cycle stages, fish are most vulnerable during the

spawning and incubation periods due to the relative immobility of embryos and eggs (Kemp *et al.*, 2011). For salmonids the main risk during these periods is fine sediment accumulation in spawning gravels and the deoxygenation of redds (Greig *et al.*, 2005). Although theoretically cattle would enhance salmonid egg mortality due to increased fine and organic sediment inputs from bank destabilisation and animal faeces, cattle are not present in the environment during the spawning period and therefore cannot have a direct effect upon salmon populations at this time.

This is not to say that the presence of cattle outside specific ecological windows does not affect those organisms or the environment. There are many theoretical ways in which indirect effects could occur.

With respect cattle excreta, it is likely that disintegrating faeces will continue to contribute nutrients and organic matter to the fluvial environment when cattle have been removed. Faeces can remain for between two to 12 weeks after deposition, depending upon the rate of decomposition, which is predominantly dependent upon the meteorological conditions (Dimander *et al.*, 2003). During this time, phosphorous, nitrogen and potassium may be gradually leached through the soil and into the river, whilst rainfall events can mobilise entire cow pats during instances of overland flow (McDowell *et al.*, 2008; Muirhead and Littlejohn, 2009).

There may also be remnants of physical impact that remain beyond the grazing season. Cattle-made landforms and cattle-induced changes in river channel morphology will exist in the absence of cattle (Trimble and Mendel, 1995). Certain features, such as cow ramps, may be self-sustaining following the cessation of cattle pressure if other processes (e.g. overbank flow and scouring) occur (Trimble, 1994).

Additionally, the effect of changes induced in the environment by cattle during the grazing season may not manifest themselves in terms of impact until cattle are removed. Such effects rely upon seasonal changes that occur outside the period of cattle grazing. For example, cattle may reduce the stability of river banks, but not necessarily

sufficiently to cause bank failure. When the bank is subject to heavy precipitation events, bankfull or overbank flows, and soil saturation during the winter months, the bank may fail; partly as a function of the pressure applied by cattle throughout the grazing season. Whilst similar lagged effects due to cattle have been observed with respect to plant composition (Foran, 1986) and nutrient inputs (Hubbard *et al.*, 2004), as Trimble and Mendel note (1995) note, there is little known about geomorphic lag effects.

The biotic elements of the chalk stream environment are also likely to be influenced outside of the grazing season as a consequence of changes that occur during the grazing season. Additional nutrient loading from cattle faeces will enhance the availability of essential plant building materials in the soil for a period after cattle removal, and may encourage competitiveness amongst winter plant species. Defecation hotspots, preferential locations for grazing, and areas of cattle poaching will maintain heterogeneity in vegetation community distribution and composition for some time following cattle exclusion (Peinetti *et al.*, 1993; Dimander *et al.*, 2003; Oudshoorn *et al.*, 2008).

All of the aforementioned considerations are pertinent in the context of when biota are in the chalk stream environment, and when they are most susceptible to the effects of cattle grazing (Figure 4.7).



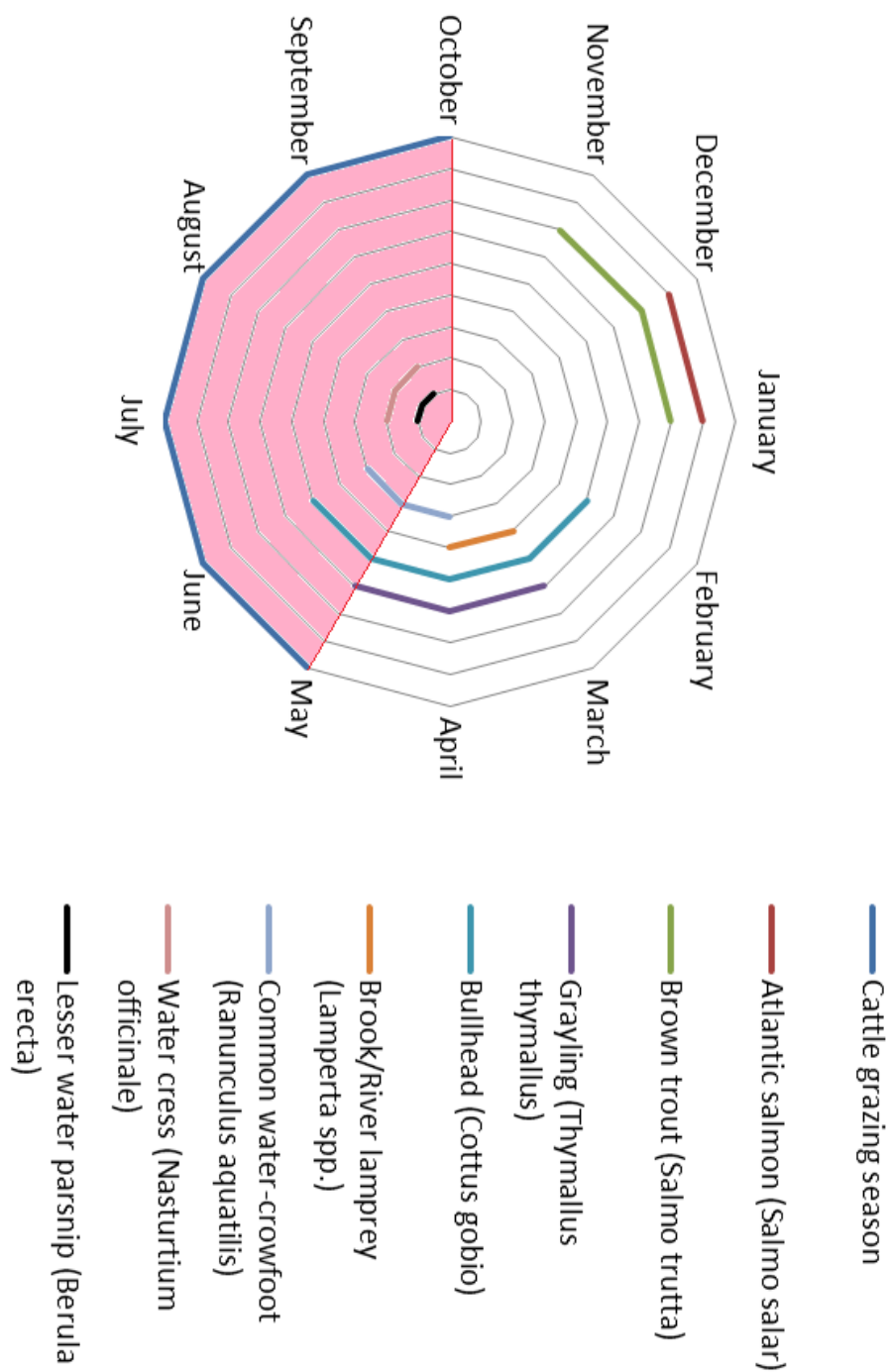


Figure 4.7. Different species of fish and macrophyte are at their most vulnerable during different periods of the year, and these periods may or may not coincide with the cattle grazing season. The pink area within the red lines highlights the cattle grazing season. The figure shows that typically cattle are not present during the salmon and trout spawning period (November-January).

## 4.5. Discussion

There are an increasing number of studies that support the notion of cattle as management tools for maintaining species-rich ecosystems. Indeed, the usefulness of cattle as

ecosystem engineers has been demonstrated, theoretically at least, by Derner *et al.* (2009) in their paper on restoring grassland bird habitat in the Western Great Plains of North America. The key, as highlighted above and by Derner *et al.* (2009), is the heterogeneity within a landscape that cattle facilitate and maintain. As an example, recent work by Yoshihara *et al.* (2010) has shown that grazing by livestock in the Mongolian steppe can lead to spatial heterogeneity in vegetation community composition and soil properties, with associated benefits for biodiversity.

Although none of the work conducted so far is directly analogous to an English lowland chalk stream landscape, the new breed of studies all use the same transferable, biological theory framework. The major problem in applying these ideas in practice in chalk stream environments is stakeholder concern. Because there are few quantitative studies into the impacts of cattle upon chalk streams, there is no objective, empirical basis upon which to form an argument for the benefits, or otherwise, of grazing. Consequently, in a landscape with relatively high economic and ecological value, stakeholders may be unwilling to jeopardize ecosystem functionality to test a theory.

There are other barriers to qualifying these ideas. Firstly, for some stakeholders, namely fisheries managers and livestock owners, improving biodiversity may be secondary to improving stock productivity. Secondly, the hydrogeomorphology of English chalk streams is a function of prehistoric glacial and peri-glacial processes; geomorphic agency by cattle, particularly in terms of gravel bed disruption and bank destabilisation, may not be easily rectified by natural processes. Thirdly, there are logistical and financial constraints to testing these hypotheses; identifying suitable sites, finding cooperative landowners, acquiring cattle, procuring GPS cattle collars, etc.

#### **4.6. Testable hypotheses**

The choice of which hypotheses to test is based firstly upon viability and secondly upon importance with respect to improving our understanding. For example, although it would be of great value to test those hypotheses dealing with the ecological components illustrated in Figure 5.5, constraints regarding the response times of such elements to

forcing mean it is beyond the remit of this project. Equally, whilst installing several tens of GPS collars upon cattle across various chalk stream catchments throughout England would enable the testing of hypotheses regarding landscape utilisation (Figure 4.3; Figure 4.4) it is not viable financially or logistically.

The hypotheses that will be investigated are as follows:

H<sub>1</sub> - Air temperature is a driver of cattle-river interactions; cattle use waterways for thermoregulation as suggested by Legrand *et al.* (2011). This is addressed because it is important to understand the drivers of river-utilisation if cattle are to be effectively managed, particularly at a time of global climate change. This hypothesis is investigated in section 6.1.

H<sub>2</sub> - Cattle will spend more time in areas with better quality forage (relative to the area available), such as riparian zones, than in areas with poor quality forage, such as valley slopes, as suggested by Huber *et al.* (1995). This is addressed because riparian areas are relatively high biodiversity transitional zones that link the terrestrial and aquatic environment. Cattle may spend time in such areas because of the comparatively good forage available, potentially harming the organisms that inhabit riparian zones. This hypothesis is investigated in section 6.1.

H<sub>3</sub> - Cattle-made landforms, such as cow ramps and cattle trails, form in areas used most regularly by cattle, as suggested by Trimble (1994) and Trimble and Mendel (1995). This is addressed as no previous study has explicitly shown that cattle-made landforms are created in the areas most frequently used by cattle; the connection is assumed. If the locations in which cow ramps and cattle trails will form can be predicted based upon the spatial distribution of cattle, it may be possible to prevent the geomorphic effects of cattle grazing in particularly vulnerable areas. This hypothesis is investigated in section 7.7.

H<sub>4</sub> – Soils in areas subject to greatest usage by cattle will have a lower horizontal shear stress than areas infrequently used by cattle. This hypothesis connects cattle behaviour to geomorphic agency by cattle, and is investigated in section 7.4.

H<sub>5</sub>- The areas of greatest risk from diffuse pollution and fine sediment sources created by cattle are those with the greatest connectivity to the landscape and which cattle most frequently occupy. As with H<sub>4</sub>, this hypothesis connects behaviour with geomorphic agency, suggesting that cattle trails and cow ramps act as pathways for fine sediment and diffuse pollution sources at the catchment scale. This hypothesis is investigated in chapter 8.

#### **4.7. Summary**

There is a large volume of literature that can help us hypothesize the ways in which cattle might interact with chalk stream environments and the effects these interactions could have. Theories from applied ethology explain how the need to graze and drink will modulate landscape utilisation in respect to the spatial distribution of water and high quality forage (Platts and Nelson, 1985; Willms *et al.*, 2002). Studies investigating cattle locomotion suggest cattle will avoid steep-sided banks and slippery surfaces when moving through the chalk stream environment, and that chalk stream landscape elements, such as exposed gravels and disused man-made structures, could influence cattle mobility (Phillips and Morris, 2001; Telezhenko *et al.*, 2007; Platz *et al.*, 2008). Combining research into the effects of cattle grazing (herbivory, trampling and excretion) with chalk stream specific scenarios enables us to construct hypotheses describing how archetypal chalk stream species, such as Atlantic salmon and common water-crowfoot, may be affected by cattle. The intermediate disturbance hypothesis theorizes that whatever the effects of cattle, moderate forcing, rather than high or low forcing, will enhance species diversity (Grime, 1973; Connell, 1978; Wilkinson, 1999). Finally, the ecological windows concept helps us understand how seasonality and the time of year may determine the degree and nature of interaction between cattle and the chalk stream ecosystem (Francois, 1998; Stone *et al.* 1999; DeGasperis and Motzkin, 2007).

### *Study theory and hypotheses*

It is evident that existing knowledge can be used to hypothesise about the effects of cattle grazing within chalk stream environments but that without further study our understanding of cattle-river interactions will remain theoretical. To address this, a number of testable hypotheses regarding cattle behaviour and the consequences of cattle behaviour (detailed previously) will be investigated. The next chapter considers the methods and techniques that have been employed before to study cattle and their effects, as well as the methods and techniques that could be used to test the aforementioned hypotheses of this study.

## **5. Grazing research methodologies and study sites**

### **5.1. Introduction**

Broadly speaking, grazing research methodologies can be divided into three groups: behavioural studies, impact studies and modelling studies. Each method is often applied within a different field: behavioural studies are preferred by livestock scientists and rangeland owners; impact studies are typical amongst geomorphologists, ecologists and environmental managers; and modelling studies are conducted by landscape and systems scientists.

The array of different methodological approaches adopted within grazing research is vast. Studies of nutrient intake, excrement content, geomorphic changes, water quality measurements, ecological surveys, atmospheric changes, rates of herbivory, milk and meat yields, GPS animal tracking, and grazing impact models, are just some of the methodologies found within the grazing literature. Regardless of the general field in which they are conducted, all of these research approaches require reviewing if grazing as a whole is to be well understood.

### **5.2. Behavioural studies**

#### **5.2.1. Direct manual observation**

Although several studies have used video cameras (e.g. Griffiths *et al.*, 2006), force sensors (e.g. Pastell *et al.*, 2008), radio-tracking equipment and GPS (e.g. Rutter *et al.*, 1997; Schlecht *et al.*, 2004; Barbari *et al.*, 2006) and even acoustics (e.g. Ungar and Rutter, 2006) to monitor cattle behaviour and activity, the traditional method of cattle monitoring for the purposes of scientific study is direct observation (Altmann, 1974; Van Rees and Hutson, 1983; Mitlöhner *et al.*, 2001; Phillips, 2002). Within this approach are a number of methodologies based upon both the type of sampling applied (i.e. *ad libitum*, focal, scan, behaviour), the time spent recording (e.g. *ad hoc*, time interval, continuous, instantaneous), and the focus of the observation (e.g. diet selection, landscape

and habitat utilisation, foraging behaviour, etc: Boitani and Fuller, 2000; Mitlöhner *et al.*, 2001; Schaich *et al.*, 2010).

#### 5.2.1.1. *Sampling strategies*

*Ad libitum* sampling involves the observation and recording of everything the observer sees. Although useful in establishing the fundamental behaviours of animals, or to identify activity that may otherwise be overlooked in a heavily focused study, this sampling method has two major flaws (Lehner, 1992). Firstly, if the observer has preconceived ideas regarding the importance of a particular activity or individual, then that activity or individual may be over-represented in the results e.g. the way in which early research into primate behaviour overstated the role of males because the research was being conducted by men (Morell, 1993; Boitani and Fuller, 2000). Secondly, whilst the observer is supposed to record everything, those activities or individuals that are particularly eye-catching are more likely to be recorded than inconspicuous (although possibly as important) activities or individuals that the observer may ignore or consider insignificant (Boitani and Fuller, 2000); consequently, *ad libitum* sampling is ill-suited to statistical data analysis (Lehner, 1992).

Focal sampling involves an observer concentrating on the behaviour of one individual. Such an approach neglects overriding trends in group behaviour and may omit contextual information (Lehner, 1992; Boitani and Fuller, 2000). Nonetheless, because focal sampling is detailed, more can be learnt in a given space of time, with validation being added through repeat observation (Boitani and Fuller, 2000). This method is especially effective in groups in which behaviour between individuals is relatively minor, and has been used efficiently in key work by Schaich *et al.* (2010).

Scan sampling requires the observer to record the behaviour of each animal in turn at set intervals (Lehner, 1992). The effectiveness of this technique is a function of the frequency of observation and the maximum duration of observed behaviours (Mitlöhner *et al.*, 2001). Overly frequent observations are inefficient, whilst observations less

frequent than the duration of certain behaviours may omit those behaviours from the results (Boitani and Fuller, 2000).

The final type of sampling, behaviour sampling, simply records the nature, frequency and duration of one or more particular behaviours (Mitlöhner *et al.*, 2001). Useful when concerned with a specific activity, this sampling technique is unlikely to be applicable to a study of cattle impact upon chalk streams unless it is found that one behaviour (e.g. bank trampling) has a far greater impact than any other.

All of the aforementioned approaches have their uses and it is rare that a single method is applied discretely; most studies require the combination of two or more techniques to realise their research objectives (Boitani and Fuller, 2000).

#### 5.2.1.2. *Observation study focus*

Typically an observational study of cattle behaviour will focus upon one or a number of particular animal activities that are relevant to the research objectives. The concern may regard the location of cattle in space, relative to specific landscape features, habitats, the herd, or other fauna (e.g. Bailey *et al.*, 2001). Equally, the researcher may be interested in the type of vegetation the cattle eat, or the frequency with which the subject defecates and urinates (e.g. Lamoot *et al.*, 2005; Oudshoorn *et al.*, 2008). The focus could be upon specific social behaviour, such as aural communication or grooming, or specific internal behaviour, such as digestion or rumination (e.g. Senft *et al.*, 1985; Overton *et al.*, 2003).

Many different study foci are identifiable within the cattle grazing literature. Schaich *et al.* (2010), in their study of cattle grazing in a restored river floodplain in Luxembourg, considered a number of cattle-landscape and cattle-ecosystem interactions. The behaviour of cattle was recorded at 10 minute intervals for 6 hours a day across 48 days. During this period, Schaich *et al.* (2010) counted the number of steps and bites taken by the cattle to gather quantitative information of forage intake and intensity. Researchers also monitored the location of cattle in space, dividing the accessible landscape into broad vegetation patches and counting the amount of time spent in each. Using a similar methodology,



Bagshaw *et al.* (2008) recorded the behaviour of hill-grazing cattle in New Zealand, with an emphasis upon the utilization of water sources (i.e. water troughs and streams) by grazing animals. Additionally, Bagshaw *et al.* (2008) monitored the frequency of drinking, as well as considering the importance of external factors in determining cattle behaviour (e.g. time of day, weather conditions). In a study of free-grazing cattle in western Africa, Schlecht *et al.* (2006) focused instead upon excretion behaviour, the distance travelled by cattle and the duration of grazing, resting and walking behaviour. As well as direct monitoring by human observers Schlecht *et al.* (2006) also employed GPS (global-positioning system) units and GIS; an increasingly popular means of remotely observing cattle for the purposes of scientific research.

### **5.2.2. GPS**

The use of GPS technology to monitor cattle movement is a relatively modern practice dating back to the mid-1990's (Harbin, 1995). In the intervening time the technology and methodologies employed have developed and been refined, such that modern GPS cattle collars are flexible in their application and widespread in their use (Agouridis *et al.*, 2004; Barbari *et al.*, 2006; Cabrera *et al.*, 2007).

Modern GPS cattle collars are increasingly sophisticated. As well as the basic function of recording latitude and longitude at fixed or variable intervals through time, the latest GPS cattle collars also have inbuilt bi-axial directional sensors (to indicate time spent resting and grazing), accelerometers (to detect movement), mortality sensors, temperature sensors and a remote data download facility (Ungar *et al.*, 2005; Moreau *et al.*, 2009). Moreover, some collars can acquire a spatial resolution of up to two meters using differential GPS (Moen *et al.*, 1997). Combined with the capability to take locational fixes as frequently as once every seven seconds continuously for a period of over three weeks, the GPS cattle collar is a high temporal and spatial resolution tool for monitoring cattle behaviour (Barbari *et al.*, 2006). Once acquired, data from GPS collars can be input into geographical information system (GIS) software and processed to identify trends in behaviour and landscape utilisation (Turner *et al.*, 2000).

Generally speaking, GPS cattle collars offer a compromise between longevity (as determined by the size of the battery) and the frequency of recording intervals. Consequently, studies in this field are either short-term with a high fix-rate (e.g. recording the location of cattle once a second for six days; Guo *et al.*, 2009) or long-term with a low fix-rate. The majority of academic studies opt for comparatively short-duration, high frequency settings (e.g. Schlecht *et al.*, 2004; Guo *et al.*, 2009; Pandey, 2009), whilst long-term monitoring is the preference for livestock owners in the vast ranges of North America and Australia (Barbari *et al.*, 2006).

In all instances, although clearly useful, GPS cattle collars are not faultless. One of the main concerns within the literature is the horizontal or positional accuracy of GPS devices (Agouridis *et al.*, 2004). Although many manufacturers provide tested specifications of spatial resolution, there is not always an accuracy measure or error detector showing the resolution acquired or potential error for each locational fix (Agouridis *et al.*, 2004). What is more, accuracy is a function of atmospheric and environmental conditions; accuracy can be reduced in areas with tree canopy cover or adverse weather conditions (Schlecht *et al.*, 2004; Barbari *et al.*, 2006)

As well as issues of accuracy, studies have shown that GPS collars can affect animal behaviour, particularly if insufficient thought has been given to animal welfare and collar weight (Schlecht *et al.*, 2004). Blanc and Brelurut (1996) recorded skin irritation, increased energy expenditure and abnormal social behaviour in red deer, whilst Rufete *et al.* (2006) observed diversion from normal behaviour in sheep carrying overweight GPS devices. However, with careful consideration, device-modified behaviour can be avoided. GPS collars should be relatively light (<1% of the animals body weight) and animals should be given time to get used to their presence before behaviour is recorded (Schlecht *et al.*, 2004); these considerations are observed in this study (see section 6.2).

Nonetheless, GPS cattle collars remain useful, providing an automated means of monitoring several important elements of animal behaviour accurately across time and space (Schlecht *et al.*, 2004; Barbari *et al.*, 2006).

### **5.2.3. Methods chosen for this study**

A lack of research into the way in which cattle utilise rivers necessitates a manual observational study of cattle-river interactions. A simple classification of behaviour, such as that used by Senft *et al.* (1985), will be applied to record the occurrence, frequency and duration of key activities likely to affect chalk streams (e.g. grazing [herbivory], defecation and urination [excretion], and cattle movement [animal transit]). An additional classification, detailing the location of cattle as per a methodology similar to that exercised by Schaich *et al.* (2010), will be used to associate behaviour with the landscape. Alongside meteorological and other environmental data, this approach will allow for the identification of any relationships between cattle behaviour and river utilisation. Moreover, quantifying the amount of time spent by cattle in different chalk stream locations will improve our understanding of their potential effects.

As a means of validation, to enable efficient data collection and to extend the duration of observation, GPS cattle collars will also be deployed (Figure 5.1). GPS collars will allow for the remote collection of data without the presence of an observer, increasing the time available for the researcher to be engaged in other activities. Being active for 24 hours, GPS collars will collect data during the night when it may be impractical or unsafe to observe cattle manually. Furthermore, GPS collars will produce spatial data that can be manipulated to calculate the amount of time cattle spend in-stream and in the riparian environment. There is also the potential to correlate GPS data; associating instances of in-stream cattle activity with changes in water quality as measured by probes logging turbidity, dissolved oxygen and water temperature.



**Figure 5.1.** A cow from the study wearing an AgTrax LD2 GPS cattle collar.

### **5.3. Impact studies**

Cattle grazing impact studies invariably involve the measurement of environmental indicators thought to be responsive to grazing pressure. These environmental indicators can be either abiotic (non-living components e.g. water temperature) or biotic (living components e.g. a population of fish).

#### **5.3.1. Abiotic indicators**

The abiotic response to grazing pressure is often swifter than the biotic response. Hence, studies conducted within a limited time frame may opt to monitor abiotic rather than biotic variables. Moreover, although abiotic variables are liable to environmental changes, the stochastic component of variability is less significant than within biotic

variables. Additionally, abiotic variables are generally easier to measure, offer more repeatability and transferability, and can be used as a proxy for the biotic response.

Short-term geomorphic and hydrologic responses to grazing are some of the most commonly studied abiotic components. Many physical soil properties can be measured within the field, including soil surface resistance (using a penetrometer), infiltration rates (using a disc permeameter or ring infiltrometer) and rates of run-off (using natural precipitation or rainfall simulators; e.g. Trimble and Mendel, 1995; Yates *et al.*, 2000; Daniel, 2003; Sharrow, 2007; Stavi *et al.*, 2008). Changes in soil and near-ground microclimate due to grazing can also be measured in situ; subterranean soil temperature, surface soil temperature, air temperature, relative humidity, and wind speed (e.g. Roath and Krueger, 1982; Yates *et al.*, 2000; Risch *et al.*, 2007).

Long-term geomorphic and hydrologic responses can also be monitored. Over sufficiently long periods of time, the introduction or removal of grazing pressure can induce geomorphic changes in rivers that alter planform, depth, width, bank steepness and river bed substrate (Trimble and Mendel, 1995; Summers *et al.*, 2008; Strauch *et al.*, 2009). These in turn can affect hydrological components such as velocity and discharge. Such variables can be measured within one river reach subject to different grazing pressures over time, or across several similar river reaches subject to different grazing pressures at the same time (e.g. Summer *et al.*, 2008). In either instance the magnitude of difference observed can be expected to be a function of time and the intensity of forcing.

Most chemical soil properties require a laboratory to be identified, including % organic matter, % chemical composition (e.g. nitrogen, phosphorous, carbon, calcium), electrical conductivity, and pH (e.g. Mwendera *et al.*, 1997; Powell *et al.*, 1998; Schuman *et al.*, 1999; Stavi *et al.*, 2008). Some physical soil properties, such as soil bulk density and soil moisture content, also require a laboratory to be quantified (e.g. Yates *et al.*, 2000; Stavi *et al.*, 2008).

In the terrestrial environment, faecal grab samples can also be taken and analysed for their chemical composition (e.g. Fraser *et al.*, 2009). With knowledge of the magnitude and frequency of animal excretion events, total contributions of potentially harmful organic matter, phosphorous and nitrogen into the landscape can be calculated.

Within the aquatic environment, numerous measures of chemical and physical water quality can be used to detect grazing impact (Gary *et al.*, 1983). Water temperature, which may be effected by riparian shade removal by animals, is a key habitat variable for ectothermic salmonid species, and affects the rate of many chemical reactions, as well as dissolved oxygen content (Beschta, 1997; Armstrong *et al.*, 2003; Davie, 2008). The acidity of the water, represented by its pH, is also important to many fish, and may be modified by animals through excrement inputs and riparian buffer removal (Watt, 1987; Howells, 1994).

Dissolved oxygen (DO) content, measured both as an absolute concentration or percentage saturation, is a function of temperature, and can be reduced by organic matter decomposition; coarse fish (e.g. *Cyprinus carpio* [carp]) can survive in concentrations as low as  $2\text{mg l}^{-1}$  whilst salmonid species generally require concentrations greater than  $5\text{mg l}^{-1}$  (Coble, 1961; Davie, 2008). Organic nitrogen, which can break down into ammonia, nitrite and nitrate in the presence of oxygen, is derived from animal waste, and as discussed previously, can induce algal blooms, eutrophication and associated negative consequences (Withers and Lord, 2002; Davie, 2008). Organic phosphate, which occurs readily in dairy farming river catchments, varies in concentration seasonally, has a high residence time, and can also induce algal blooms and eutrophication (Davie, 2008; Withers and Hodgkinson, 2009).

Total suspended solids (TSS), which can enter rivers due to animal-induced bank shearing, excretion, or increased runoff and sediment inputs, have many detrimental effects upon aquatic ecology, with direct (e.g. siltation of fish eggs) and indirect (e.g. increased light attenuation leading to reduced macrophyte growth) consequences (Trimble and Mendel, 1995; Bilotta and Brazier, 2008). Turbidity, a measure of the

cloudiness of the water, is often used as a proxy for the concentration of TSS, and similarly indicates degradation within a water system, with stress, reduced feeding and competitor avoidance recorded in salmonid species in high turbidity environments (Bilotta and Brazier, 2008; Foltz *et al.*, 2008); short-term but frequent increases in turbidity may result from animals fording rivers.

Nearly all of these water quality indicators can be measured within the laboratory, although increasingly sophisticated equipment can also be used *in-situ* to provide high temporal resolution data regarding water quality. For example, the Hydrolab DataSonde 4a employed by Davies-Colley *et al.* (2004) in their study of cattle fording was able to record changes in turbidity, pH, temperature, conductivity and dissolved oxygen once every minute (Hydrolab, 2009). Daraigan *et al.* (2007) used an optical sensor to measure light scattering as a proxy for total suspended sediment load, whilst values for total dissolved solids can be taken from instant measurements of electrical conductivity, rather than time consuming gravimetry (Davie, 2008).

Generally, studies measure a range of abiotic indicators. This acts both as a means of validating observations and relating changes in different response variables. Three of the best examples of extensive grazing-water quality studies come from Neal *et al.* (2006), Strauch *et al.* (2009) and Wilcock *et al.* (2009). By considering a wide range of abiotic indicators, rather than just one or a few, these studies are able to comprehensively understand the non-living chemical and physical consequences of cattle grazing upon water quality.

### **5.3.2. Biotic indicators**

Biotic indicators have long been used as a means of classifying rivers and identifying their condition (e.g. Carpenter, 1928). With respect to grazing, a number of studies have considered the impact of cattle upon biota (e.g. Braccia and Voshell, 2007; Summers *et al.*, 2008). Measureable impacts can be both direct (e.g. the predation of in-stream or riparian plants) and indirect (e.g. increased macrophyte growth due to nutrients derived

from excretion inputs), with biota exhibiting a range of response times from short (e.g. migratory fish) to long (e.g. slow-growing macrophytes).

One widely used indicator of grazing pressure, owing predominantly to their economic and recreational importance, their relative ease of identification and measurement, and their sensitivity to the effects of cattle grazing, are fish. Fish condition can be just as informative as fish species richness and abundance, with the loss of scales and dwarfism as potential indicators of environmental stress (Adams and Abele, 1990). When using fish as a biological indicator it is particularly important to monitor long after the application of treatment. Short-term monitoring of fish populations and condition can lead to erroneous results as many fish species have a high degree of landscape mobility. Moreover, regular electric fishing surveys (often the preferred means of catching fish in Environment Agency studies) can be expensive and labour intensive (Beaumont *et al.* 2002; Davie, 2008).

One of the few examples of using fish as a biotic indicator in a UK chalk stream subject to grazing pressure comes from Summers *et al.* (2008). Summers *et al.* (2008) monitored juvenile and adult brown trout (*Salmo trutta*) populations in two stretches of river in Dorset. Across a period of six years, researchers recorded changes in abundance, condition, age and size of fish prior to and following the cessation of an intense grazing pressure (Summers *et al.*, 2008). The results suggest that the removal of cattle benefited the trout population: juvenile trout numbers increased in rehabilitated short sections but decreased in in rehabilitated long sections; adult trout numbers increased in both rehabilitated short and long sections (Summers *et al.*, 2008).

Another useful group of biological indicators is invertebrates (Chapman, 1996). The presence or absence of invertebrates is determined by the prevailing environmental conditions; different species occupy different niches and their presence or absence reflects different levels of environmental stress. For example, stoneflies (*Plecoptera*) and mayflies (*Ephemeroptera*) are generally indicative of low pollution river reaches, whilst worms (*Oligochaeta*), with a high tolerance to stress, are ubiquitous, and hence may



suggest high pollution levels in the absence of other macroinvertebrate fauna (Chapman, 1996). Furthermore, different macroinvertebrate groups (e.g. diatoms, chironomids, and cladocera) are sensitive to different pressures, and there are many different indices of water quality and river habitat based upon specific groups (e.g. the Biological Diatom Index [BDI]: Coste *et al.*, 2009). Some indices, such as the Biological Monitoring Working Party (BMWP) index in Britain, assign an overall pollution score based upon the occurrence of a range of species from different taxonomic groups (Chapman, 1996). Other indexes, such as the Chandler index, also include some measure of relative species abundance (Chapman, 1996).

In-stream macroinvertebrates are often captured using kick sampling; a three minute duration sweep of a 1mm mesh hand net across the range of different microhabitats within a river reach (Freshwater Biological Association, 2010). Terrestrial macroinvertebrates are often captured according to a similar methodology using a sweep net, although more elaborate techniques, such as light trapping, have been used in grazing studies (Littlewood, 2008).

Although macroinvertebrate communities in UK chalk streams have been monitored to understand the impact of vegetation management (e.g. Armitage *et al.*, 1994), for pollution and water quality assessments (e.g. Boreham, 1990), and for river habitat surveys (Raven *et al.*, 1998), only one published study has considered the impact of grazing upon macroinvertebrates in UK chalk streams; Harrison and Harris (2002). Gathering kick samples from three different types of aquatic habitat in two stretches of river from 1996-1997, Harrison and Harris (2002) were able to establish differences in riparian macroinvertebrate community structure between grazed and ungrazed river reaches. Specifically, Harrison and Harris (2002) identified no difference in the total abundance of macroinvertebrates between grazed and ungrazed reaches, although taxon richness and species diversity were greater in ungrazed plots than grazed plots.

The final major group of biotic indicators are macrophytes (Holmes *et al.*, 1999). As with macroinvertebrates, there are numerous community diversity-community health indices

for macrophytes (Jorgensen *et al.*, 2005). Unlike macroinvertebrates, macrophyte community response to livestock activity is likely to be direct; macrophytes may be trampled, predated or subject to increased nutrient loading from excretion. Moreover, macrophyte communities can be monitored with respect to not only diversity but also plant height, condition and density; although there can be key indicator species (e.g. Carbiener *et al.*, 1990; Onaindia *et al.*, 2005), these are not always necessary to understanding environmental conditions. What is more, most plant species are easily identified, the process of measurement is usually non-destructive and the perennial nature of many aquatic plants allows for simple year-to-year comparisons (Schaumburg *et al.*, 2004; Jorgensen *et al.*, 2005).

There are numerous ways in which macrophytes can be measured, both with respect to the sampling method employed (e.g. transects, random, selective, quadrats, scan, etc) and the indicator measure used (e.g. biomass, species diversity, sward height, community structure, etc: Downing and Anderson, 1985; Holmes *et al.*, 1999; Raven *et al.*, 2000; Critchley *et al.*, 2008). For example, Fraser *et al.* (2009) conducted chemical analysis of plant composition in their study of cattle and sheep diets across restored moorland, whilst Holland *et al.* (2008) recorded monthly measurements of herbage height and primary productivity in their study of grazing treatment impacts upon *Nardus stricta* dominated grassland. As with other indicators, the precise application used is determined by the objectives of the study.

Although no studies of UK chalk streams have explicitly recorded changes in macrophyte communities in response to cattle grazing impact directly, River Habitat Surveys (RHS) have identified differences in vegetation between poached and unpoached reaches in chalk streams (Raven *et al.*, 1998). These surveys involve the completion of restrictive but transferable tick-box questionnaires, distinguishing between in-stream vegetation types (e.g. free floating, filamentous algae, liverworts, mosses, lichens, etc) and bankside vegetation structure (e.g. bare earth, uniform, simple, complex), as well as land-use (e.g. rough pasture, broadleaf/mixed woodland, wetland, etc: Raven *et al.*, 1998). Whilst useful in the context of a country-wide river habitat assessment, the RHS approach is

generic; it is likely the methods required for this study will be more specific, detailed and focused, as per the techniques documented in Brown (1954), Haslam (1978), and Moore and Chapman (1986).

Other biological indicators that may respond to cattle activity within chalk stream environments include amphibians (Blaustein *et al.*, 2003), birds (Kati *et al.*, 2004; Nelson *et al.*, 2011), mammals (Everard, 2007) and bacteria (Kloot, 2007). To date there have been few focused studies considering such interactions, albeit there is some evidence for extrapolated, complex, indirect relationships between cattle and other organisms, both in chalk stream environments and elsewhere (Evans *et al.*, 2006; Everard, 2007; Martin and McIntyre, 2007).

The choice of indicator is determined by the response variable being measured, and the time, finance and human resources available. Although many abiotic variables will respond comparatively rapidly to pressure, these measures are only proxies for environmental stress and their monitoring can require expensive equipment. Contrastingly, whilst biota surveys are often time-consuming and labour intensive, organism indicators do allow for a direct assessment of system response to change. As such, and as with nearly all methodological approaches, the choice of a particular indicator is determined by the requirements of the experiment.

### **5.3.3. Methods chosen for this study**

Time constraints reduce the viability of measuring biotic factors within this study. Although it would be possible to compare grazed versus ungrazed chalk stream reaches, as per Harris and Harrison (2002) and Summers *et al.* (2008), such an approach would not improve our understanding of cattle-river interactions.

Instead, a series of techniques aimed at quantifying the direct and indirect effects of cattle grazing upon abiotic factors will be employed. By using a terrestrial laser-scanner, the amount of river bank material removed by cattle over the grazing season will be assessed.

In-stream water quality probes will be used to monitor any changes in important variables, such as turbidity (a proxy for suspended sediment), that result from cattle activity. Laboratory analysis of faeces for key nutrients such as phosphorous, nitrogen and potassium, similar to Hubbard *et al.* (2004), will improve understanding of the chemical loading due to cattle. The critical shear stress required to erode cattle trails will be measured using a cohesive strength meter (CSM) to establish erosion risk from cattle trails.

#### **5.4. Modelling studies**

One approach to quantifying the impact of cattle grazing upon chalk streams is to use a numerical model. Such models can be relatively simple (e.g. a predictor of cattle distribution based upon the optimal foraging theory) or complex (e.g. a model showing changes in river channel geomorphology over time as a consequence of cattle distribution), but all require a certain amount of empirical data for calibration if they are to be accurate. The modeller may be able to extrapolate such data temporally or spatially to predict the impact of agents across scales that would be unrealistic to measure within the actual environment. Moreover, the modeller can prescribe and manipulate rules to modify the environmental conditions or the behaviour of agents within the model to identify the consequences of hypothetical scenarios.

It should be noted that although there are several models relevant to cattle grazing in rivers, they do not fall into easily defined categories. There are those models dealing with grazing intensity (e.g. Salski and Holsten, 2006), those dealing with animal behaviour and movement (e.g. Karen and Olson, 2006), those concerned with river bank stability and landscape topography (e.g. Marlow *et al.*, 1987), those dealing with pollution from pastoral land-use (e.g. Maillard and Santos, 2008), and those that consider large-scale socio-economic factors and non-environmental agents (e.g. Koch *et al.*, 2008). Because there are no clearly defined groupings, the literature is best understood through a number of key examples.

#### **5.4.1. Modelling cattle behaviour and grazing intensity**

Salski and Holsten (2006) modelled the intensity of cattle grazing at low stocking densities across pastureland in Germany. Three input variables were used (forage quality of the vegetation being eaten at any given time, forage quality of the surrounding vegetation, water table level) within two types of *if-then* fuzzy-logic model. The first model, the Mamdani-type model (Mamdani and Assilian, 1975), uses linguistic terms (e.g. short, long; low, high) to define its rules (Salski and Holsten, 2006). The second model, the Sugeno-type model (Sugeno, 1985), uses linear functions (e.g. one to ten) to define its rules (Salski and Holsten, 2006). The latter is more accurate when predicting grazing intensity in areas analogous to those upon which its calibration sets are based, whilst the former remains relatively accurate when transferred to other site types (Salski and Holsten, 2006). Neither model correctly accounts for socially determined changes in grazing intensity, irregular barriers within the study area, or grazing across very large areas (Salski and Holsten, 2006). For these variables to be considered and predicted accurately, behavioural models are required.

Predictive, quantitative models of animal behaviour and movement have a surprisingly long history (e.g. Saarenmaa *et al.*, 1988; Folse *et al.*, 1989). However, it is only recently with improved computational power, high spatial and temporal resolution data sets of observed animal behaviour, and increasingly thorough validation techniques that such animal behaviour models have become relatively accurate. One of the few studies to incorporate these factors into a spatially explicit cattle behaviour and movement model is detailed by Guo *et al.* (2009). Using high sample rate GPS for locational fixes, accelerometers to indicate time spent resting and moving, and magnetometers to detect direction and time spent grazing, Guo *et al.* (2009) were able to develop a predictive model of animal behaviour. The final model, which comprises a Hidden Markov model (see Cappé *et al.*, 2005 for a description) for animal activity within rest zones, and a long-term prediction model for animal movement between rest zones, demonstrates the heterogeneous nature of landscape utilisation by cattle (Guo *et al.*, 2009).

Where Salski and Holston (2006) have succeeded in understanding animal-landscape interactions, Guo *et al.* (2009) have failed, and where Guo *et al.* (2009) have succeeded in considering the importance of non-herbivory activity, Salski and Holsten (2006) have failed. By overlooking the role of environmental, physiological, sociological and climatological factors in determining activity, Guo *et al.* (2009) cannot understand the drivers of behaviour. Consequently, and despite suggestions to the contrary within the paper by Guo *et al.* (2009), the transferability of this model is minimal. Although technically the rules and algorithms generated by Guo *et al.* (2009) do provide the framework for a universal model of animal behaviour, any future use of the model in a different environment, at a different time, or with different animals, would require calibration and potentially the recalculation of existing rules and algorithms.

Contrastingly, although Salski and Holsten (2006) have considered the role of foraging quality and water table level variables in determining grazing intensity, their model is far from comprehensive. A number of potentially important drivers of behaviour (e.g. herd mentality, landscape barriers) have been overlooked. Salski and Holsten (2006) suggest that the three input variables used for their model are sufficient to map grazing intensity without a significant loss of accuracy; for the purposes of their exercise this may be true, but as discussed previously in this document there are more controls upon grazing intensity than in-patch forage quality, adjacent-patch forage quality and water table levels. What is more, the model output is focused upon grazing intensity but offers no understanding of the processes that cause changes in grazing intensity i.e. herbivory, trampling, excretion.

It is important to stress that the two studies discussed here are not fatally flawed; they achieved their aims and present the discipline with a number of innovative methods for modelling animal behaviour and grazing intensity. Indeed, Salski and Holsten (2006) highlight a number of limitations of their model in their conclusion, with a more recent study investigating the grazing of reed beds by geese in German lakes addressing some of these limitations (Salski and Holsten, 2009). What is required, and where there is a clear research gap, is a model that incorporates both landscape elements *and* the behavioural characteristics of cattle.

#### **5.4.2. Modelling the indirect effects of cattle**

As well as those models dealing with cattle behaviour and grazing intensity, there are a number that consider the indirect effects of cattle.

McGechan *et al.* (2005) modelled through-soil transport of diffuse and point source phosphorous pollution from pastoral agricultural land to surface waters in both the summer (dry) and the winter (wet) using the MACRO model (a two dimensional hydrological model - for a technical description see Jarvis, 1994). The researchers were able to quantify the importance of macropore flow in transporting phosphorous rich colloidal faeces particles from the terrestrial environment to the aquatic environment; the more widely recognised mechanism for phosphorous transport is surface runoff (McGechan *et al.*, 2005). Despite limitations in parameterisation, which were highlighted in the article by McGechan *et al.* (2005), the model was effective at simulating general trends in outflow phosphorous concentrations, although short-term peaks in outflow were sometimes missed. More recent work by McGechan *et al.* (2008), using the MACRO model to simulate ammonia and faecal bacteria concentrations in waterways adjacent to a Scottish dairy farm, produced output whose accuracy improved upon the McGechan *et al.* (2005) study. The model in McGechan *et al.* (2008) accurately simulates both general trends and the timing of short-term peaks in contamination, although, as with the original, fails to correctly predict the magnitude of loading. Nonetheless, these two studies represent the refinement of a complex but very useful, transferable model for forecasting contamination as a result of cattle activity. However, pollution from excrement is not the only indirect consequence of cattle activity.

The literature pertaining to bank stability and bank erosion modelling is significant (Kondolf and Piégay, 2003; Bennett and Simon, 2004; Couper, 2004). However, whilst it is also well documented that cattle at high enough densities can cause bank instability and erosion (Kauffman and Krueger, 1984; Trimble and Mendel, 1995), relatively few modelling studies consider the cow as a discrete geomorphic agent. Although many existing models could be adapted to simulate the impact of cattle activity upon bank

stability (e.g. by removing riparian vegetation), there is no evidence within the literature of anyone having done this. Moreover, there appear to be no studies directly modelling cattle impact upon bank stability; studies have considered the role of changing vegetation (e.g. Van de Wiel and Darby, 2007) and soil characteristics (e.g. Parker *et al.*, 2008b) but not cattle stocking density specifically.

#### **5.4.3. Modelling grazing in the future**

It is evident from the discussion above that there is much left to be done with respect to modelling grazing. Existing attempts at modelling behaviour have overlooked the role of landscape features in determining activity (Salski and Holsten, 2006), whilst existing attempts at modelling grazing intensity have overlooked non-landscape features in determining activity (Guo *et al.*, 2009). Furthermore, although some grazing impacts, such as changes in water quality, have been modelled several times using different techniques (McGechen *et al.*, 2005; McGechen *et al.*, 2008), other impacts, such as changes in river bank stability, bed disturbance, and nutrient inputs from faeces, have not been modelled at all.

The way forward in this area of research may take elements from studies not dissimilar to Koch *et al.* (2008), whose complex LANDSHIFT.R modelling framework incorporated four sub-components to assess the potential impact of future grazing management strategies upon land-use change in the River Jordan region (Israel, Jordan, Palestine). In their study, Koch *et al.* (2008) considered several exogenous macro-scale drivers and parameters (e.g. population density, technological change and environmental policy) that influence land-use change and grazing pressure. Koch *et al.* (2008) also considered numerous micro-scale landscape conditions and climate variables (e.g. drainage density, slope, precipitation) that would also influence land-use change and grazing pressure. The input data were then combined with a WADISCAPE model (GLOWA Jordan River Project, 2007) to simulate shrub and herb growth, and a DayCent model (Parton *et al.*, 1998) to simulate crop growth. All these components together form the LUC (land-use change) module; the core element of the LANDSHIFT.R model from which output data can be derived (Koch *et al.*, 2008: Figure 5.2).



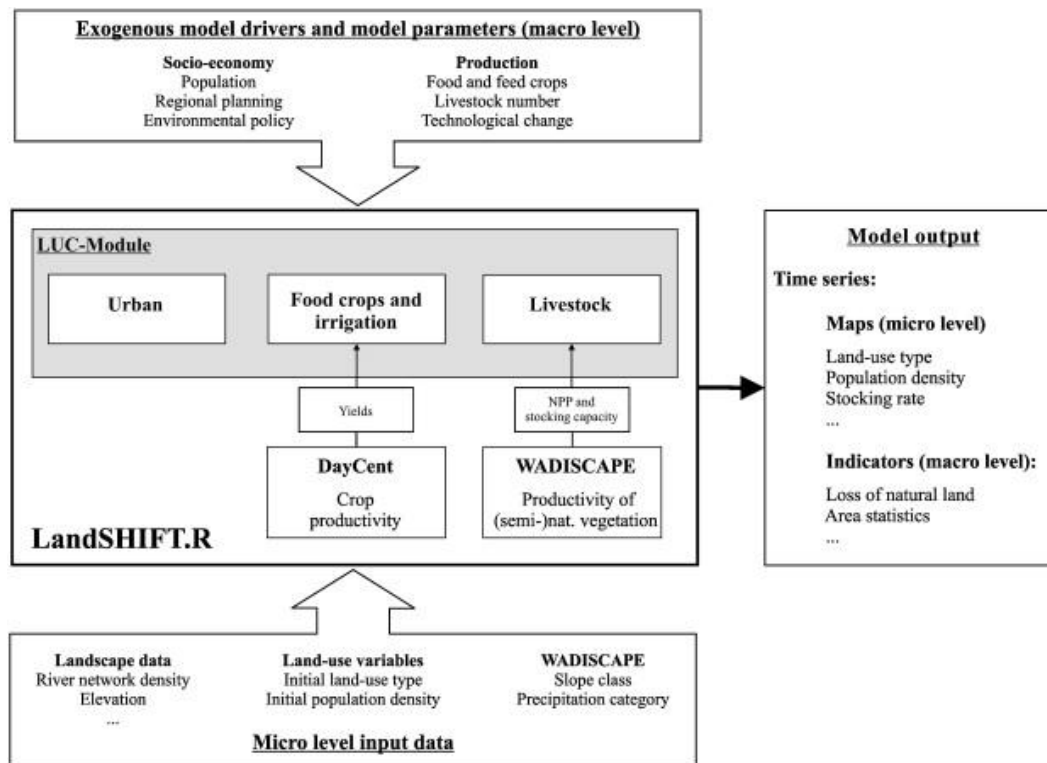


**Figure 5.2.** Diagrammatic representation of the LANDSHIFT.R model, its inputs and outputs, and component parts (re-printed from Koch *et al.*, 2008)

Although the specifics of the Koch *et al.* (2008) study may not be directly relevant to studying the impact of cattle grazing in chalk streams, the conceptual basis of the modelling employed is. Most existing models related to grazing focus upon only water quality, or only cattle behaviour, or only grazing intensity. Koch *et al.* (2008) have demonstrated that with sufficiently thorough data sets, a holistic knowledge of influencing variables and feedback mechanisms, and an ambitious approach to modelling, this not need be the case.

#### 5.4.4. Methods chosen for this study

Models will be used in a number of contexts to enable the amalgamation, re-scaling and display of empirically gathered data.

Specifically, digital elevation and terrain models of study sites will be used within GIS to map key features within the landscape (e.g. river channels, drainage ditches, vegetation, etc). GIS will also provide the platform into which GPS cattle data are uploaded, analysed, displayed and combined with other datasets. Additional landscape mapping will be undertaken using low-level aerial photography to record the distribution of cattle trails, adding detail to the elevation model. Digital elevation models will also be made using high resolution point cloud data from terrestrial laser scans of cow ramps.

All of these models could act as inputs for SCIMAP; a framework for modelling and mapping diffuse pollution and sediment risk across landscape (Reaney *et al.*, 2011). Using this framework it is possible to map fine sediment and erosion risk based upon rainfall, land cover (erodibility) and connectivity within the landscape. Crucially the SCIMAP model is able to map spatial differences in pollution risk that can be superimposed upon habitat data to link the effects of cattle grazing to potential consequences.

Finally, back-of-the-envelope calculations, which are becoming increasingly popular in a range of geographical applications (e.g. Löfgren, 1996; Dessus *et al.*, 2008; Aspinall *et al.*, 2009), will be employed to quantify the effects of cattle grazing in chalk streams at spatial and temporal scales that were impractical to work at directly. In particular, data from the faecal analysis experiment will be combined with defecation frequency data from the observational study to determine the total nutrient loading by cattle into a chalk stream. As well as allowing for the effects of reach-scale loading to be upscaled, such an approach enables realistic estimates of nutrient loading by cattle to be calculated in the absence of water quality data. Moreover, these calculations attribute a value to nutrient loading by cattle that is distinguishable from nutrient loading due to other inputs such as agricultural fertilizers and surface runoff. With manipulation, calculations may also allow for the prediction of likely nutrient loading due to cattle in rivers not currently subject to cattle grazing, if the number of cattle, the period of exposure and the river characteristics are known.

## 5.5. Study sites

The methods chosen for this study will be employed across a number of sites. Each of the sites is characteristic of southern England's chalkland, sharing as they do a common climate, geomorphology and ecology. Specific details relating to each study provided within the various methods sections in chapters six, seven and eight, but a generic description of the locations, landforms, topography and soils found across the region will be provided herein.

All of the studies involving the collection of empirical data were conducted within the English county of Hampshire (Figure 5.3).

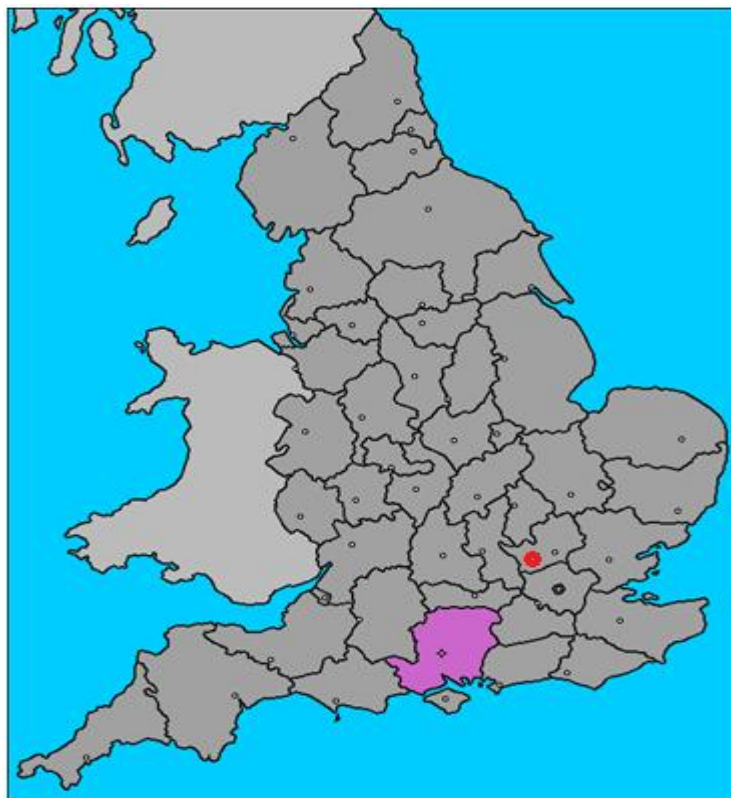


**Figure 5.3. A map of the counties of England and their administrative capitals. The county of Hampshire is highlighted in purple. The Lee catchment described in section 8.3.1.2 is shown in red.**

Located to south of England, Hampshire contains a high concentration of chalk streams, the most well-known of which are the River Itchen and River Test SSSI's; archetypal

chalk river environments. The empirical data collection sites within Hampshire are situated at Winnall Moors on the River Itchen, near Droxford on the River Meon, and at Tichborne on the Tichborne stream (Figure 5.4). The Test catchment used in the modelling study was also in Hampshire (section 8.3.1.4); only the Lee catchment in Hertfordshire (section 8.3.1.2) was not in Hampshire (Figure 5.3).

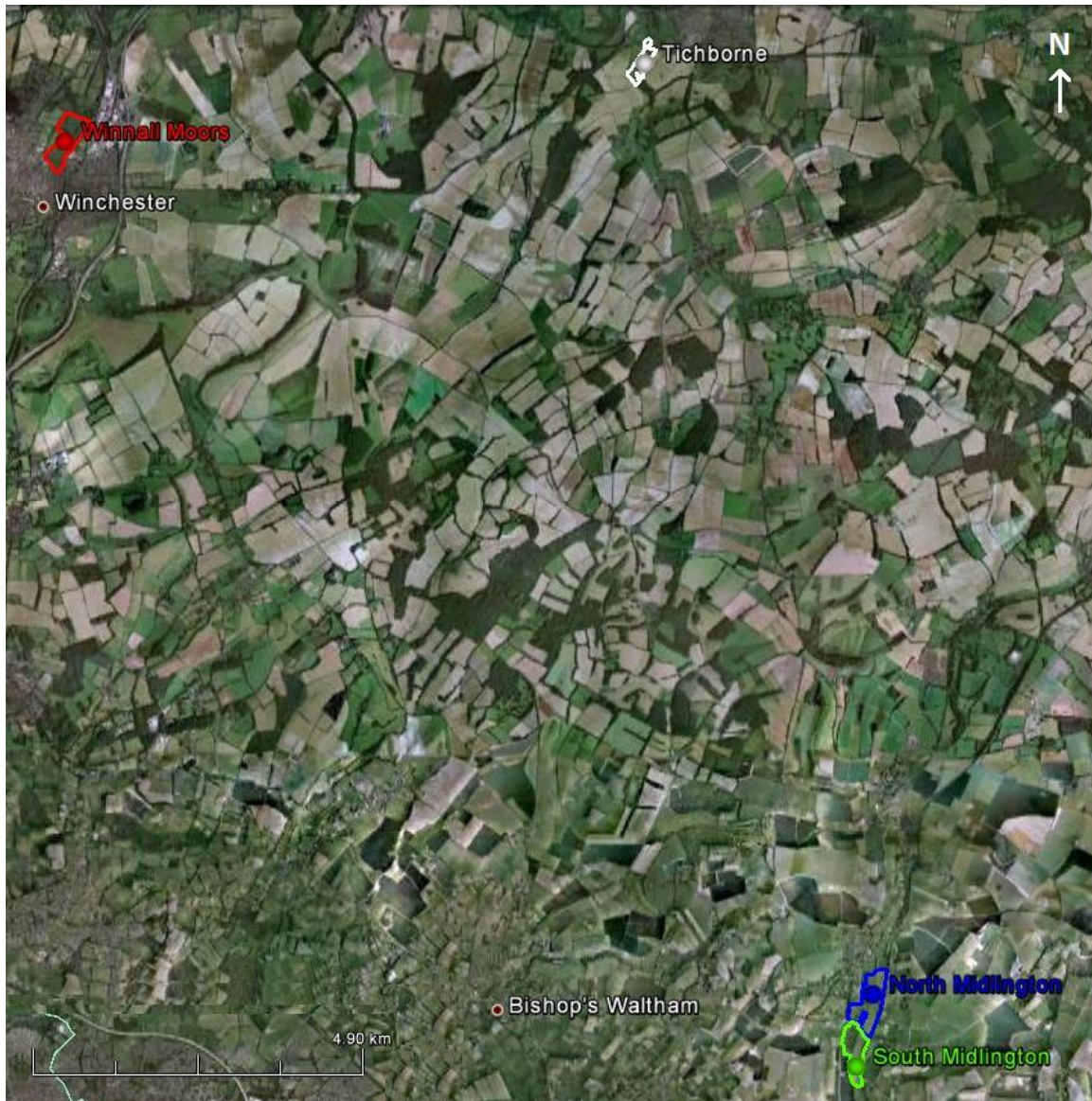


**Figure 5.4.** Satellite imagery of the Winnall Moors, northern and southern Midlington sites. The city of Winchester and the town of Bishop's Waltham are highlighted for geographical reference. The Tichborne site, discussed in section 6.2, is also shown (Google, 2012).

The climate of southern lowland England is temperate, with the greatest temperatures and lowest rainfall in the summer months. In the year of the observational study (2010) the total precipitation was 100mm below average and air temperature in the summer months was approximately 0.5 °C above average (compared to values from 1971-2001; Figure 5.5: UK Met Office, 2010).

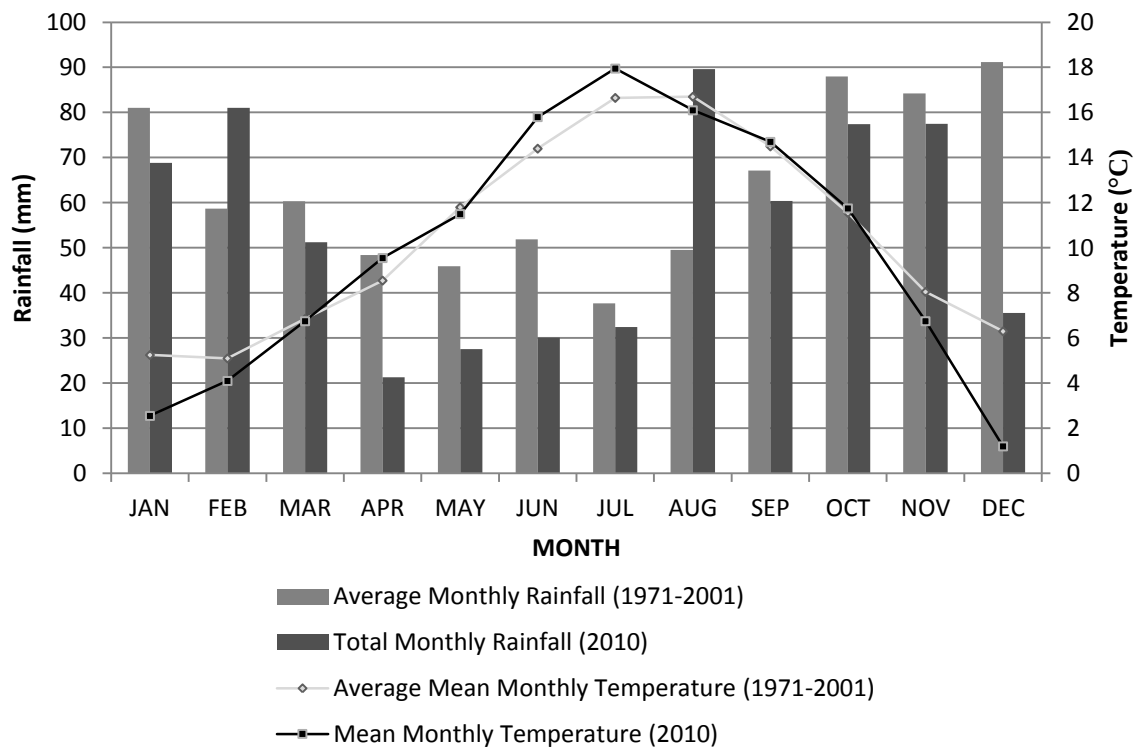


**Figure 5.5. Meteorological data for southern England (data from Southampton Weather Station: UK Met Office, 2010)**

Hydrologically, the River Meon, River Itchen, River Lee and the Tichborne stream are typical of ‘classic’ English chalk streams, with a groundwater dominated flow regime, stable temperatures, and a non-flashy flood hydrograph (Sear *et al.*, 1999; Smith *et al.*, 2003). As the largest catchment within this study the River Test is more heavily influenced by local variations in land-use and geology, and is resultantly more responsive to precipitation events. Water quality is naturally high across all sites, with clear, alkaline and mineral-rich water (Smith *et al.*, 2003). In-stream sediments are predominately flint gravel-based, although fine sediment accumulates in areas of slow flow or where there

are substantial fine sediment sources (e.g. arable agriculture: Mainstone, 1999; Smith *et al.*, 2003). At the Midlington sites, pool-riffle sequences are present, as well as cow ramps; destabilised, shallow banks created by cattle repeatedly entering and leaving the aquatic environment (Trimble, 1994; Trimble and Mendel, 1995). In many reaches, such as along the Tichborne stream, these watercourses are elevated ('perched') above their floodplains. As a consequence of groundwater flow, seepage and frequently high water tables, chalk stream floodplains, which may be up to 100m wide in the middle to lower catchment, are generally saturated throughout the winter and may remain wet in the summer months.

Floodplain soils are typically characterised by a shallow, humus-rich surface layer containing silt alluvium and deep peat subsoils with small fragments of chalk (Melville and Freshney, 1982), although there are local variations on this theme. At Tichborne the soils are shallow, well drained, calcareous and silty, underlain by the Seaford chalk formation and overlain by gravels and sands. The Meon valley is similar, albeit with steeper valley slopes and a greater concentration of alluvium.

Evidence of water meadow management is clear across all sites, with numerous artificial drainage ditches superimposed upon relict floodplain channels (Everard, 2005). None of the sites contained water troughs, although both drainage ditches and floodplain channels were observed to retain surface water following large precipitation events. The sites are generally devoid of trees, shrubs and bushes except where there is fencing or a field boundary; grazing and other management practices (e.g. grass mowing) prevent the establishment of woody vegetation.

Ecologically, the sites provide an array of different habitats and support a large number of common chalk stream organisms, including riparian plants (e.g. greater pond sedge: *Carex riparia*), emergent aquatic macrophytes (e.g. water mint: *Mentha aquatica*; and watercress: *Nasturtium officinale*), fish (e.g. grayling: *Thymallus thymallus*; Atlantic salmon: *Salmo trutta*; and brook lamprey: *Lampetra planeri*), invertebrates (e.g. mayfly species: *Ephemeroptera* spp.) mammals (e.g. European water vole: *Arvicola terrestris*),

birds (e.g. grey wagtail: *Motacilla cinerea*; and the great egret: *Ardea alba*) and amphibians (e.g. European common frog: *Rana temporaria*: UKBAP, 1995; Raven *et al.*, 1998; Mainstone, 1999).

## **5.6. Summary**

As discussed, although visual monitoring has been the traditional means of recording cattle behaviour, there is an increasing body of literature using GPS and remote sensing to good effect. In either instance, there are a range of different methodologies that can be employed that vary in terms of their duration, frequency and scale. The suitability of a particular approach is dictated by the aims and objectives of the study. With respect to measuring cattle grazing impact, there are a number of useful indicators that can be measured. These indicators measure abiotic or biotic variables, with the suitability of a particular indicator again determined by the desired outcomes of the study. The future of cattle grazing studies looks towards behavioural and impact modelling studies, with a small number of existing models providing a platform on which to build.

From this review of existing methodologies it has been possible to identify those that will be of greatest use in this study. A high-temporal resolution observational study of cattle will be undertaken to improve our understanding of cattle-chalk stream interactions. A study of cattle spatial distribution within chalk stream environments will also be undertaken using GPS cattle collars to quantify the amount of time cattle spend in different locations. To assess the effects of cattle grazing, a number of studies focused upon geomorphology and nutrient inputs will be conducted. River bank destabilisation, mass loss and changes in topography will be measured using a terrestrial laser scanner. The horizontal shear stress of cattle trails will be quantified using a cohesive strength meter to determine their erodibility relative to untrodden soils. In-stream turbidity probes will provide a measure of the amount of suspended sediment resulting from cattle activity within the river. The nutrient content of cattle faeces will be evaluated using laboratory methods to calculate the loading to chalk stream systems due to excrement inputs. The SCIMAP diffuse pollution and fine sediment model will be used to investigate the

relationship between the effects of cattle grazing and the connectivity of chalk stream catchments.

The aforementioned methods, combining original and tried-and-tested techniques, are chosen on the basis of their feasibility and suitability. Together they allow for a comprehensive assessment of the behaviour and effects of cattle grazing in chalk streams across aquatic, riparian and terrestrial zones. In considering both behavioural and impact elements it is possible to refine one methodology based upon the findings from another. Moreover, by investigating fields as diverse as geomorphology, water chemistry and ethology, a multidisciplinary approach is assured, with the outputs from the study of scientific and practical interest to the myriad of stakeholders involved in river basin and cattle management.



## **6. Cattle behaviour in chalk streams studies**

### **6.1. Observational study**

#### **6.1.1. Introduction**

Cattle have the potential to be important geomorphic and ecological agents in the low-energy, high biodiversity chalk streams of southern England (see section 3.3). However, a lack of research into cattle activity in these environments limits our understanding of the extent to which this agency is manifest. To date there have been few studies into the way in which cattle behave in chalk stream environments, with the limited existing body of literature focusing solely on the consequences of allowing cattle access to chalk streams (Harrison and Harris, 2002; Summers *et al.*, 2005, Summers *et al.*, 2008). This dearth of studies is not specific to chalk streams, and highlights a broader research gap of interest to ethologists and zoogeomorphologists (Butler, 2006); how and why do large mammals interact with watercourses?

To improve our understanding of cattle-river interactions, a high temporal resolution study of cattle behaviour and distribution was conducted. Cattle were monitored for over 500 hours across three chalk stream sites in Hampshire, England (UK) between April and October 2010. The principle aim was to quantify the amount of time cattle spent involved in different activities in different locations, with a focus upon the riparian and aquatic zones (providing data to test hypothesis H<sub>2</sub>). It was also hoped that spatial and temporal patterns in activity could be identified and related to potentially important external drivers such as air temperature and humidity (providing data to test hypothesis H<sub>1</sub>). These data would provide the basis for further assessments of cattle impact both within this thesis and beyond. A shorter document detailing the study described herein has been published in the *Journal of Livestock Science* (Bond *et al.*, 2012).

### **6.1.2. Methods**

#### **6.1.2.1. Study sites**

The observational study was conducted across three sites in Hampshire, England: the northern and southern Midlington sites on the River Meon at Droxford; and the Winnall Moors site on the River Itchen at Winchester (Figure 5.4)

The northern Midlington site covers 29ha and is bisected by the River Meon which runs for 1200m through the site. Access to the River Meon at the north Midlington site is partially restricted by barbed-wire fencing that runs for 600m along its length, leaving 600m of accessible river (Figure 6.1).



**Figure 6.1. A bullock grazing beyond the fenced riparian margin at the northern Midlington site. The River Meon can be seen in the background.**

The southern Midlington site is 19ha in size, with 770m of accessible river and no river-side fencing. Public access is largely prohibited, although the landowner does permit fishermen to enter the field during the fishing season (Figure 6.2).



**Figure 6.2. A bullock grazing in the River Meon at the unfenced southern Midlington site.**

The Winnall Moors site is situated within the 64ha Winnall Moors Nature Reserve. Cattle observation took place within a 7.5ha field with 450m of accessible river, no river-side fencing and no access to other fields (Figure 6.3).





**Figure 6.3** A shaded area of the River Itchen at the Winnall Moors site.

Although the sites share a landscape and cultural history that is characteristic of southern-England chalklands (explained in section 5.5), there are a number of important differences between the sites. First, the river reach at the southern Midlington site is shorter with a more sinuous planform than that at the northern site; the river reach at Winnall Moors is the shortest and has lowest sinuosity of the three sites. Second, cattle have unrestricted access to the River Meon at the southern Midlington site and the River Itchen at Winnall Moors; at the northern Midlington site there is partial riparian fencing. Third, and partly due to the presence of fencing, the cross-sectional profile of the River Meon at the northern Midlington site is more variable than at the southern Midlington site; the cross-section of the River Itchen at Winnall Moors is highly uniform, steep-banked and relatively deep. Fourth, at the southern Midlington site the riparian margin is characterized by sporadic distributions of trees including oak, willow and maple; the riparian margins at the northern Midlington and Winnall Moors sites are almost entirely

devoid of trees. Finally, elevation across the southern Midlington site is more variable, with a greater frequency of former channels and ditches than the northern Midlington site.

#### *6.1.2.2. Study animals*

From April until late-October 2010, the northern Midlington site was occupied by 35 Holstein bullocks aged between 10-12 months at the time of introduction (approximately 1.5 livestock units per hectare). Over the same period the southern Midlington site was occupied by 33 Holstein bullocks aged between 8-10 months at the time of introduction (approximately 2 livestock units per hectare). The northern Midlington site is separated from the southern Midlington site by a road, and cattle were not able to move between the two sites.

From early May until mid-October 2010, Winnall Moors Nature Reserve was occupied by a variety of different breeds of cattle including Welsh blacks, Galloway's and Red polls, of different ages (from calves to adults) and genders, although all at low stocking densities (<2 livestock units per hectare). During the period of observation the field in which the observational study was conducted contained six cattle all greater than two years of age: four Welsh blacks (two male and two female) and two Galloway's (one male and one female).

#### *6.1.2.3. Field methodology*

Cattle were observed for 65 days between April and October 2010: 30 days at the northern Midlington site, 29 days at the southern Midlington site and six days at the Winnall Moors site (Table 6.1). At the two Midlington sites cattle were observed between 0830 and 1600 each observation day. The timing of observations at Winnall Moors varied.

| Date/Month | April           | May            | June            | July            | August          | September       | October         |
|------------|-----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1          |                 | S <sup>a</sup> |                 | N <sup>ab</sup> |                 |                 |                 |
| 2          |                 |                |                 | N <sup>b</sup>  |                 |                 |                 |
| 3          |                 |                |                 |                 |                 |                 |                 |
| 4          |                 | S              |                 |                 |                 |                 |                 |
| 5          |                 |                |                 | S <sup>b</sup>  |                 |                 |                 |
| 6          |                 | S              |                 | S <sup>b</sup>  |                 | N <sup>ab</sup> |                 |
| 7          | N <sup>*a</sup> | S              |                 |                 |                 | N <sup>b</sup>  |                 |
| 8          |                 |                |                 | S <sup>b</sup>  |                 |                 |                 |
| 9          | N <sup>±</sup>  |                | W <sup>†a</sup> | S <sup>b</sup>  | N <sup>ab</sup> | N <sup>b</sup>  |                 |
| 10         |                 |                | W <sup>†</sup>  |                 | N <sup>b</sup>  | N <sup>b</sup>  |                 |
| 11         |                 | S              |                 |                 |                 |                 |                 |
| 12         |                 |                |                 |                 | N <sup>b</sup>  |                 |                 |
| 13         | N               |                |                 |                 | N <sup>b</sup>  | S <sup>b</sup>  |                 |
| 14         | N               | S <sup>b</sup> | W <sup>†</sup>  |                 |                 | S <sup>b</sup>  |                 |
| 15         | N               | S <sup>b</sup> | W <sup>†</sup>  |                 |                 | S <sup>b</sup>  |                 |
| 16         | N               |                |                 |                 | S <sup>b</sup>  | S <sup>b</sup>  |                 |
| 17         |                 | N <sup>b</sup> | W <sup>†</sup>  |                 | S <sup>b</sup>  |                 |                 |
| 18         |                 | N <sup>b</sup> | W <sup>†</sup>  |                 | S <sup>b</sup>  |                 | N <sup>ab</sup> |
| 19         | N               |                |                 |                 | S <sup>b</sup>  |                 | N <sup>b</sup>  |
| 20         | N               | N <sup>b</sup> |                 |                 |                 |                 |                 |
| 21         |                 | N <sup>b</sup> |                 |                 |                 |                 | N <sup>b</sup>  |
| 22         | N               |                |                 |                 |                 |                 | N <sup>b</sup>  |
| 23         |                 |                |                 |                 |                 |                 |                 |
| 24         | S               | S <sup>b</sup> |                 |                 |                 |                 |                 |
| 25         |                 | S <sup>b</sup> |                 |                 |                 |                 | S <sup>b</sup>  |
| 26         | S               | S <sup>b</sup> |                 |                 |                 |                 | S <sup>b</sup>  |
| 27         | S               | S <sup>b</sup> |                 |                 |                 |                 |                 |
| 28         |                 |                | N <sup>b</sup>  |                 |                 |                 | S <sup>b</sup>  |
| 29         |                 |                | N <sup>b</sup>  |                 |                 |                 | S <sup>b</sup>  |
| 30         |                 |                |                 |                 |                 |                 |                 |
| 31         |                 |                |                 |                 |                 |                 |                 |

**Table 6.1.** N = Northern Midlington site, S = Southern Midlington site, W = Winnall Moors site,\*  
Observed for 360 minutes, <sup>±</sup> Observed for 420 minutes, <sup>†</sup> Observed for 720 minutes, <sup>a</sup> Validation day  
(two observers), <sup>b</sup> Combined focal and herd observation day

Prior to the first instance of data collection at each site, each herd was familiarised with the observer for one day. Only one observer was used during the study, with another observer used on the first day of observation each month to validate observations. The observer entered the sites 10 minutes prior to the first observation each day, and left 10 minutes after the final observation of each day. The observer remained within approximately 50 metres of the animal at all times and within 200m of the furthest herd member. Where herd movement and landscape obstacles (i.e. trees, buildings, changes in elevation) prevented the monitoring of all animals simultaneously, focal sampling took precedence over group sampling and the observer moved according to the position of the focal animal, rather than the position of the herd. Binoculars were used to ensure the accuracy of behavioural and locational classifications. Cattle were identified by their unique alphanumeric ear tags, colour markings and patterns, anatomy and any other distinctive features.

Each observation day, one previously unobserved animal from the herd was chosen at random and its behaviour monitored; the same animal was never monitored twice. At the beginning of every minute of observation, the behaviour and location of the focal animal at that moment in time were classified according to pre-defined criteria (Table 6.2 and Table 6.3); this is a focal, discontinuous-scan sampling approach (Boitani and Fuller, 2000). Defecation and urination behaviour were recorded irrespective of the precise time they were observed, and allocated to the nearest minute of observation. Where the focal animal's body was equally divided between two different locations simultaneously (e.g. aquatic and riparian), precedence was given to the location the animal had most recently moved into; in all other instances location was determined by the area in which the majority of the animal was found.

| <i>Behaviour class</i> | <i>Description</i>                                                                                                                                                                                                                                                                                                          |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Defecating</b>      | Behaviour in which the animal defecates whilst standing, either static or moving, or resting. Cattle often engage in secondary behaviour whilst defecating and may graze, move, drink or groom at the same time. In all instances, the Defecating classification takes precedence over any other behavioural classification |
| <b>Drinking</b>        | Behaviour in which animals are drinking whilst standing in either the Aquatic, Riparian or Floodplain environment. Characterised by a head-down position devoid of neck rotation                                                                                                                                            |
| <b>Grazing</b>         | Behaviour in which animals remove and eat vegetation from the landscape. Does not include the browsing of trees. Identified by the animal standing but with a head-down position and characteristic neck-twisting motion                                                                                                    |
| <b>Moving</b>          | Behaviour in which animals move through the landscape continuously. No head-down position or grazing. May include bucking and running as well as walking                                                                                                                                                                    |
| <b>Other</b>           | Behaviour including grooming, scratching, fighting, playing, browsing and any other activity that is not covered by the previously listed behaviours                                                                                                                                                                        |
| <b>Resting</b>         | Behaviour in which animals lie down in the landscape. Animals may ruminate (characterised by rhythmic jaw movement), sleep or groom whilst resting; in these instances, the Resting classification takes precedence over the Other classification                                                                           |
| <b>Standing</b>        | Behaviour in which animals are standing but static and not grazing or involved in another activity such as grooming. May include ruminating.                                                                                                                                                                                |
| <b>Urinating</b>       | Behaviour in which the animal urinates whilst standing, either static or moving, or resting. Typically animals remain still whilst urinating and do not engage in other activities. In all instances the Urinating activity takes precedence over any other behaviour except Defecating                                     |



**Table 6.2. Classification of behaviour types**

| <i>Location class</i> | <i>Description</i>                                                                                                                                                                                                                                                                                                                                             |
|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Aquatic</b>        | Landscape elements within the main river channel. Does not include river banks, which are classified as Riparian, but does include fluvial landforms such as riffles and channel bars.                                                                                                                                                                         |
| <b>Floodplain</b>     | Landscape elements including relict channels and drainage ditches. Characterised by low elevation, depressions within the floodplain and, often, distinctive flora or vegetation health. May contain stagnant or slow flowing water. The Floodplain classification takes precedence over the Wooded classification in Floodplain environments containing trees |
| <b>Wooded</b>         | Contiguous areas beneath trees that are neither in the Aquatic, Riparian or Floodplain environment. Such areas are characterised by shading from trees and the presence of sub-canopy non-grass plant species including the clovers ( <i>Trifolium spp.</i> ) and the common nettle ( <i>Urtica dioica</i> )                                                   |
| <b>Valley</b>         | Landscape elements in the valley. These areas are identified both visually within the field and from LiDAR data as regions of high elevation (>10m above the height of the rivers' surface)                                                                                                                                                                    |
| <b>Riparian</b>       | Any area within 5m of the main river channel that is not within the channel itself. The Riparian classification takes precedence over the Wooded classification in riparian environments containing trees                                                                                                                                                      |
| <b>Terrestrial</b>    | Landscape elements within the floodplain that are neither floodplain channels nor within 5m of the main river channel nor under trees                                                                                                                                                                                                                          |

**Table 6.3. Classification of location types**

In addition, on observation days after 11<sup>th</sup> May 2010 at the Midlington sites, herd activity data were also collected (22 days at the southern Midlington site and 20 days at the northern Midlington site). At one minute intervals, the behaviour of each individual within the herd was classified into three categories; lying, activity in the aquatic environment, activity in the non-aquatic environment. This discontinuous group scan-

sampling (Boitani and Fuller, 2000) was conducted concurrently over the same period of time as the focal animal observation and conducted by the same sole observer; a 30 second interval between group and focal sample frequency made this possible.

Alongside the observational data gathered at the respective sites, meteorological data from the nearest weather station, at Southampton Airport (approximately 11 miles from the study sites), were collected. These data, accounting for air temperature, precipitation events, overhead conditions (e.g. cloudy, clear skies, mist), air pressure and humidity every 30 minutes, were extrapolated (averaged) across the observation data sets, providing minute-by-minute values for each variable.

#### 6.1.2.4. *Data analysis*

The area of each location type was derived from analysis of LiDAR data of site terrain and surface elevation in ArcMap 9.3. This information was then used with empirical observational data from the study and input into Hunter's (1962) index of preference ( $P_i$ ) to determine whether cattle preferentially utilised particular location types:

$$P_i = U_i / A_i$$

Where  $U_i$  is the percentage of observations of cattle in location type  $i$ , and  $A_i$  is the percentage of the study site classified as location type  $i$ .

For herd observation data, an in-stream cattle-activity coefficient was calculated for each day:

$$C = \sum(n * t)$$

Where  $n$  refers to the number of cattle in-stream each minute of observation and  $t$  refers to the number of minutes  $n$  cattle are in-stream. This provided a quantitative value for in-stream herd activity between days that could be compared against meteorological variables such as air temperature, humidity and precipitation.

Pearson's product-moment co-efficient ( $r$ ) was calculated to investigate the relationship between the in-stream cattle activity (individual and herd) and air temperature using pairwise two-tailed bivariate tests. For these tests, the number of observations of cattle in-stream at different temperatures was represented as a percentage, due to differences in the number of observations made at different air temperatures (i.e. 30 observations at 28°C compared to 2682 observations at 17°C). Statistical tests, such as the two-sample student t-test, were also used to test the significance and strength of relationships between other continuous variables (e.g. landscape utilisation between sites; river utilisation and humidity).

The remainder of the data analysis involved calculation of descriptive statistics to compare cattle behaviour and location spatially (i.e. between sites) and temporally (i.e. between months and across days). ArcMap 9.3, Minitab 16 and SPSS Statistics 17 were used for statistical analyses.

It should be noted that the majority of statistical and qualitative analyses applied herein omit data from Winnall Moors due to the relatively small number of observations taken at this site.

### **6.1.3. Results**

Results from the cattle observation study tell us much about the nature and drivers of interactions between cattle and chalk stream environments. For the most part the results are dominated by the simple quantification of the time spent in different environments and involved in different activities. This general overview is augmented by river-specific results, comparisons between sites and a consideration of herd-level activity. Finally, the relationship between cattle activity and air temperature is examined.

6.1.3.1. Cattle location overall

Cattle did not spend an equal amount of time in each location over the course of the study (Table 6.4).

|                | Aquatic | Floodplain | Wooded | Valley | Riparian | Terrestrial |
|----------------|---------|------------|--------|--------|----------|-------------|
| Total time     |         |            |        |        |          |             |
| (minutes)      | 565     | 752        | 2451   | 2451   | 2002     | 17727       |
| Daily mean     |         |            |        |        |          |             |
| (minutes)      | 10      | 13         | 50     | 41     | 34       | 305         |
| SD (minutes)   | 20      | 24         | 72     | 82     | 49       | 106         |
| Daily range    |         |            |        |        |          |             |
| (minutes)      | 0-95    | 0-137      | 0-294  | 0-436  | 0-197    | 3-445       |
| Total time (%) | 2.17    | 2.89       | 6.60   | 9.43   | 7.71     | 68.23       |

**Table 6.4. Focal cattle distribution across the Midlington sites.**

Moreover, the amount of time cattle spent in each location did not reflect the availability of each location type; cattle preferred certain areas within the landscape and avoided others. Hunter's (1962) index of preference shows that cattle used riparian, terrestrial and wooded locations more than would be expected based on the availability of those locations; aquatic, floodplain channel and valley locations were under-utilised (Table 6.5)

|                      | Aquatic | Floodplain | Wooded | Valley | Riparian | Terrestrial |
|----------------------|---------|------------|--------|--------|----------|-------------|
|                      |         | channels   |        |        |          |             |
| <u>Northern site</u> |         |            |        |        |          |             |
| $A_i$ (%)            | 2.73    | 4.99       | 4.61   | 48.54  | 4.01     | 35.12       |
| $U_i$ (%)            | 2.00    | 3.09       | 7.90   | 12.28  | 10.39    | 64.35       |
| $P_{iü}$             | 0.73    | 0.62       | 1.71   | 0.25   | 2.60     | 1.83        |
| <u>Southern site</u> |         |            |        |        |          |             |
| $A_i$ (%)            | 2.99    | 5.06       | 5.86   | 46.47  | 4.38     | 35.24       |
| $U_i$ (%)            | 2.35    | 2.70       | 11.20  | 6.61   | 5.05     | 72.09       |

|       |      |      |             |      |             |             |
|-------|------|------|-------------|------|-------------|-------------|
| $P_i$ | 0.79 | 0.53 | <b>1.91</b> | 0.14 | <b>1.15</b> | <b>2.05</b> |
|-------|------|------|-------------|------|-------------|-------------|

**Table 6.5. Cattle landscape availability ( $A_i$ ), utilization ( $U_i$ ) and preference ( $P_i$ ) at the northern and southern Midlington sites.  $P_i$  values:  $<1$  = avoidance (italicised),  $>1$  = selection (bolded). The magnitude of  $P_i$  values reflects the degree of avoidance/selection.**

Additionally there were site-specific differences in utilisation, although none of these was found to be statistically significant; the greatest difference between sites was in riparian location utilisation ( $T = -1.65$ ,  $P = 0.106$ ,  $df = 40$ ).

#### 6.1.3.2. Cattle location by time

Cattle location varied according to the time of day (Figure 6.4).

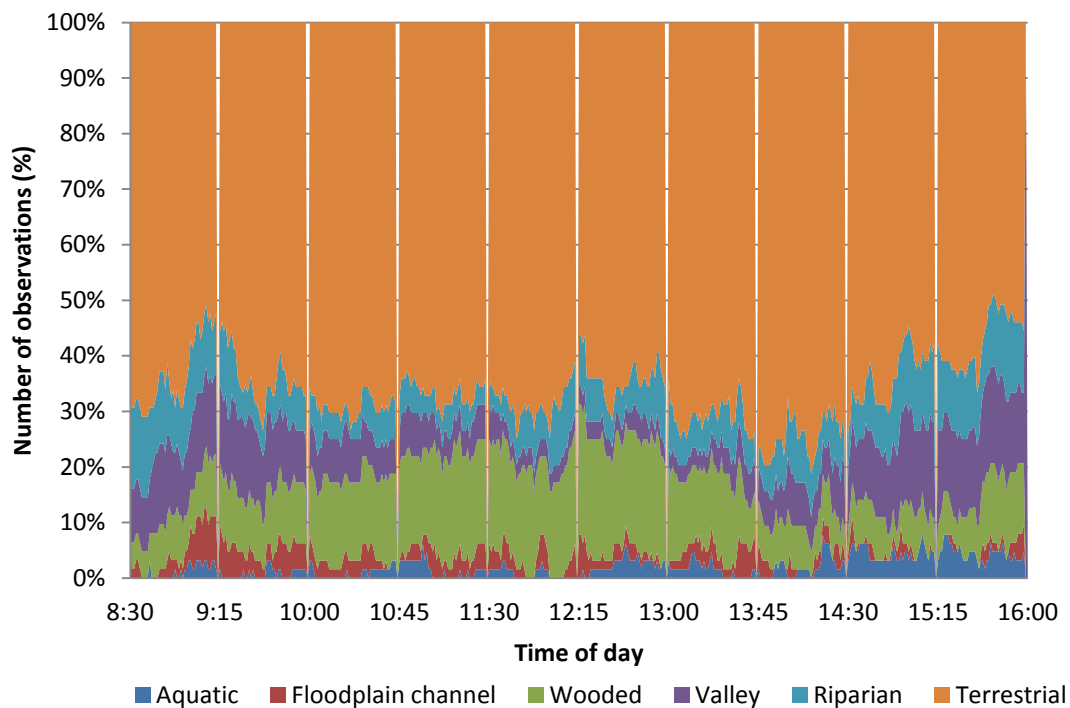


**Figure 6.4. Minute-by-minute cattle landscape utilization at different times of the day based on cumulated daily data from the Midlington sites.**

For all locations there were statistically significant differences in landscape utilisation during different parts of the day. The greatest of these was the difference in wooded location utilisation between 12:15-13:00 and 14:00-14:45 ( $T = 42.5$ ,  $P = 0$ ,  $df = 86$ ). Aquatic location utilisation differed significantly between 09:15-10:00 and 15:15-16:00 ( $T = -13.69$ ,  $P = 0$ ,  $df = 76$ ), whilst riparian location utilisation differed significantly between 08:30-09:15 and 10:45-11:30 ( $T = 21.41$ ,  $P = 0$ ,  $df = 67$ ).

Cattle location also varied across different months (Figure 6.5).

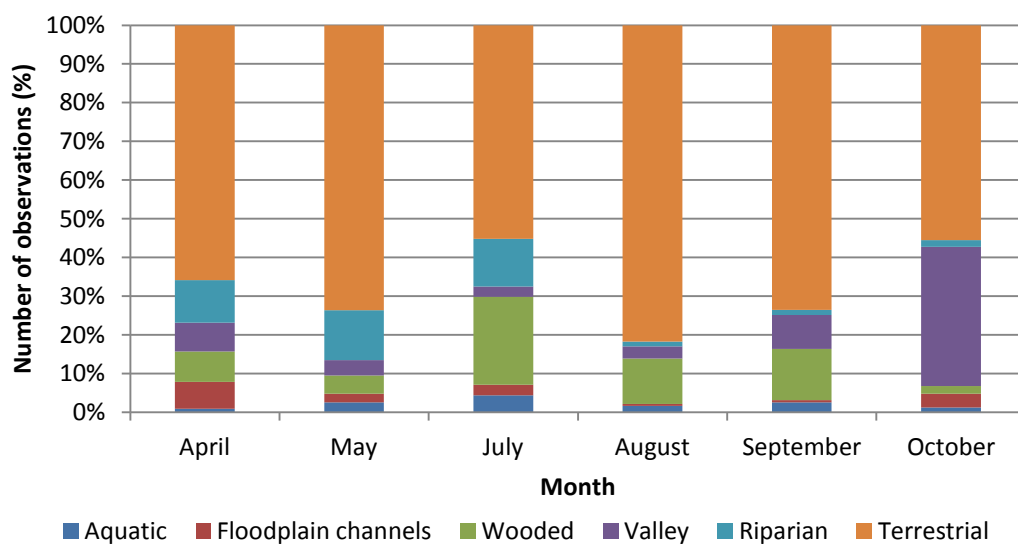


**Figure 6.5. Cattle landscape utilization during different months based on data from the Midlington sites.**

Statistically significant differences in landscape utilisation between months were established for floodplain channel (the difference between April and September:  $T = 2.44$ ,  $P = 0.035$ ,  $df = 10$ ), valley (the difference between July and October:  $T = 2.93$ ,  $P = 0.022$ ,  $df = 7$ ), riparian (the difference between May and August:  $T = 3.96$ ,  $P = 0.001$ ,  $df = 15$ ) and terrestrial (the difference between July and August:  $T = -2.37$ ,  $P = 0.034$ ,  $df = 13$ ) locations. There were no statistically significant differences in landscape utilisation between months for aquatic and wooded locations.

6.1.3.3. *Cattle behaviour overall*

Cattle spent different amounts of time engaged in different activities over the course of the study (Table 6.6).

|             | Urinating | Standing | Resting | Other | Moving | Grazing | Drinking | Defecating |
|-------------|-----------|----------|---------|-------|--------|---------|----------|------------|
| Total time  |           |          |         |       |        |         |          |            |
| (minutes)   | 20        | 3046     | 8710    | 251   | 606    | 13068   | 120      | 159        |
| Daily mean  |           |          |         |       |        |         |          |            |
| (minutes)   | >1        | 55       | 148     | 4     | 10     | 225     | 2        | 3          |
| SD          |           |          |         |       |        |         |          |            |
| (minutes)   | >1        | 62       | 68      | 9     | 9      | 50      | 3        | 1          |
| Daily range |           |          |         |       |        |         |          |            |
| (minutes)   | 0-4       | 1-246    | 0-315   | 0-38  | 0-39   | 113-338 | 0-18     | 0-6        |
| Total time  |           |          |         |       |        |         |          |            |
| (%)         | 0.08      | 11.72    | 33.53   | 0.97  | 2.33   | 50.30   | 0.46     | 0.61       |

**Table 6.6. Focal cattle behaviour across the Midlington sites.**

The daily number of observations made in each category of behaviour did not differ significantly between the two Midlington sites except in the moving category ( $T = 2.09$ ,  $P = 0.042$ ,  $df = 44$ ). For all other behaviour there was no statistical difference between the two Midlington sites.

Behaviour also varied between different locations (Figure 6.6)

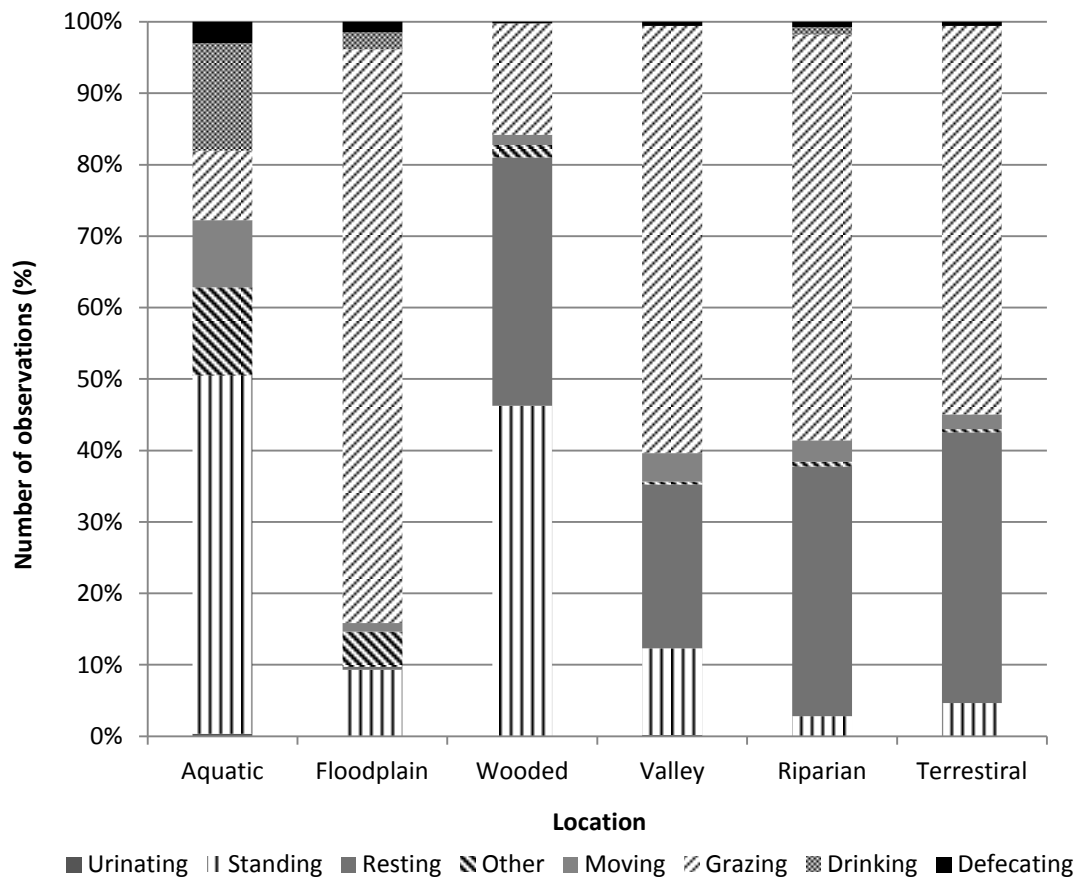


**Figure 6.6. Differences in cattle behaviour in different locations.**



#### 6.1.3.4. Cattle behaviour by time

Cattle behaviour varied according to the time of day (Figure 6.7).

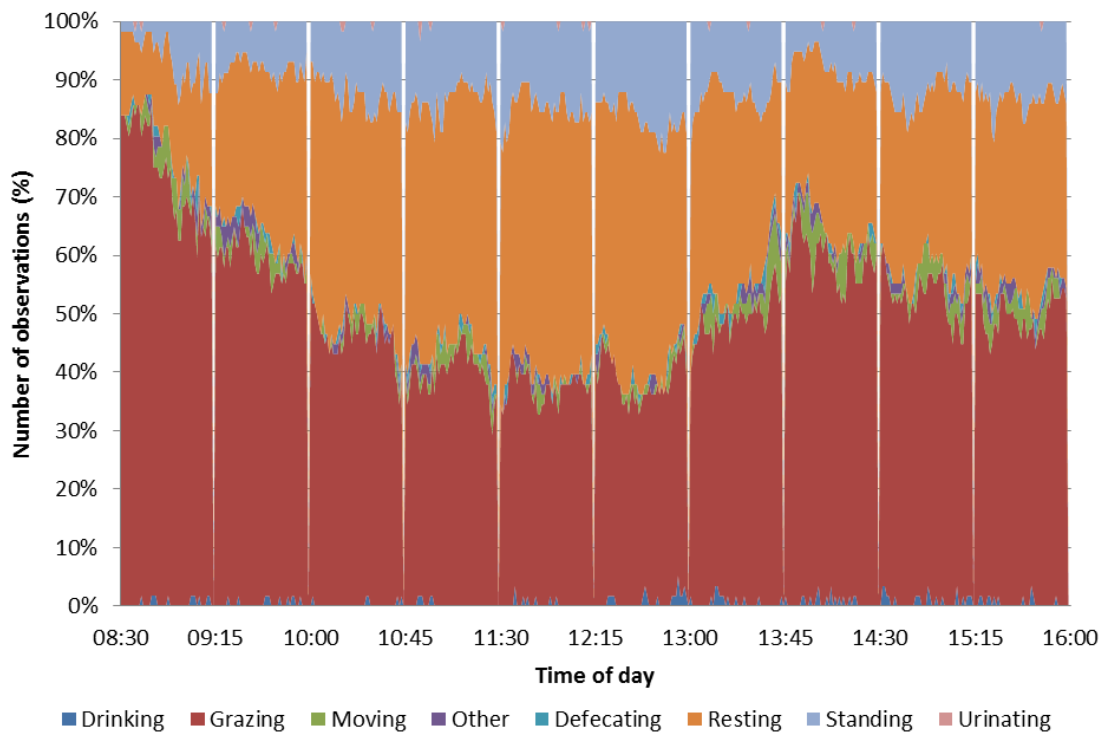


**Figure 6.7. Minute by minute cattle behaviour at different times of the day based on cumulated daily data from the Midlington sites.**

For all categories of behaviour, apart from urinating, there were statistically significant differences in cattle activity during different parts of the day. The greatest of these was

the difference in resting activity between 08:30-09:15 and 10:00-10:45 ( $T = -31.65$ ,  $P = 0$ ,  $DF = 87$ ). Unlike location, there were no statistically significant differences in cattle behaviour between months.

#### 6.1.3.5. Cattle activity in the aquatic environment

Focus cattle did not enter the aquatic environment on over 25% of the observation days. In terms of the frequency and duration of in-stream activity, focus cattle generally spent short periods of time in the aquatic environment; focus cattle spent ten minutes or less in-stream on 31 out of the 43 days upon which they entered the aquatic environment (Figure 6.8).

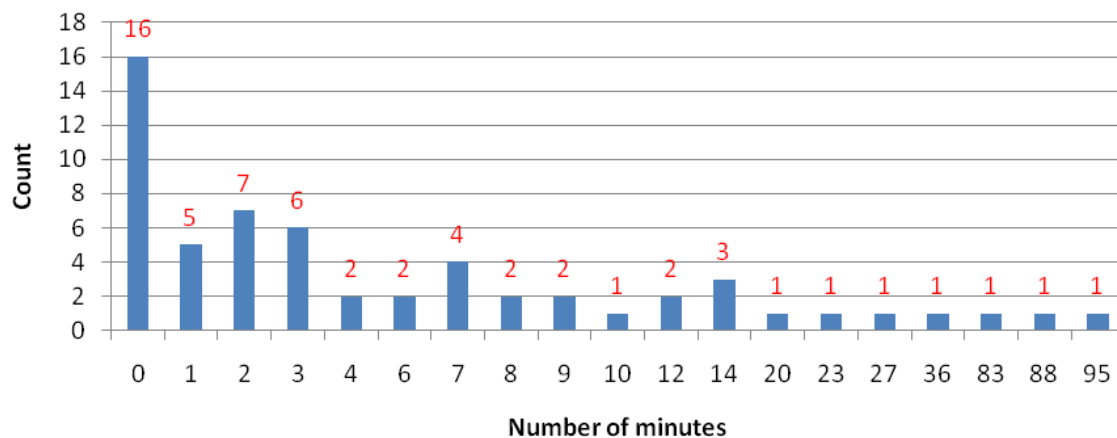


**Figure 6.8. Count of minutes spent in the aquatic environment per day by focus cattle. The total number of observation days is 59.**

However, focus cattle were also observed, on occasion, spending extended periods of time in-stream. On 25<sup>th</sup> July 2010, subject A25 spent over one and a half hours in the aquatic environment at the Southern Midlington site; time spent in-stream by the subject accounted for approximately 21% of the time spent in any environment across this observation day.

6.1.3.6. *Defecation behaviour*

On average, cattle defecated 2.76 times per day (450 minutes) of observation. With respect to defecation location, it was observed that focus cattle defecated most frequently in the terrestrial environment overall (Table 6.7).

|               | Aquatic | Floodplain | Trees | Valley | Riparian | Terrestrial | Woodland |
|---------------|---------|------------|-------|--------|----------|-------------|----------|
| Total minutes | 17      | 11         | 3     | 14     | 12       | 100         | 2        |
| % Overall     | 0.07    | 0.04       | 0.01  | 0.05   | 0.05     | 0.38        | 0.01     |
| % Defecating  | 10.69   | 6.92       | 1.89  | 8.81   | 7.55     | 62.89       | 1.26     |
| % Environment | 3.01    | 1.46       | 0.18  | 0.57   | 0.60     | 0.56        | 0.26     |
| Ratio %       | 4.93    | 2.39       | 0.29  | 0.93   | 0.98     | 0.92        | 0.42     |

**Table 6.7. Focus cattle defecation. % Overall refers to the time spent defecating in each environment as a proportion of the total time observed across all environments. % Defecating refers to the time spent defecating in each environment as a proportion of the total time spent defecating. % Environment refers to the time spent defecating in each environment as a proportion of the total time spent in each environment. Ratio % is the ratio between the percentage time defecating in each environment and the percentage time spent in each environment overall.**

However, as a percentage of the time spent by focus cattle in a given environment, the most popular location for defecation was the aquatic environment; cattle spent approximately 3.2% of their time in the aquatic environment defecating, compared to 0.6% of their time defecating overall. In terms of the total time spent defecating, focus cattle were seen to spend over ten per cent of their time defecating in the aquatic environment; the ratio between the time spent defecating in the river and the total time spent in the river was the highest of any environment. Qualitative observations of the

herd support the notion that cattle preferentially defecate in wet environments, including active floodplain channels, as suggested by the observation data.

#### 6.1.3.7. Study site differences

Neither the amount of time cattle spent involved in different behaviours ( $N = 8$ ,  $T = 0$ ,  $P = 1$ ,  $df = 13$ : Figure 6.9) nor the amount of time cattle spent in different locations ( $N = 6$ ,  $T = 0$ ,  $P = 1$ ,  $df = 9$ : Figure 6.10) varied significantly between sites.

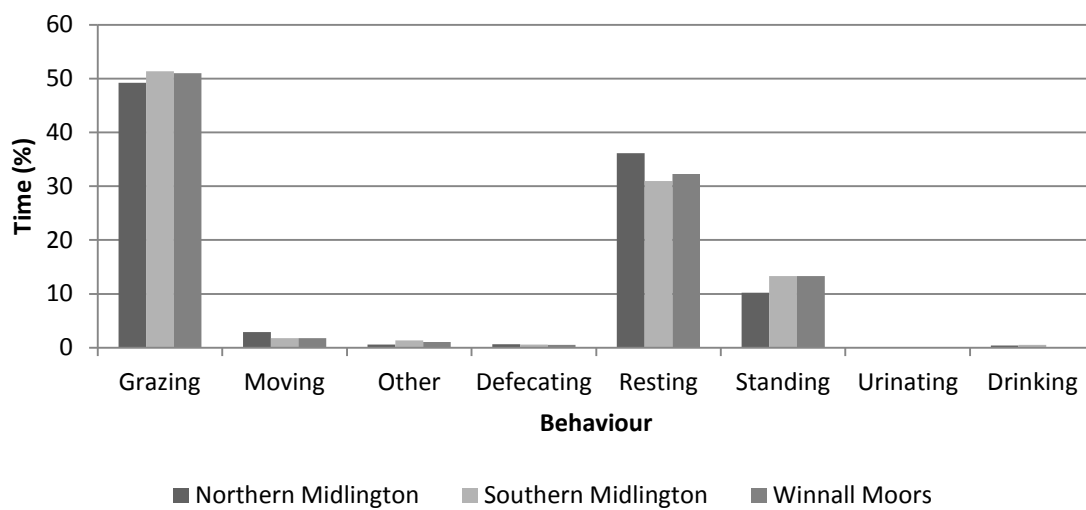


Figure 6.9. Cattle behaviour across sites.

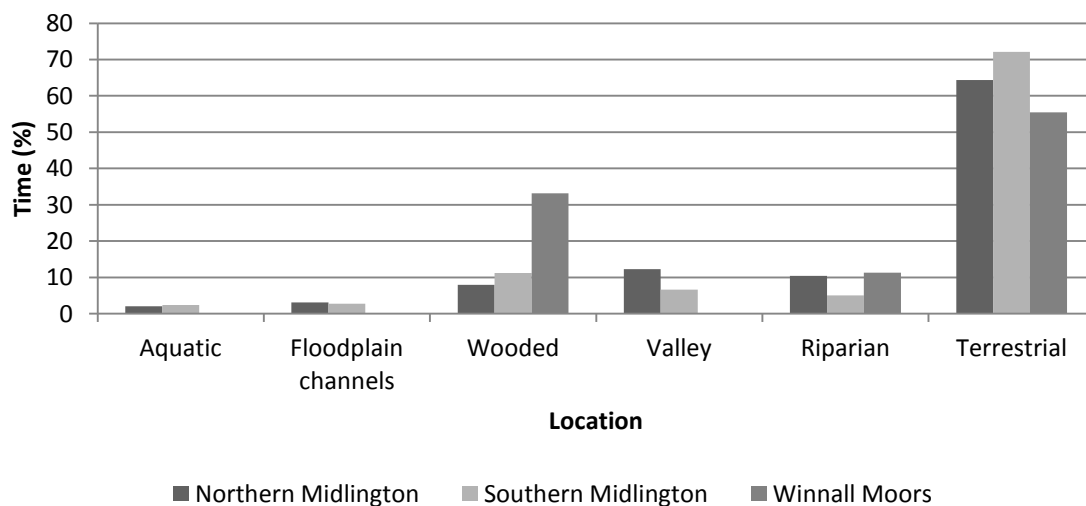


Figure 6.10. Cattle location across sites.

6.1.3.8. *Herd activity*

It was seen that across the 42 days of herd activity observation, there were no cattle in the aquatic environment for 84.4% of the time. Of the 2872 minutes during which at least one herd member was observed in the aquatic environment, the number of cattle in-stream was generally low, with ten or less cattle in-stream for 87.4% of the time. There were only two days when a member of the monitored herd did not enter the aquatic environment. The daily cattle activity co-efficient ranged from zero on the days when no cattle entered the river, to 2648 on a day when there was at least one animal in-stream for 43% of the observation period and the number of cattle in-stream peaked at 35 (the entire herd was in the river). Generally however, the daily cattle activity co-efficient did not exceed 500, with a mean cattle activity co-efficient of 343 per observation day.

6.1.3.9. *In-stream herd activity and focus cattle data comparison*

A statistically significant positive correlation ( $r = 0.727$ ,  $N = 42$ ,  $P < 0.01$ ) between the amount of time spent in-stream by focus cattle and the in-stream cattle-activity coefficient was observed; this agrees with qualitative observations of many cattle entering the aquatic environment simultaneously (Figure 6.11).

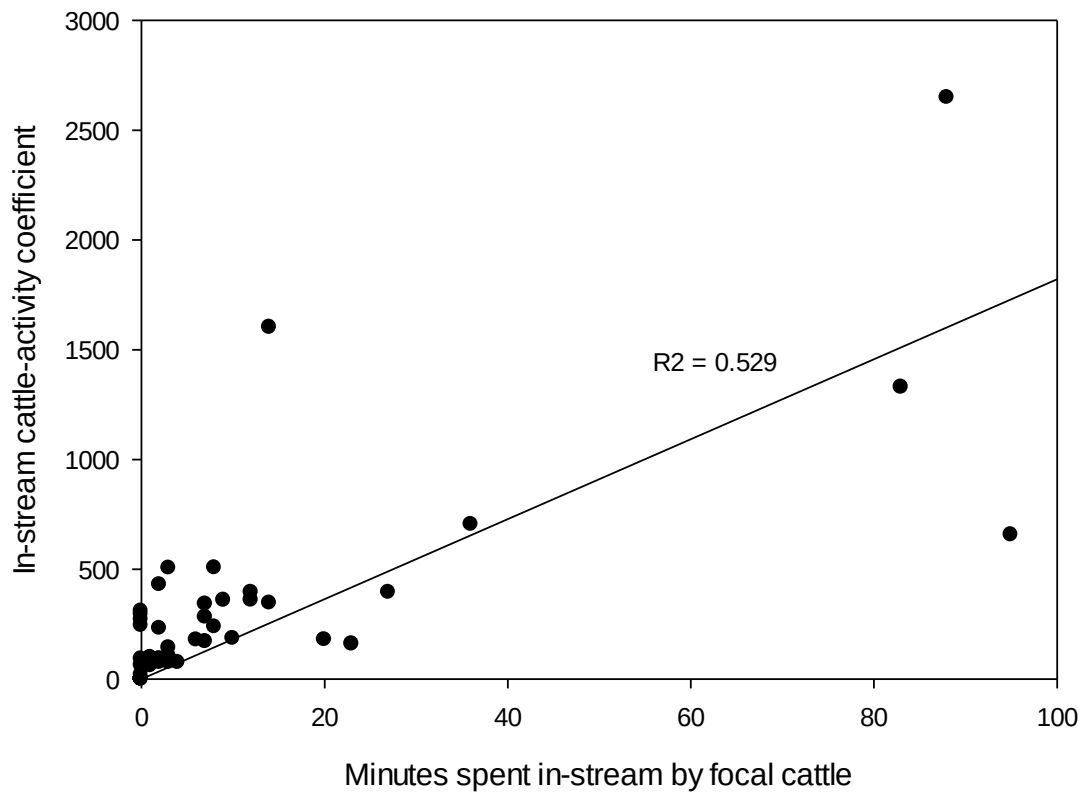


**Figure 6.11. The relationship between individual and herd utilisation of the aquatic environment.**

#### 6.1.3.10. Cattle activity and air temperature

The behaviour and location of cattle varied with air temperature. It was observed that between -4°C and 6°C, cattle did not rest at all, instead spending the majority of this time grazing. The proportion of time cattle spent resting increased with air temperature, with the amount of time spent grazing decreasing with air temperature. Cattle also spent more time standing as air temperatures rose. No statistically significant relationship was observed between humidity and the time cattle spent in-stream ( $r = -0.084$ ,  $N = 80$ ,  $P = 0.448$ ) or any other activity.

With respect to cattle location, the valley environment was regularly utilised at low air temperatures, whilst cattle spent more time under trees and in the riparian environment when air temperatures were high; cattle spent 45% of observations made at 23°C in the

riparian environment, whilst all observations made at 27 and 28°C recorded cattle standing under trees. There were no noticeable differences in the utilisation of the terrestrial environment and floodplain channels with changing air temperatures. A statistically significant positive correlation between the amount of time cattle spent in-stream and air temperature was recorded ( $r = 0.356$ ,  $N = 33$ ,  $P, <0.05$ ; Figure 6.12).

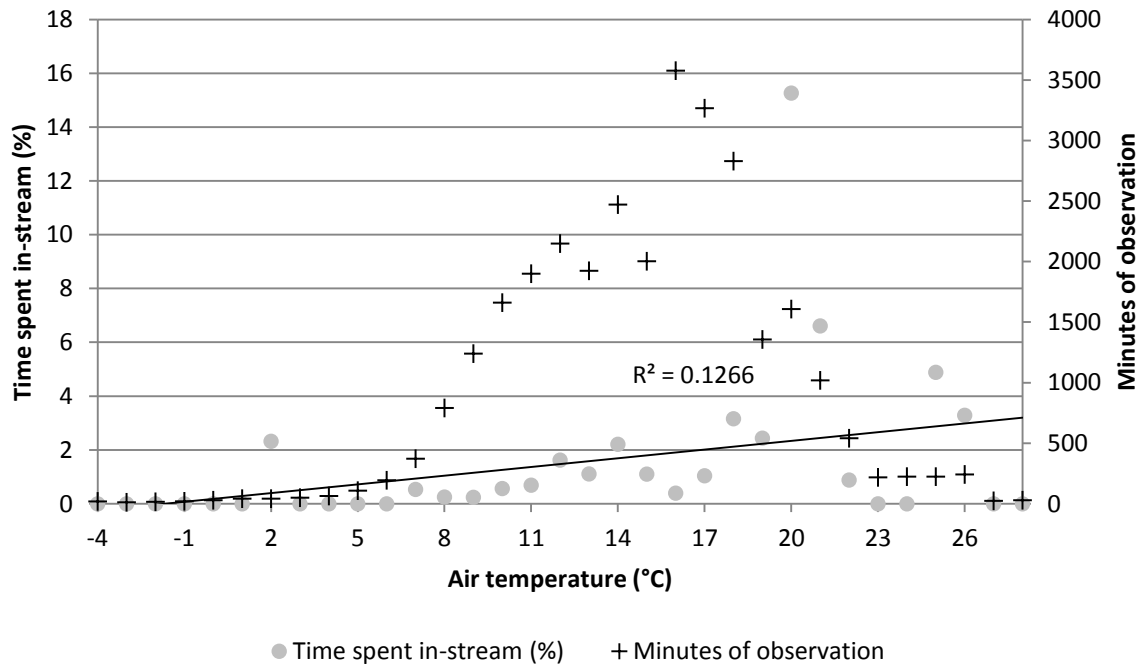


**Figure 6.12. Time spent in-stream (%) refers to the number of in-stream observations as displayed as a percentage of the total number of observations made at each air temperature. The total number of observations at each air temperature, a correlation trend line for the time spent in-stream (%) and  $R^2$  value are also provided.**

#### 6.1.4. Discussion

##### 6.1.4.1. Limitations

###### 6.1.4.1.1. Observation timing

The observational component of this study had a number of practical and logistical constraints. It was not possible to observe the subject animals every minute of every day. Because animals were only observed, on average, for 7.5 hours each day, it is possible that certain behavioural elements were not observed. In an attempt to mitigate this problem, a large volume of data was collected over a relatively long period of time; few

if any studies in the existing literature have been conducted near-continuously for over six months. Additionally, the data collected using the GPS cattle collars helped categorise behaviour during non-observation time. The GPS data also supported evidence from the literature in suggesting that cattle are predominantly active during daylight hours, and that not observing cattle during the night is an acceptable constraint.

#### 6.1.4.1.2. Observation frequency

Another limitation was the recurrence interval of observations. Sub-minute behaviours may have been missed if they occurred in between the one minute observational recordings. Consequently it is thought that the frequency of behaviours such as defecation, and particularly urination, which was difficult to observe at any time, are underestimated in the data sets produced. Indeed, parts of the literature suggest defecation and urination frequencies above those observed during this study (e.g. Hafez and Bouissou, 1975; Aland *et al.*, 2002; Orr *et al.*, 2012). Higher estimates were observed in these studies as observers remained closer to subject animals than was possible in our study and hence more accurately recorded urination and defecation frequency.

#### 6.1.4.1.3. Observation methodology

Problems were also encountered in trying to keep the subject animal and the herd in view at all times. At the Meon Valley site the large herd sizes meant that sometimes non-subject animals would obscure the view of the subject animal. Moreover, on rare occasions the herd would divide into separate groups that were difficult to monitor simultaneously due to their distance from one another. At both sites, but particularly Winnall Moors, topography, vegetation, trees and other obstacles within the landscape would also occasionally prevent the observer from monitoring the subject animal. Additionally, the cattle at the Meon Valley site especially were prone to sudden, fast movement events that, even with the use of binoculars, could move the cattle out of view of the observer. In all such instances of view obstruction the observer would move to a better vantage point for monitoring, still recording subject behaviour and location every



minute. In the event of a herd division that prevented the observation of all cattle simultaneously, the group containing the subject animal were monitored preferentially.

#### 6.1.4.1.4. Classification limitations

It could also be argued that the classifications of behaviour and landscape position were arbitrary. However, because this study was unique in its objectives, it was held that the methodological approach did not necessarily need to conform to an existing convention. Indeed, there was no existing classification system, with many previous studies adopting behavioural classifications designed to effectively categorise the behaviour of interest (e.g. Tulloh, 1961; Friend and Polan, 1974; Albright, 1993). Hence the classification of behaviour and landscape position in this study reflected those elements that were of geomorphic interest i.e. aquatic versus terrestrial, grazing versus resting. Moreover, because each category is given a description (Table 6.2, Table 6.3) there is transparency in the definition of behaviour.

#### 6.1.4.1.5. Cattle breed

The choice of cattle also presents a small limitation to the findings. The majority of cattle observed were relatively young, male, beef cattle. It is thought that different animals would display different temperaments and hence different behaviours. Specifically, the bullocks observed were held to be more inquisitive and investigatory than average cattle, which may have resulted in the observed cattle spending more time in obscure locations or moving between landscape elements. Moreover, as the herds were dominated by males it is likely that an above average number of combative interactions (classified in the data set as 'other') between cattle were observed. Finally, and most crucially, because the cattle were predominantly beef cattle rather than dairy cattle, it is thought that the amount of time spent drinking may be underestimated if compared to other cattle. Indeed, any activity relating to milk production (including grazing) could be under represented in this data.

The counter point and justification for the limitations of the choice of cattle is three fold. Firstly, the small number of existing studies comparing dairy against beef cattle suggest that differences in behaviour are relatively small (Albright, 1993; Arave and Albright, 1997). Secondly, a small number of female cattle were included in the herds observed and their behaviour did not deviate significantly from that of their male counterparts. Thirdly, and most importantly, the animals observed were the most representative of the types of cattle grazed in chalk stream environments (DEFRA, 2010b)

#### 6.1.4.2. *Focal cattle observations*

##### 6.1.4.2.1. Location

Due to the lack of existing studies of landscape utilization by cattle in chalk stream environments, it is difficult to ascertain whether the amount of time spent in different environments by focus cattle during this study is as expected. The nearest comparable study is Schaich *et al.* (2010); although their division of the landscape into hydrological zones and vegetation habitat types is not compatible with our data set.

Haan *et al.* (2010) observed that cattle spent 10.5% of their time in the riparian zone in their three year study of Angus cow activity in North America; the value is relatively high as the riparian margin was defined as anywhere up to 10m from the water's edge. Bagshaw *et al.* (2008) observed that cattle spent 1.5% of their time in the riparian zone in their two year study of beef cattle behaviour in Hamilton, New Zealand; the value is relatively low as the riparian margin was defined as anywhere up to 2m from the water's edge. Our study observed that focus cattle spent, on average, 7.7% of their time in the riparian zone; based upon the aforementioned studies this value appears representative of cattle utilisation of the riparian environment adjacent to chalk streams.

In terms of focus cattle utilization of the aquatic environment, there are only a few comparable studies. Ballard and Krueger (2005a) observed that cattle spent less than one per cent of their time in-stream, whilst Haan *et al.* (2010) recorded the duration of in-stream cattle activity as 1.1% of total observation time. Both values are less than observed in our study (2.2%), although this is explicable given the methodological

differences between the studies (i.e. our study had a greater observation frequency). Environmental, ecological and herd differences aside, methodologically both Ballard and Krueger (2005a) and Haan *et al.* (2010) employed an insufficiently frequent recording interval for observation. Our study recorded that on 70% of the days upon which cattle entered the river, they did so for less than ten minutes; the recurrence interval of observations in the Ballard and Krueger (2005a) and Haan *et al.* (2010) studies was once every ten minutes, and so it is possible that in-stream activity between observation intervals was missed.

The daily variability in location, including in-stream activity, was high. Although cattle only spent 2.17% of their time in-stream overall, on a particular observation day an individual spent 95 minutes (21% of the daily observation period) in the aquatic environment. The variability in other environments was even higher, with the daily time spent in valley and terrestrial environments ranging from 0% of daily observation time to 99% of daily observation time. The discrepancy between the average amount of time spent in different locations and the range of time spent in different locations raises a number of points. Firstly, the distribution of cattle in space clearly varies across different temporal scales; observation across a day is not informative of observation across a month, for example. Secondly, the data imply that the location of cattle is not only driven by the prevailing characteristics of different locations, but also factors independent of landscape (e.g. weather, internal biological mechanisms). Thirdly, the period of time over which cattle are observed influences the representativeness of their activity, and any conclusions drawn from time-restricted observations must take this into consideration.

On the second point, it seems unlikely that the precise reasons as to why cattle spend such varying amounts of time in different environments on different days will ever be fully understood. Theoretically, and according to the aforementioned OFT model of foraging behaviour (MacArthur and Pianka, 1966; Schoener, 1971), the principle driver of cattle location will be forage quality. Within a given area, forage quality will vary across space due to differences in soil, elevation, micro-climate and plant community composition, amongst other variables. Equally, within a given area forage quality will

vary across time due to changes in meteorological conditions, grazing pressure and the abundance of the forage resource. Consequently, the different factors that influence the spatial distribution of cattle will vary constantly, simultaneously, and hence the high variability in their day-to-day location is not unexpected.

#### 6.1.4.2.2. Behaviour

The proportion of time focus cattle were observed engaged in grazing broadly agrees with the existing literature on cattle activity; Broom and Fraser (2007) note that cattle may spend between four to 14 hours grazing per day, whilst our study observed cattle grazing for approximately 50% of the time. Although the time focus cattle were observed resting was less than suggested by Broom and Fraser (2007) and Jensen (2009), this is accounted for by the time frame of our study. Because our observation period span from 08:30 until 16:00 each day, the main period of cattle rest (the night time) was not observed, and so our results likely underestimate the total time spent resting per day.

With respect to the timing, frequency and duration of grazing behaviour, focus cattle activity was similar to that previously recorded in other studies. Focus cattle were most commonly observed grazing in the mid-morning between 08:30 and 10:00, and in the early afternoon, from 13:30 until 15:00; periods of time identified by Broom and Fraser (2007) as preferential for grazing. Furthermore, the average duration of grazing bouts was 150 minutes, which again falls within the range suggested by Broom and Fraser (2007).

In terms of the R:G ratio, which was crudely estimated by dividing the overall time spent resting by the overall time spent grazing, the value for the study sites was 0.66; an expected ratio for chalk water meadows and grassland (Phillips, 1993).

As previously mentioned, it is suspected that the observations of defecation, and urination in particular, recorded in our study underestimate the true frequency of these events. Cattle were seen to defecate, on average, 2.7 times per seven and a half hours; approximately eight times a day. This is less than recorded by Aland *et al.* (2002: dairy cattle) and Hafez and Bouissou (1975: dairy cattle), but approximately the same as

Oudshoorn *et al.* (2008: dairy cattle; mean defecation frequency of 0.37 per cow per hour, approximately nine times per day). Given that the cattle in our study were adolescent, beef bullocks, the discrepancy between our study results and existing study results are explicable.

Urination frequency for our study was, on average, once every 24 hours which is clearly an underestimate of the true urination frequency. Oudshoorn *et al.* (2008) suggest a mean urination frequency of 0.26 per cow per hour (approximately six urination instances a day, per cow), whilst Aland *et al.* (2002) and Fuller (1928) observed an average of 9 and 7.9 urination instances a day respectively. Evidently the true number of urination instances was not recorded. There were several reasons for this. In order to have consistently monitored the frequency of urination instances it would have been necessary to stay proximate (within 20m) of the subject cattle for the entire period of observation. Not only would this have been impractical but such close observation may have influenced animal behaviour, as well as posing a potential safety risk for the observer. The other major reason for missing urination instances was their duration. In all cases urination instances lasted less than a minute, and although the observation methodology allowed for the replacement of the timed one minute interval recordings with a defecation or urination observation in the event of a defecation or urination instance, this rarely occurred. Whilst defecation was associated with clear animal body language indicators, such as the raising of the animals' tail vertically, urination instances occurred relatively spontaneously and without visual clues. Moreover, whereas defecation occurred regularly following resting periods, or whilst subject cattle were in-stream, there were no location or timing associations with urination, and hence no triggers to alert the observer to a potential urination instance. Consequently, although it is possible to justifiably accept the recorded defecation data as representative of cattle behaviour, the urination data is unsuitable for further analysis or any subsequent assessment of cattle impact.

For the remaining types of behaviour it is difficult to determine whether the observed results are as expected. Several studies have considered drinking frequency (e.g. Vega *et*

*al.*, 2010), but all existing observations were made under significantly different conditions from those in our study.

What is clear is that the daily variation in cattle behaviour was generally less than that observed in cattle location. This is not unexpected given the essential nature of most behaviour. Cattle must graze, rest, defecate and urinate in order to live; location is of secondary importance.

#### 6.1.4.2.3. In-stream activity

The allocation of time to different tasks in the aquatic environment by focus cattle provided a useful and surprising insight into in-stream cattle activity. Focal cattle spent the majority of their time in-stream standing, which has a number of potential hydromorphological implications. In shallow gravels, the presence of the cattle led to the formation of eddies and white-water, and the redirection of flow around cattle legs. Moreover, it was observed that periodic stamping of shallow gravels by cattle during in-stream standing periods (in response to bites from flies in the *Tabanidae* family) across the summer months, caused fine sediment particles previously trapped within the gravel bed substrate to become dislodged. Even when standing cattle were not completely static for every minute of observation prescribed to the Standing classification, and river bed disruption was a characteristic of all observations of in-stream cattle activity. In shallow silty environments, such as those at the base of a cow ramp, the principle consequence of in-stream cattle activity was to mobilize relatively large quantities of fine sediment. However, because of the comparatively slow flow in such environments, the transport of fine sediment horizontally, and subsequently laterally downstream, was minimized. Instead, fine sediment was transported through areas of slow flowing bank adjacent water, being deposited where bed or bank resistance increased or, more commonly, where emergent macrophytes led to further reductions in flow velocity.

The most significant geomorphic impact of in-stream cattle activity appears to be from allochthonous nutrient and organic sediment inputs in the form of cattle faeces. Cattle were six times more likely to defecate in the aquatic environment than in the terrestrial

river floodplain, and spent approximately 10% of their time defecating in the aquatic environment, despite only spending approximately 2% of their time in-stream. Ballard and Krueger (2005a) observed a similar disparity, albeit with a weaker relationship; cattle spent less than one per cent of the observation period in-stream, but spent two per cent of their time defecating in-stream. In our study, cattle also defecated more frequently in floodplain channel environments than might be expected.

Within the academic literature there is no mention of cattle preferentially defecating in wet environments. However and as previously mentioned, no previous study has monitored in-stream and floodplain cattle activity in this way. As such, the observation that cattle defecate at a higher frequency in-stream than in any other environment represents a key finding in the understanding of cattle-river interactions. Moreover there are logical reasons as to why cattle would behave in this way. Direct defecation in the river removes livestock faeces from the environment in which the cattle are active. This reduces the risk of infection and illness in cattle; numerous studies have shown livestock faeces to contain potentially harmful diseases (e.g. Phillips *et al.*, 2003). Also, by defecating in-stream, cattle avoid contaminating areas in the terrestrial environment that can be grazed; livestock are known to generally avoid areas containing faeces so as to minimize their exposure to parasites and pathogens (Hutchings *et al.*, 1998).

It is known that in the terrestrial environment cattle will defecate more frequently in certain areas than others, creating defecation hotspots (Oudshoorn *et al.* 2008). Our results suggest that the aquatic environment is also a defecation hotspot. However, whereas defecation in the terrestrial environment is important for nutrient recycling and vegetation community heterogeneity (Haynes and Williams, 1993), direct faeces contributions to the aquatic environment are unlikely to benefit the riverine ecosystem (Hubbard *et al.*, 2004). In chalk streams, where concentrations of nitrogen, phosphorous and fine sediment are naturally lower than other river types, the potential consequences may be exacerbated (Mainstone, 1999; Smith *et al.*, 2003).

As to whether cattle consciously decide to defecate in wet environments is unclear. In recent years, research into cow psychology has demonstrated that cattle have greater cognitive ability than was previously thought (Webster, 2005; Broom, 2010). Yet, the notion that cattle selectively choose to defecate in-stream appears unlikely. The more realistic explanation is an intrinsic biological trigger, perhaps developed over the animal's evolutionary history, which increases the probability of the animal defecating in the aquatic environment. To date, and despite numerous studies focusing solely upon defecation and urination behaviour in cattle (e.g. Villettaz *et al.*, 2011), this has not been investigated.

#### 6.1.4.3. *Herd activity*

The statistically significant positive correlation between the in-stream focus cattle and in-stream herd activity variables supports the notion that generally the behaviour of an individual is reflected by the behaviour of the herd and vice-versa, particularly in terms of aquatic environment utilisation. Moreover, the results suggest that irrespective of whether a focal sampling strategy is employed or whether an entire population of cattle is observed, the same broad pattern of watercourse usage should emerge; as the amount of time spent in the aquatic environment by an individual increases, the amount of time spent in the aquatic environment by the herd should increase.

#### 6.1.4.4. *Drivers of aquatic environment utilisation*

Quantitative observational data gathered throughout this study have shown the ways in which cattle interact with the aquatic environment. However, whilst it is now known that cattle spend most of their time in-stream standing, and that cattle defecate at a higher frequency in the aquatic environment than anywhere else, the mechanisms that cause cattle to enter rivers remain unclear.

The fundamental drivers are likely to be internal and biological. Cattle will seek the aquatic environment for its resources and attributes. Specifically, qualitative and quantitative observational data suggests there are two principle reasons for in-stream



cattle access; to drink and for thermoregulation. The notion that cattle enter rivers to lower their body temperature is supported by the statistically significant positive correlation between air temperature and the amount of time cattle spend in-stream. This connection is further supported by previous studies that have investigated thermoregulation in cattle (Armstrong, 1994; Kendall *et al.*, 2007; Legrand *et al.*, 2011)

Cattle also need to drink. Although a substantial amount of their water comes from their diet during the autumn, winter and spring months, there may be times when this needs to be supplemented with water directly sourced from the river. This will be particularly true in the summer, where increasing air temperatures will increase the body temperature of cattle. As cattle get warmer they will expel water through perspiration, becoming thirstier as a consequence and therefore drinking more frequently or for longer periods from the river. What is more, on-going sessions of dry or warm weather will reduce the availability of water from forage, exacerbating the reliance of the cattle upon the river as a water source.

In addition to the internal biological drivers, there are external factors that can cause cattle to enter rivers. In particular, the dissecting of the landscape into areas only accessible by crossing the river meant that cattle often passed through the aquatic environment solely to reach patches of fresh forage or other, specific landscape elements. Of far less significance but worth noting is that cattle also occasionally entered the river in reaction to disturbance by large birds, low flying aircraft, loud noises and the presence of people; cattle would cross the river in an attempt to distance themselves from the disturbance.

#### **6.1.5. Testable hypotheses**

The first testable hypothesis ( $H_1$ ) for this section, that air temperature is a driver of cattle-river interactions and that cattle use waterways for thermoregulation, as suggested by Legrand *et al.* (2011), is supported by the statistically significant relationship identified between air temperature and river utilisation by cattle.

The second testable hypothesis ( $H_2$ ) for this section, that cattle will spend more time in areas with better quality forage (relative to the area available), such as riparian zones, than in areas with poor quality forage, such as valley slopes, as suggested by Huber *et al.* (1995), is also supported by the results. Hunter's (1962) index of preference shows that cattle spent more time in riparian areas and less time in valley areas than would be expected based on the availability of different land cover types.

#### **6.1.6. Conclusion**

During this study cattle spent approximately 2% of the observation period in-stream; for 84% of the study period there were no cattle in the river. Cattle behaviour and location varied according to the time of day, the time of year and between study sites. Cattle avoided certain locations and selectively spent time in others, irrespective of the availability of different land cover types. Cattle also spent more time in riparian environments containing fencing than those without fencing, and there was a statistically significant positive correlation between air temperature and the amount of time individual cattle, and the herd, spent in-stream; as air temperature rose, cattle spent more time in-stream. Finally, cattle defecated more frequently in-stream, per unit time, than in any other environment; cattle spent 3.2% of their time in-stream defecating, compared to an average time spent defecating, across all environments, of 0.6%.

This study represents the first quantitative analysis of cattle behaviour within chalk stream environments. Moreover, it exists as one of only a few studies that has investigated the nature and drivers of cattle behaviour within rivers. As such the findings have significant implications for our understanding of how and why cattle interact with rivers, suggesting that thermoregulation rather than thirst is often the principle driver of stream utilisation by cattle in lowland chalk environments. Methodologically, the high recurrence interval of observations signifies an important diversion from previous cattle behaviour studies that was necessitated by the nature of the phenomena observed; in-stream cattle behaviour typically occurs for a few minutes at a time. Further studies utilising similarly intense observations will be necessary to see whether the river-cattle behaviour observed within this study are inherent to all cattle. In particular, research into

whether in-stream cattle activity is greater in warmer climates would be insightful at a time of global climate change. Global warming leading to increased river-utilisation by cattle due to higher air temperatures, combined with reduced stream flows due to lower precipitation inputs, has the potential to exacerbate the effects of cattle grazing in chalk streams beyond those recorded in this study.

## **6.2. GPS study**

### **6.2.1. Introduction**

Although the application of GPS cattle collars to aid our understanding of cattle-environment interactions is becoming increasingly popular (e.g. Ganskopp and Bohnert, 2009; Butt, 2010), to date no studies using GPS to monitor cattle behaviour in chalk stream environments have been conducted. Moreover, no existing study has used GPS to quantify the amount of time spent in-stream and in the riparian environment by cattle, nor to map the utilisation of the aquatic environment by cattle.

A high-temporal resolution study into the spatial distribution of cattle within a chalk stream environment was conducted over several months. The amount of time spent by cattle in the aquatic and riparian environments was calculated, and compared with observational data. The spatial distribution of cattle relative to other factors, such as local topography and the time of day, were also investigated.

### **6.2.2. Methods**

#### **6.2.2.1. Study site**

GPS cattle collars were employed at the Tichborne site, which is situated in the village of Tichborne, Hampshire, approximately 10km east of Winchester and south-west of the villages of Alresford and New Alresford (Figure 5.4). The site consists of a number of former water meadows divided into fields of varying sizes that are used for the grazing of cattle between May and October. Running through the site is a stream referred to locally as the Tichborne stream or Cheriton stream; a tributary of the River Itchen. The Tichborne stream is a classic chalk stream, no greater than 10m in width along any part

of its course (Smith *et al.*, 2003). Its inhabitants are archetypal chalk stream species, including *Ranunculus* spp., brown trout (*Salmo trutta*) and damselflies (*Zygoptera* spp.). The site forms part of the larger River Itchen SSS (Mainstone, 1999; Natural England, 2001). Further information regarding the climate, soils and geomorphology of the site are provided in section 5.5.



**Figure 6.13. The Tichborne study site. The red line shows the perimeter of the site and the blue line shows the location of the Tichborne stream.**

Cattle access to the river is restricted by fencing for the majority of the reach. The only access to the river is located to the south-east of the site; a 10m wide by 10m long crossing point. To the north of the site is a large (50m<sup>2</sup>), shallow pond with deep (>0.5m), silty substrate; this represents the only other source of drinking water for cattle within the study site (Figure 6.13).

#### *6.2.2.2. Equipment and techniques*

Three cattle were equipped with individual AgTrax LD2 GPS cattle collars for three week periods from May until October. Collars were programmed to record the location of the cattle once every 20 seconds; a potential number of GPS fixes in excess of 90,000 per collar per usage. It was necessary to have a high temporal frequency of GPS fixes as the observational study (section 6.1) revealed that cattle can spend short periods of time in-stream, and a 20 second interval rate ensured all instances of in-stream cattle activity were recorded. After each three week period the collars were removed, GPS data were downloaded, the batteries recharged, and the collars reattached.

Although initially the intention had been to collect and use data from all collars, technical problems restricted the quantity of data gathered. Typically only one out of the three collars would work effectively during each three week period. In such instances, data from the two inefficient collars were used to validate data on the fully functional collar to ensure that the collars captured the activity of the herd.

#### *6.2.2.3. Analysis*

GPS data were downloaded from the GPS cattle collars into Microsoft Excel spreadsheets. Data were then uploaded into ArcGIS 9.3 and displayed on a georeferenced map of topography, as derived from LiDAR data. GPS data were cleaned using the ArcGIS editor function to remove any data points that were identified as erroneous following a visual inspection (i.e. data points that appeared outside of the study area). Further erroneous data points were removed using the GPS collars in-built measurements of horizontal accuracy; any data points with a horizontal error of greater than 10 metres

were removed. Once cleaned, data points were divided into a number of categories including monthly data, daily data and hourly data, and converted into raster files showing the spatial extent and intensity of cattle distribution.

Other raster files were then made using the raster calculator tool to calculate the amount of time cattle spent in-stream and in the riparian zone. Additional analyses relating cattle activity to topography, air temperature and soil properties were also conducted.

### **6.2.3. Results**

Limitations of the equipment, principally relating to the longevity of the batteries and the failure of the collars to work under cloud cover and tree canopies, restricted the total amount of data collected from all collars to 24 full days. Data points removed due to horizontal inaccuracy further limited the total number of points used in the results. Table 6.8 shows the distribution of data collected over the study period.

| Date/Collar | Number of data points collected | Start date and time   | Finish date and time  | Total duration of collection (minutes) |
|-------------|---------------------------------|-----------------------|-----------------------|----------------------------------------|
| May (1)     | 26624                           | 13:06:03,<br>16/05/11 | 23:12:56,<br>22/05/11 | 9246                                   |
| May (2)     | 0                               | n/a                   | n/a                   | 0                                      |
| May (3)     | 2939                            | 10:30:23,<br>16/05/11 | 03:46:27,<br>17/05/11 | 1036                                   |
| June (1)    | 6125                            | 12:17:52,<br>12/06/11 | 20:40:13,<br>15/06/11 | 4823                                   |
| July (1)    | 10107                           | 16:00:48,<br>07/07/11 | 18:01:12,<br>10/07/11 | 4441                                   |
| July (2)    | 50471                           | 08:00:29,<br>08/07/11 | 19:00:27,<br>20/07/11 | 17940                                  |
| July (3)    | 12655                           | 08:00:28,             | 09:16:08,             | 4396                                   |

|               |       | 08/07/11  | 11/07/11  |       |
|---------------|-------|-----------|-----------|-------|
| September (1) | 9668  | 12:22:17, | 21:21:11, | 3419  |
|               |       | 07/09/11  | 09/09/11  |       |
| September (2) | 11418 | 12:24:53, | 06:27:49, | 3963  |
|               |       | 07/09/11  | 10/09/11  |       |
| September (3) | 65530 | 12:30:29, | 23:28:38, | 23818 |
|               |       | 07/09/11  | 23/09/11  |       |
| October (1)   | 1657  | 09:00:38, | 15:31:00, | 26281 |
|               |       | 11/10/11  | 29/10/11  |       |
| October (2)   | 11884 | 09:00:48, | 08:44:46, | 4305  |
|               |       | 11/10/11  | 14/10/11  |       |
| October (3)   | 102   | 09:31:07, | 00:30:54, | 14940 |
|               |       | 11/10/11  | 22/10/11  |       |

**Table 6.8. The distribution of data collected from three GPS cattle collars.**

#### 6.2.3.1. *Cattle activity overall*

Across the entire GPS study 0.88% of fixes were recorded in the aquatic environment and 2.43% of fixes were recorded in the riparian environment. Estimates of the total daily distance travelled by cattle were calculated by adding the cumulative distance between consecutive GPS fixes (Figure 6.14).

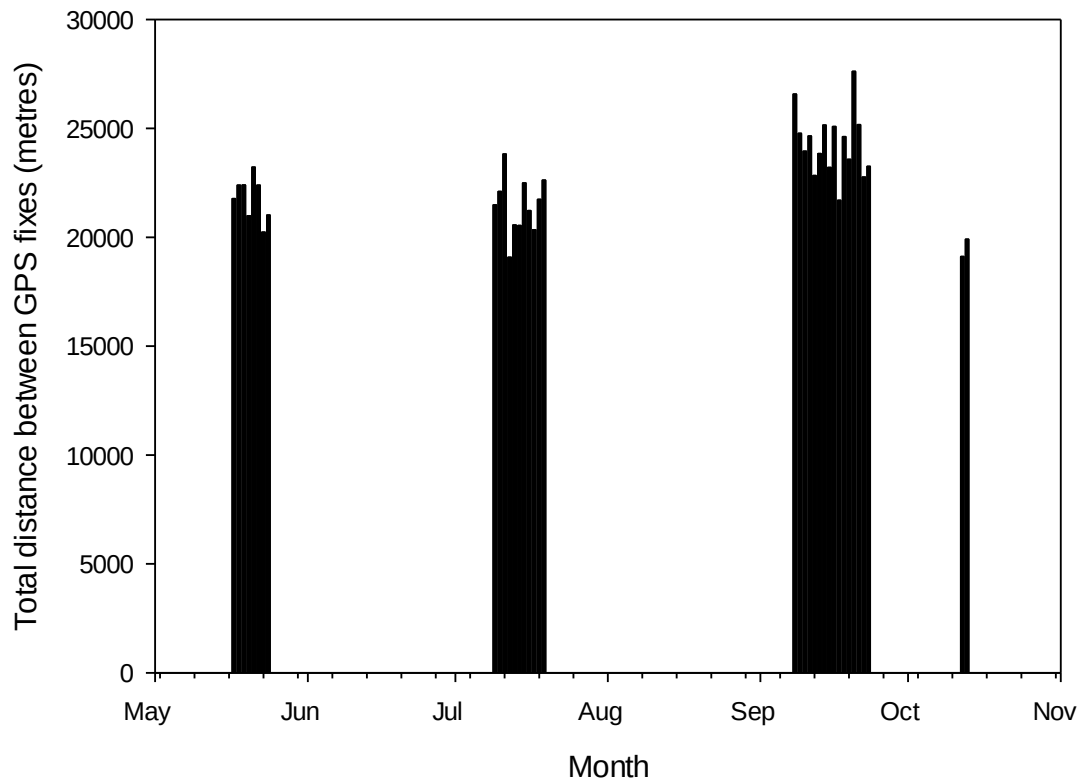


**Figure 6.14. Estimates of the distance travelled by cattle daily.**

The maximum estimated daily distance travelled was 27.6km, whilst the minimum estimated daily distance travelled was 19.1km. The average daily distance travelled in September (24.3km) was greater than in either May (21.8km) or July (21.4km). Moreover, there was a statistically significant difference between the daily distance travelled by cattle in May and July compared to September ( $T = -5.89$ ,  $P = 0$ ,  $df = 28$ ).



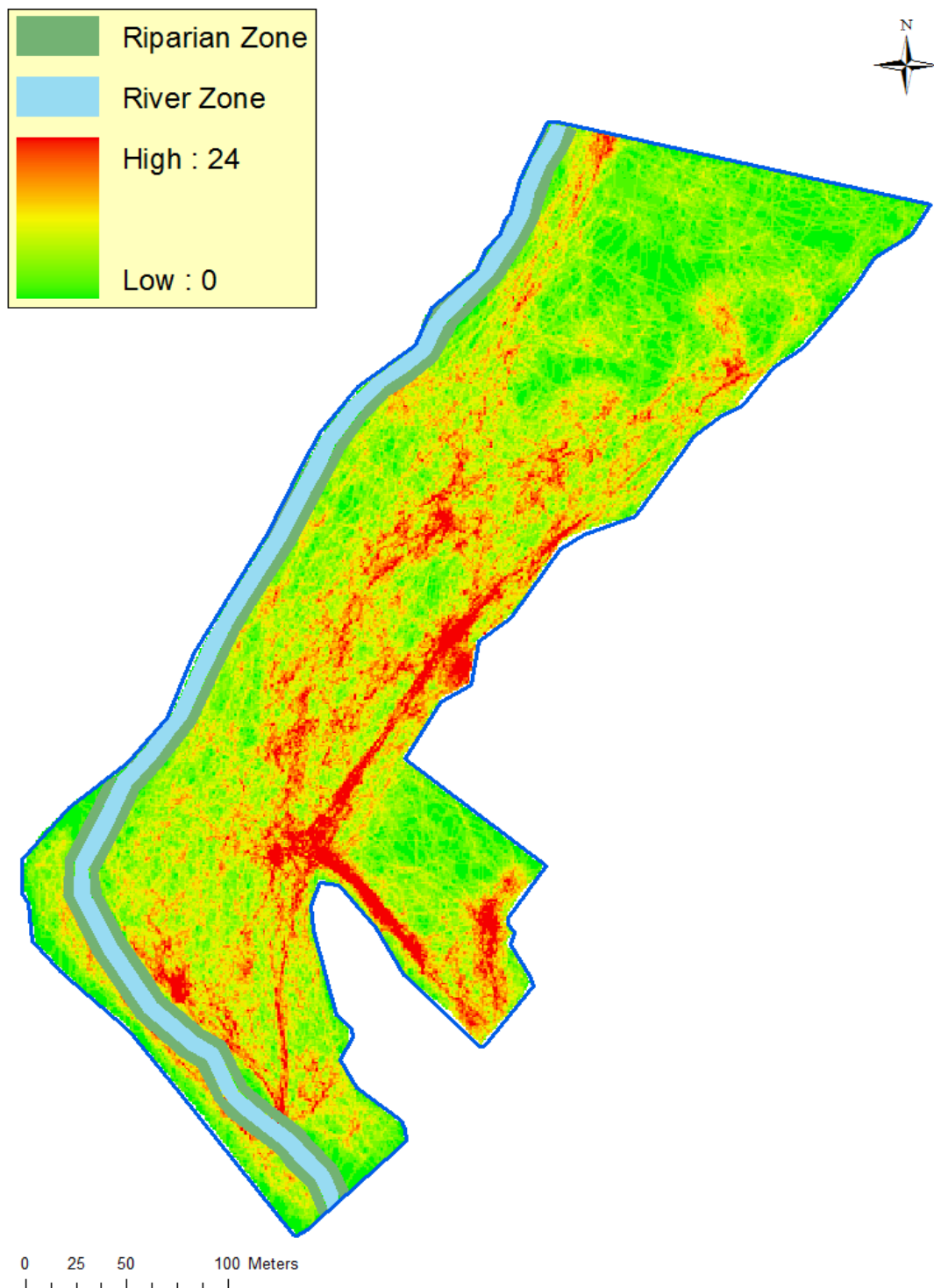


**Figure 6.15.** Cattle environment utilisation over the course of the study. 1m horizontal resolution raster data set. The colour scale refers to the number of full days cattle were observed. The blue line demarcates the study area boundary.

Results showing the spatial distribution of cattle activity over the course of the study reveal clear areas of preferential use (shown in red in Figure 6.15). A number of routes of regular usage can be seen with the red line leading to the river crossing point in the south-eastern section of the map being of particular interest because of its potential implications upon floodplain connectivity. The pathways that run through the site suggest that cattle frequently use the same areas day after day to move through the landscape.

#### *6.2.3.2. River utilisation and air temperature*

A statistically significant positive correlation between air temperature and the number of in-stream GPS fixes was recorded ( $r = 0.521$ ,  $N = 20$ ,  $P < 0.05$ ; Figure 6.16). No GPS fixes occurred within the aquatic environment at temperatures below 9°C. The greatest number of in-stream GPS fixes were recorded at temperatures of 13°C, whilst the greatest number of in-stream GPS fixes as a percentage of the total number of fixes at a given air temperature occurred at 19°C; 2.98% of all GPS fixes at 19°C were in the aquatic environment.

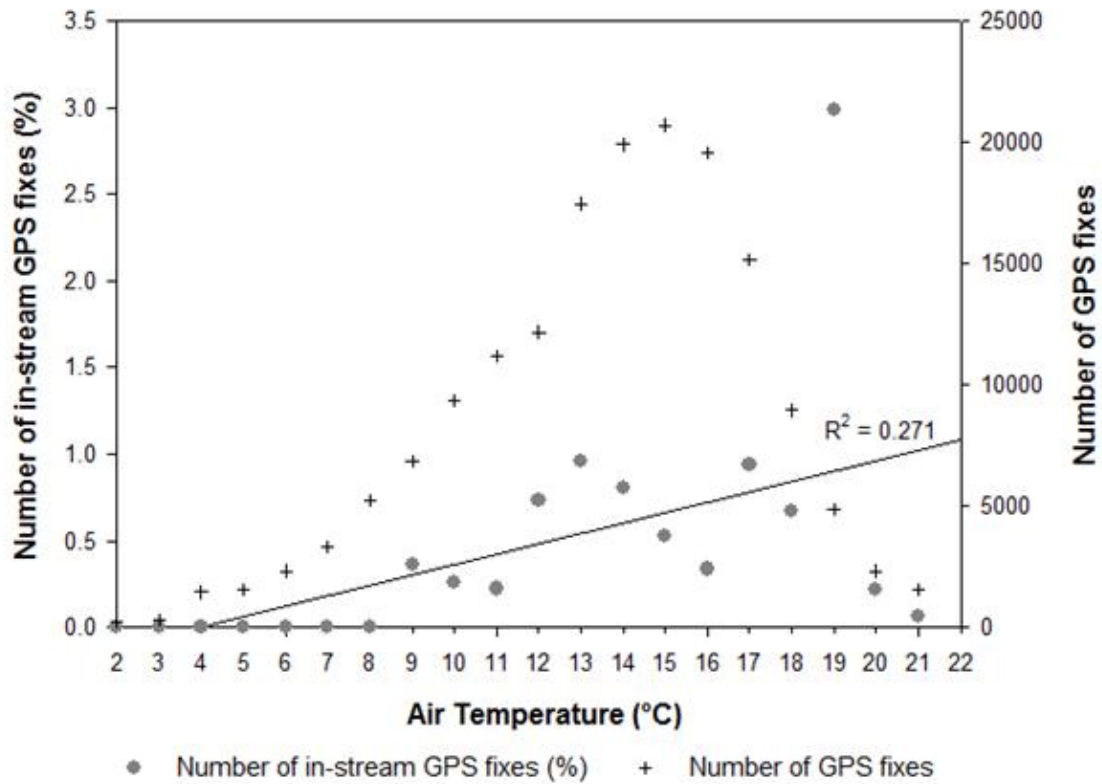


Figure 6.16. The relationship between air temperature and aquatic environment utilisation by cattle. A regression line is displayed.

#### 6.2.3.3. Cattle activity by the time of day

The amount of time cattle spent in the aquatic and riparian environments varied by the time of day.

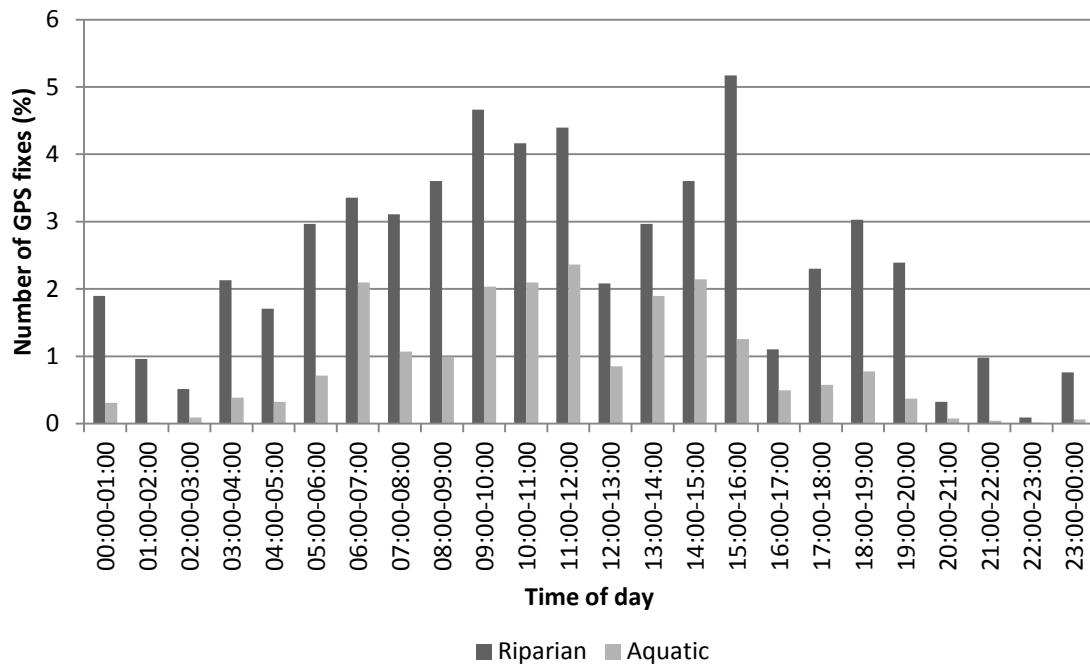


**Figure 6.17. Cattle activity in the riparian and aquatic environments as classified by the time of day. The number of GPS fixes in each environment is given as a percentage of the total number of GPS fixes in each respective time segment.**

The aquatic environment was most popular between the hours of 1100 and 1200, when in-stream GPS fixes accounted for 2.3% of all GPS fixes. The riparian environment was most popular between the hours of 1500 and 1600, when riparian GPS fixes accounted for 5.2% of all GPS fixes. GPS fixes for the riparian environment were found to be normally distributed following an Anderson-Darling normality test ( $AD = 0.232$ ,  $N = 24$ ,  $P = 0.776$ ). This suggests that riparian environment utilisation by cattle broadly mirrors changes in air temperature throughout the day; cattle spend more time in the riparian zone during the middle of the day when air temperatures are generally highest.

GPS fixes for the aquatic environment were found not to be normally distributed ( $AD = 1.203$ ,  $N = 24$ ,  $P < 0.005$ ), with this data instead adhering to a polymodal distribution.

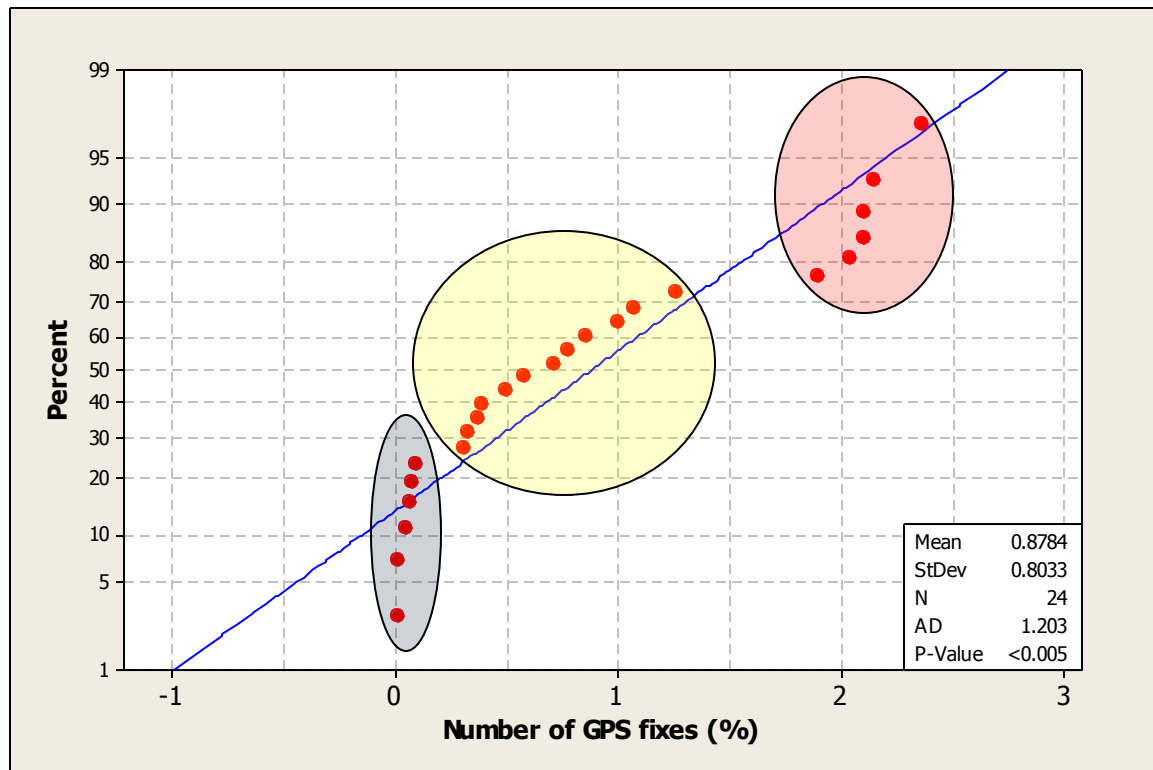


**Figure 6.18.** The distribution of aquatic GPS fixes relative to a normal distribution (blue line). Three non-normal distributions are highlighted: avoidance (blue), usage (yellow) and preference (red).

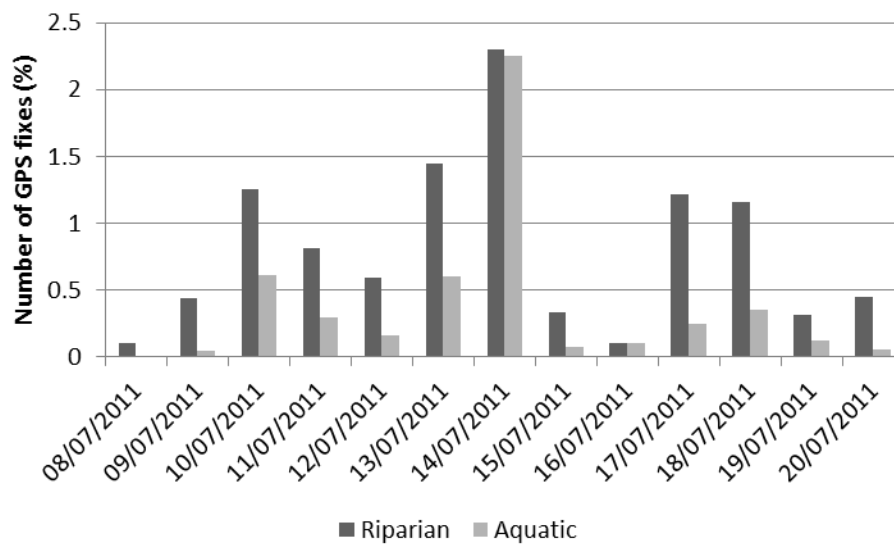
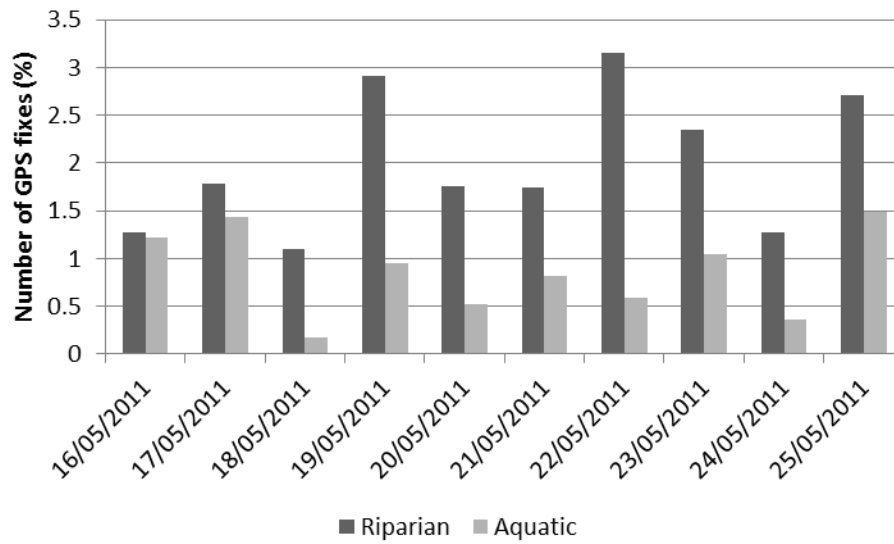
Specifically, cattle appear to have three approaches to aquatic environment utilisation that correspond to different parts of the day: avoidance between 2000 and 0300; usage between 0300 and 0600, and 1600 and 2000; and preference between 0600 and 1600 (Figure 6.18). The data suggest that cattle utilisation of the aquatic environment may relate to air temperature in a similar way to riparian environment usage, except that whereas cattle will use riparian areas at night they will not use aquatic areas.

#### 6.2.3.1. Cattle activity by day

The amount of time cattle spent in the aquatic and riparian environments varied from day to day (Figure 6.19). The maximum amount of time cattle spent in-stream within a single day was 40 minutes; 2.9% of all GPS fixes over 24 hours. The minimum amount of time cattle spent in-stream over a day was 40 seconds; 0.05% of all GPS fixes over 24 hours. The maximum amount of time cattle spent in the riparian environment within a single day was 105 minutes; 7.8% of all GPS fixes over 24 hours. The minimum amount of time

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cattle spent in the riparian environment over a day was 40 seconds; 0.05% of all GPS fixes over 24 hours.



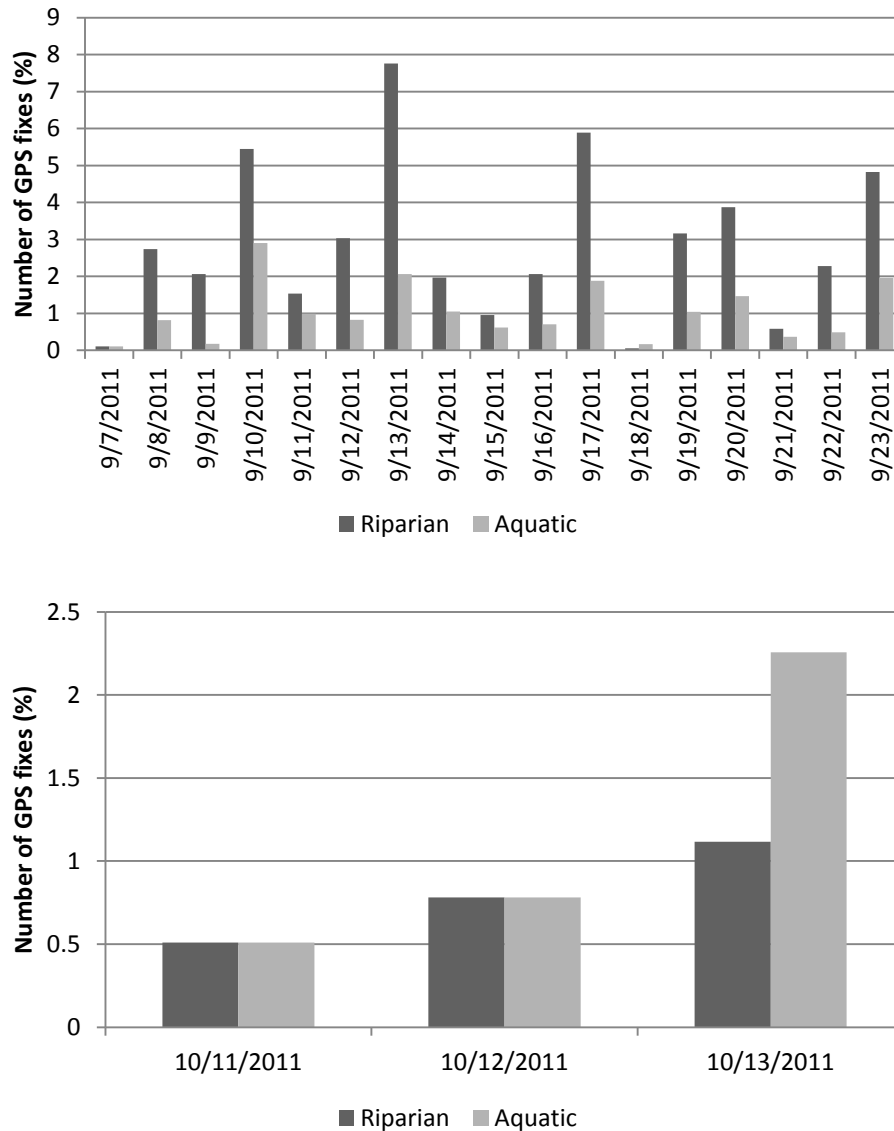


**Figure 6.19.** Cattle activity in the aquatic and riparian environments as classified by day. The number of GPS fixes in each environment is given as a percentage of the total number of GPS fixes in each respective day.

#### 6.2.3.2. Cattle activity by month

The amount of time cattle spent in the aquatic and riparian environments varied according to the month.

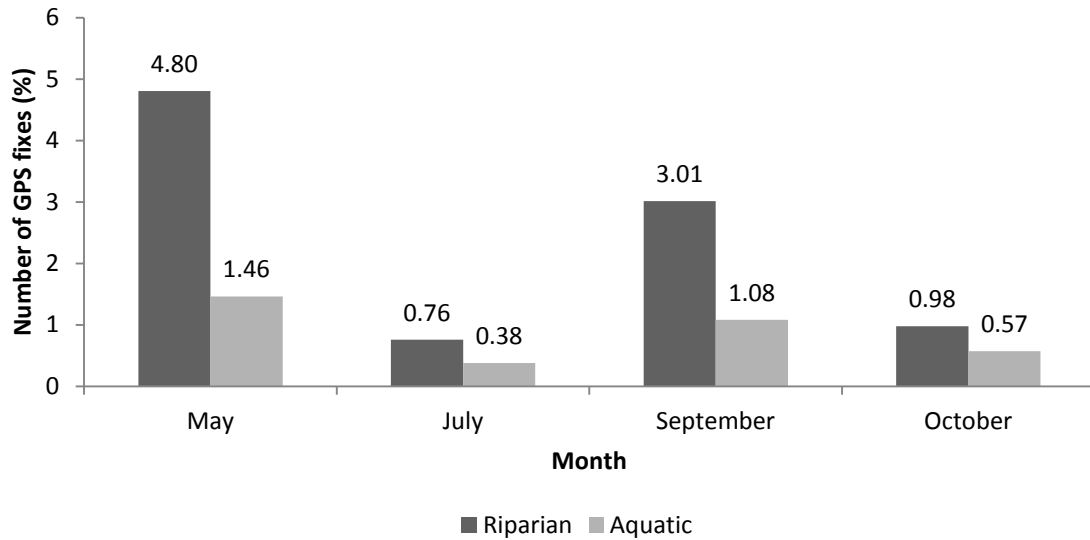


**Figure 6.20. Cattle activity in the riparian and aquatic environments as classified by month. The number of GPS fixes in each environment is given as a percentage of the total number of GPS fixes in each respective month.**

Cattle spent the most amount of time in-stream during May and the least amount of time in-stream during July. Cattle also spent the most amount of time in the riparian environment during May and the least amount of time in the riparian environment during July.

There were also very clear differences in the spatial utilisation of the Tichborne study site by cattle between months.



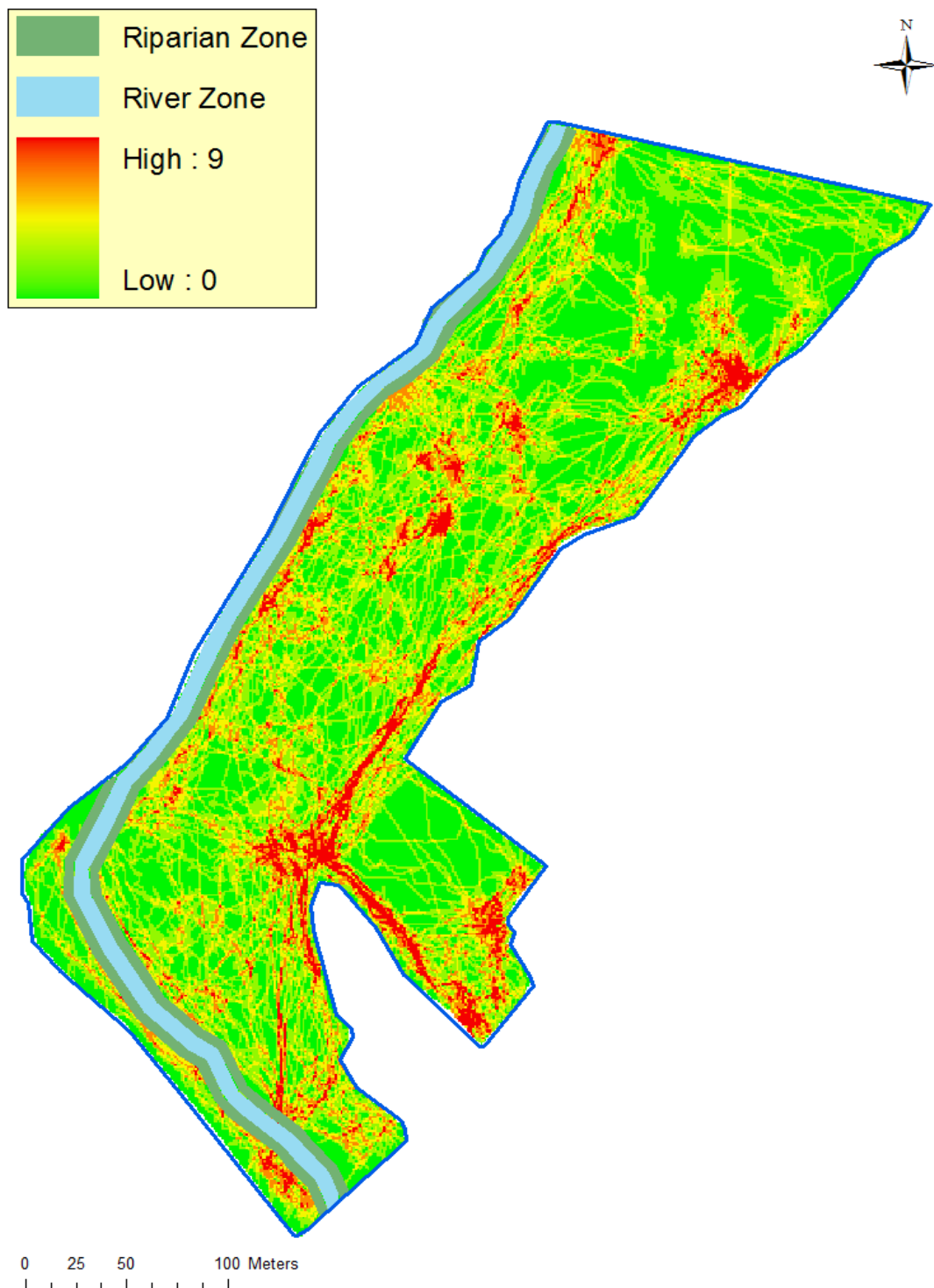


**Figure 6.21.** Cattle environment utilisation during May 2011. 1m horizontal resolution raster data set. The colour scale refers to the number of full days cattle were observed. The blue line demarcates the study area boundary.

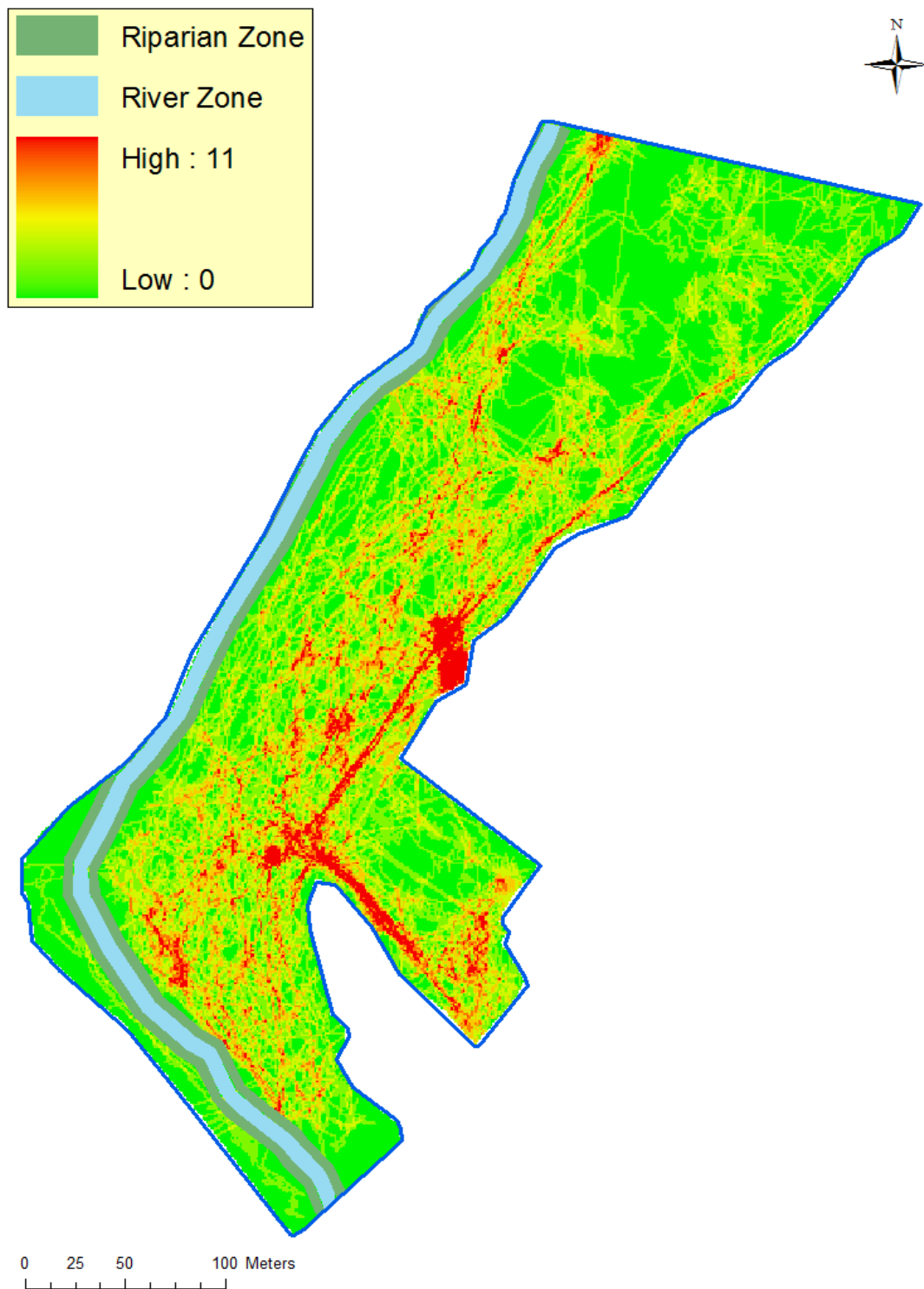


**Figure 6.22.** Cattle environment utilisation during July 2011. 1m horizontal resolution raster data set. The colour scale refers to the number of full days cattle were observed. The blue line demarcates the study area boundary.

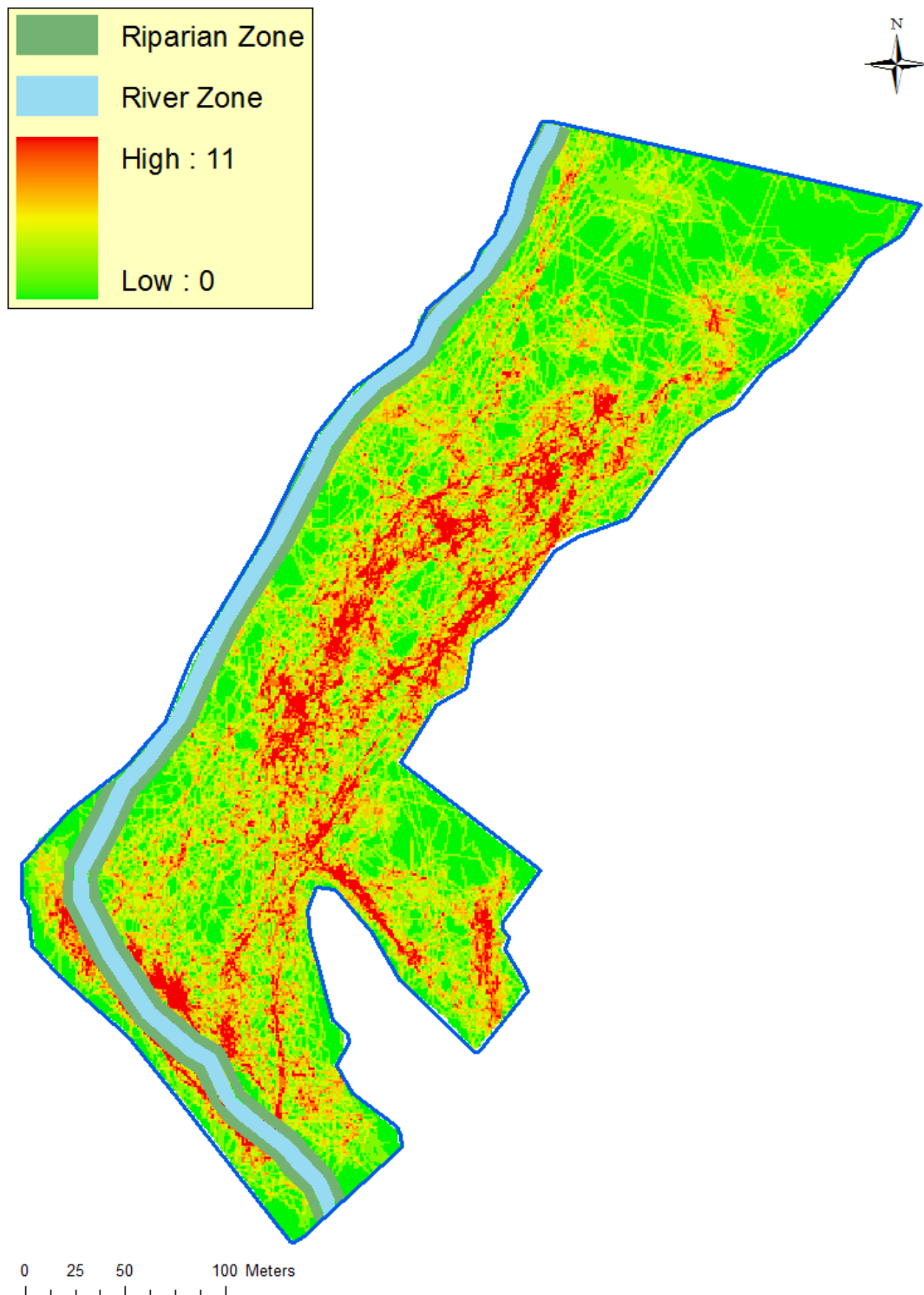


**Figure 6.23.** Cattle environment utilisation during September 2011. 1m horizontal resolution raster data set. The colour scale refers to the number of full days cattle were observed. The blue line demarcates the study area boundary.

In May (Figure 6.21) cattle spent most of their time in a few selected areas. The central cattle trail is heavily used, whilst there are a number of areas such as the south-east most corner, the north-west most corner and the riparian zone in the west of the map that cattle revisited on several days during May. None of these areas contained specific features, as inferred from qualitative observation.

In July (Figure 6.22) cattle generally spent less time focused in particular areas compared to May and September. High occupancy intensities are seen along cattle trails and in a large area in the centre of the map to the east of the study site. It appears as though cattle visited this area everyday throughout July, although as to why is unclear. Activity in the southern riparian zone, across the river and to the south of the map, is minimal in July relative to May and September, and this is reflected numerically in the comparatively low aquatic and riparian environment utilisation figures for July.

In September (Figure 6.23) cattle appear more active than in May or July, with numerous areas of repeated usage across the centre of the study site. The riparian and aquatic zones to the south of the study site are used extensively, whilst the central cattle trail that connects the northern and southern parts of the field appears relatively underused. In September, cattle spent more time within and adjacent to pathways than in previous months.

#### **6.2.4. Discussion**

##### **6.2.4.1. Limitations**

The regular failure of all three GPS cattle collars to work for the entire duration of their expected battery life restricted the quantity of data collected. Moreover, the amount of time that collars were working concurrently was limited, inhibiting the validation of results through comparisons between collars. Although ultimately sufficient data were collected to make useful observations regarding the behaviour of cattle in chalk stream environments, improvements could be made to subsequent studies.

Since the employment of the AgTrax LD2 GPS cattle collars, a number of other, potentially improved, GPS cattle collar models have entered the market. In particular the G2110E supplied by Advanced Telemetry Systems offers increased battery longevity and improved reliability (ATS, 2012). Other instruments, such as ear tags and rumen implants, have developed substantially over recent years and could offer an alternative means of cattle tracking in future studies (Pinter-Wollman and Mabry, 2010).

Beyond the implementation of different or upgraded equipment, the study could have been improved if it were not for a number of logistical constraints. With more GPS collars it would have been possible to use several study sites so as to record any differences in cattle distribution that were a function of location. However, the GPS cattle collars used within this study cost approximately £1,500 each and the research budget did not allow for the procurement of more than three. Moreover, there were delays in the delivery of the GPS collars from the suppliers, which reduced the time available for the collars to be used. With respect to time, the three year length of the project limited the number of grazing seasons over which cattle could be observed. Monitoring cattle for more seasons would have allowed for the identification of any inter-annual variability arising from year-on-year differences in weather and other environmental conditions such as forage quality and river water levels.

#### *6.2.4.2. River utilisation and air temperature*

The statistically significant positive correlation between air temperature and the number of in-stream GPS fixes agrees with the observation by Bond *et al.* (2012) that cattle spend more time in rivers when air temperatures are high. The results also agree with broader research that suggests cattle seek water for cooling when air temperatures are high (Armstrong, 1994; Kendall *et al.*, 2007; Schütz *et al.*, 2009; Legrand *et al.*, 2011).

#### *6.2.4.3. Utilisation by time*

It is unsurprising that cattle were at their least active between the hours of 2000 and 0400, given that they are perceived to be diurnal animals and are likely to have spent the

majority of this time asleep. Cattle were at their most active between the hours of 0400-0800 and 1600-2000; the periods of twilight, suggesting cattle may be crepuscular. Arnold and Dudzinski (1978), Albright (1993) and Albright and Arave (1997) recognise that cattle are at their most active at dawn and dusk and often at their least active during the middle-part of the day. Hence, although their general behaviour follows a diurnal pattern of activity during the day and rest during the night, superimposed upon this is a crepuscular pattern of grazing (Graunke *et al.*, 2011).

This creates a complex pattern of behaviour. Cattle will predominantly rest at night and be at their most active during dawn and dusk when they are grazing. However, cattle will use the aquatic environment most when air temperatures are high; generally the middle of the day (Bond *et al.*, 2012). Therefore in-stream cattle effects are likely to be greatest during the middle of the day whilst terrestrial effects are likely to be greatest during dawn and dusk. In actuality however, and as illustrated by Figure 6.17 and Figure 6.18, the two signals can become mixed, particularly in the riparian zone.

Nonetheless these broad findings have implications for our understanding of the effects of cattle grazing in chalk streams. Cattle landscape utilisation varies by time and hence the effects of cattle grazing are likely to vary by time. Specifically, cattle spend more time in-stream during the middle of the day and therefore their effects are likely to be focused around this time.

Temporal variations in cattle effects are important because risk components of the environment vary by time also. For example Ibbotson *et al.* (2006) have shown that Atlantic salmon smolt activity in the River Frome varies throughout the course of a day, with fish being least active during the middle of the day, particularly when young. This relationship is directly related to water temperature, with numerous studies having illustrated salmonids activity changing with water temperature (Solomon and Lightfoot, 2008; Elliott and Elliott, 2010; Kemp *et al.*, 2010; Kemp *et al.*, 2011). Juvenile salmonids are more active at night and less active during the day when water temperatures fall below 10°C or exceed 14°C according to a summary of findings by Armstrong *et al.*

(2003). However, this water temperature-activity relationship is not absolute and fish activity may change throughout the season, with Johnstone *et al.* (2004) showing that juvenile salmon were more active during the day in early summer than in late summer in their study in Canada.

Although water temperature controls upon salmonids are not fully understood, this example exemplifies why the timing of in-stream cattle activity is important. If periods of high in-stream cattle activity coincide with occupancy by other organisms or changes in abiotic factors, such as a fall in the river water level, then the potential effects of cattle grazing may be amplified. This extends the notion of ecological windows beyond seasonality to a finer temporal resolution wherein organism habitat and life optima occur at different times throughout the day, particularly in the presence of an external forcing, such as cattle grazing (Uehlinger *et al.*, 2002; DeGasperis and Motzkin, 2007).

#### 6.2.4.4. Activity by season

The distance travelled by GPS tracked cattle was greater in September than in May or July. The reasons for this are likely to be multi-faceted, but all connected to the time of year. Firstly, the quality and quantity of forage decreases through the grazing season, such that cattle need to spend more time searching for food and grazing towards the end of the season (August, September, October) than the beginning (May June, July). Secondly, cattle activity reflects seasonal changes in air temperature. Cattle were more active in September and October than in May and July because air temperatures were generally lower. Body movement keeps cattle warm during the colder months, and hence they spend more time moving during these months. Other potential seasonal influences on activity, such as fertility (which may be reduced when the number of daylight hours falls: Mercier and Salisbury, 1947), may also have been at work.

Increased cattle activity later during the grazing season may have implications for the management of cattle with access to rivers. Similar patterns of cattle behaviour observed in an upland stream catchment in Oregon, USA resulted in greater streambank erosion and a reduction in streambank stability during August and September compared to June

and July (McInnis and McIver, 2009). Such differences in bank erosion may represent the cumulative effect of cattle access throughout the season, or may be a function of natural seasonal changes in bank stability (e.g. increased soil water content due to increased precipitation leading to reduced bank stability).

#### **6.2.5. Conclusion**

It is possible to use GPS cattle collars to monitor riverine environment landscape utilisation despite limitations in the accuracy, reliability and longevity of the equipment. Over the course of the GPS cattle collar study, 0.88% of GPS fixes were located in the aquatic environment and 2.43% of GPS fixes were located in the riparian environment. It was observed that cattle spent more time in-stream at higher air temperatures. Additionally, cattle activity varied according to the time of day such that the aquatic environment was most popular between 1100 and 1200, and the riparian environment was most popular between 1500 and 1600. Cattle activity also varied by month, with the greatest frequency and duration of aquatic and riparian environment utilisation occurring in May.

Results agree broadly with those of the observational study and add important spatial and temporal detail regarding cattle behaviour (e.g. behaviour at night when direct observation is impractical). GPS cattle collar data has also provided contextual information regarding the potential effects of cattle grazing, which, like behaviour, do not appear to be constant in time. When considered in the context of ecological windows and temporal variations in the vulnerability of ecosystem components, it becomes apparent that the effects of cattle grazing in chalk streams may be more complex than previously thought.

Further research involving GPS cattle collars would look to qualify the observations made here, as well as to investigate the relationship between cattle behaviour and other discrete landscape elements. For example, combining GPS cattle behaviour data with LiDAR data of canopy cover would allow for analysis of the way in which cattle use trees for shading. Equally, GPS cattle collar data could be used with other remotely-



sensed data sets, such as those from Landsat satellites, to understand how forage quality (as inferred from infra-red bands) helps to determine cattle behaviour. By employing such methods a comprehensive understanding of the controls, and their relative importance, on cattle behaviour in chalk stream environments could be acquired.

## **7. Studying the effects of cattle grazing in chalk streams**

### **7.1. Introduction**

Although useful in quantifying the behaviour of cattle and understanding the drivers of cattle-river interactions, the information detailed in section 0 does not explain the consequences of cattle grazing upon chalk stream environments. Previous studies have shown that cattle can affect stream ecology, geomorphology and hydrology (Trimble, 1994; Trimble and Mendel, 1995; Harrison and Harris, 2002; Summers *et al.*, 2008), and the potential ramifications of allowing cattle access to chalk streams have been much discussed (Mainstone, 1999; Clothier, 2009; Lawton *et al.*, 2010; Kemp, 2010).

In this chapter a range of techniques are employed to investigate the effects of cattle grazing in chalk streams, based upon the three broad categories of impact discussed in section 3.3 (i.e. herbivory, animal transit and excretion). The chapter is structured as a series of separate studies that consider a range of effects induced by cattle activity in terrestrial, riparian and aquatic chalk stream zones. Together the studies provide an overview of the effects of cattle grazing in English chalk streams. Distinct from previous work, the studies discussed herein provide clear details about the timing, duration and period of exposure of the landscape to cattle, with metadata for each study site providing important contextual information that allows the findings to be compared to other locations subject to cattle grazing.

Sections within this chapter are divided into two categories: sections 7.2 and 7.3 which are concerned with consequences arising from excretion (as discussed in sections 3.3.3 and 4.3.3); and sections 7.5, 7.4, 7.6 and 7.7, which are concerned with consequences arising from animal transit. The effects of herbivory were not investigated; findings in section 6.1 revealed that cattle rarely eat in-stream macrophytes, and there is a large body of existing literature that looks at the effects of herbivory in terrestrial and riparian environments (e.g. Schulz and Leininger, 1990; Olff and Ritchie, 1998; Vera, 2001; Yoshihara *et al.*, 2010).

In section 7.2 the chemical composition of faeces produced by cattle grazing English chalklands is assessed with respect to three key nutrients: ammonia, phosphate and potassium. Section 7.3 considers the likely nutrient loading of ammonia, phosphate and potassium to the Midlington and Tichborne study sites given the findings of section 7.2 and the known characteristics of those sites e.g. river properties, stocking density, period of exposure to cattle. In section 7.4 the consequences of geomorphic agency by cattle moving through the terrestrial environment are evaluated by using a cohesive strength meter to measure the difference in erodibility between soils subject to trampling by cattle and those that are not. Section 7.5 looks at how a high-precision terrestrial laser-scanner can be employed to track cattle-induced changes in the topography of chalk stream riparian margins. In section 7.6 the effects of in-stream cattle activity upon suspended sediment concentrations are measured using a turbidity probe. Section 7.7 adds a spatial element to the overall study by analysing the landforms created by cattle and associating them with the GPS data from section 6.2. The relative importance of the findings from each of the studies are discussed in section 7.8, which provides an overview of the effects of cattle grazing in English chalk streams, explaining which elements of cattle activity are likely to have the greatest impact upon river ecology and geomorphology.

## **7.2. Faecal analysis**

### **7.2.1. Introduction**

Direct and indirect input of allochthonous organic material from cattle faeces and urine has been of interest to land managers for several decades (Doran and Linn, 1979; Gary *et al.*, 1983). However, the most well researched aspect of water quality changes induced by cattle excrement pertains to human health, and specifically the prevalence of *E. coli* bacteria in water (Collins and Rutherford, 2004; Davies-Colley *et al.*, 2004). Where nutrient loading indicators have been measured, such as nitrogen and phosphorous, investigations are often concerned with pathogens and disease; methemoglobinemia (blue baby disease) and carcinogenic materials from nitrogen, and the threat of cyanobacteria poisoning from phosphorous initiated eutrophication (Hubbard *et al.*, 2004).

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Some of the most important nutrients within chalk streams are phosphorous (phosphate), nitrogen (ammonia, nitrate and nitrite) and potassium (Mainstone, 1999). Natural background values of these nutrients are relatively low in chalk streams but can be elevated due to sewage and other allochthonous inputs from rural land-use (Casey *et al.*, 1993; Bowes *et al.*, 2005; Jarvie *et al.*, 2008).

Typical background levels of Soluble Reactive Phosphorous (SRP: the bioavailable component of phosphorous) are between 0.01 and 0.03mg l<sup>-1</sup> in healthy chalk streams (Robach *et al.*, 1996). However, elevated phosphorous levels can have numerous effects in chalk streams, as explained by Mainstone (1999), including: encouraging changes in plant community composition towards a greater abundance of rooted plants; increasing the abundance of filamentous and epiphytic algae and thereby reducing in-stream light levels; and increasing growth rates of river weeds, such as *Ranunculus aquatilis*, which require management. Phosphorous is important in moderating primary productivity in surface waters (Correll, 1999) and studies have shown the link between phosphorous and plants, with work by Bowes *et al.* (2011) demonstrating that algal biomass and productivity declined in line with declines in phosphorous levels on the River Frome in Dorset (Withers and Jarvie, 2008)

Nitrogen is relatively abundant within chalk streams compared to phosphorous due to the nitrogen-rich status of English chalk aquifers (Mainstone, 1999; Whitehead and Lawrence, 2006). Consequently, in most situations chalk streams are less sensitive to changes in nitrogen levels than they are changes in phosphorous levels (Mainstone and Parr, 2002). Nonetheless, large deviations from background nitrogen concentrations (background concentrations are typically between 2 and 4mg l<sup>-1</sup> in healthy chalk streams) can be detrimental to water quality and in-stream organisms (Heathwaite *et al.*, 1996; Houlbrooke *et al.*, 2004; Jarvie *et al.*, 2006b; Jackson *et al.*, 2008).

Potassium is not as significant as either phosphorous or nitrogen in instigating ecological changes within chalk streams. Whereas both nitrogen and phosphorous are essential to the construction of plant materials and the transfer of energy within plants, the principle

use of potassium by most plants species is in water regulation and drought resistance (Hopkins and Hüner, 2008). Consequently, whilst potassium may improve the resistance of chalk stream species to drought (Ladle and Bass, 1981), it is unlikely to trigger algal blooms or eutrophication (Ladle and Casey, 1971). However, potassium remains one of the three primary nutrients, and elevated concentrations have been recorded previously in chalk streams, particularly downstream of watercress farms (Casey and Smith, 1994).

In addition to contributing nutrients to chalk stream systems, cattle faeces have the potential to deoxygenate river water (Hubbard *et al.*, 2004). Decomposition of organic matter within river systems has been cited as the cause of fish-kills (Townsend *et al.*, 1992) and other undesirable ecological changes (Houlbrooke *et al.*, 2004; Hubbard *et al.*, 2004). In chalk streams reduced oxygen levels within the water column can affect salmonids, increasing the mortality rate of salmon and trout eggs (Acornley and Sear, 1999; Greig *et al.*, 2005; Kemp *et al.*, 2011). One widely used measure of the likely effect of organic sediment upon oxygen availability within waterbodies is chemical oxygen demand (measured in  $\text{mg l}^{-1}$ ; the mass of oxygen consumed per litre of water: Sawyer *et al.*, 2002; Davie, 2008)

Here we quantify the amount of faeces produced by cattle and investigate the composition of cattle faeces in terms of the aforementioned nutrients. Additionally, by combining observational data with faecal analysis data, we calculate the likely nutrient loading due to cattle faeces inputs directly to chalk streams and their associated floodplains.

### **7.2.2. Methods**

Approximately 100 individual cow pats from across the various study sites were weighed within the field. Entire cow pats were collected, typically using a shovel, and gathered into a plastic bag, which was then weighed and the weight recorded. Fresh samples (cow pats produced that day) were always used. Once weighed, the faeces was removed from the plastic bag and replaced in the location it was found. Some samples were retained for the purposes of laboratory analysis. All chemical analysis involved the use of test kits

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available from Fisher Scientific. The test kits used were chosen ahead of other methods because they are relative cheap, do not require any specialist equipment or training, provide an acceptable level of precision and are easily obtainable (improving the repeatability of the study).

### *7.2.2.1. Oven drying*

50 samples of cattle faeces weighing approximately 100g each were taken from cow pats collected across the study sites. From these, 60 smaller samples (between 1 to 20 grams in weight), divided into three batches, were then weighed before being dried in an oven at 65°C for 24 hours to remove moisture in accordance with Bratzler and Swift (1959) and Manoukas *et al.* (1964). Once dried, samples were weighed again and the difference in weight between the wet and dry samples recorded. Dried samples were then further divided into smaller amounts in preparation for chemical analysis.

### *7.2.2.2. Ammonia*

Ammonia concentrations in cattle faeces were investigated using a Palintest Ammonia test kit. The kit detected ammonia concentrations between 0 and 1mg l<sup>-1</sup>, and was precise to variations in ammonia concentration of 0.01mg l<sup>-1</sup>, as prescribed by the test kits manufacturers. 100 samples of wet cattle faeces weighing between 0.5mg and 284mg were placed into test tubes, which were then filled with distilled water to a volume of 10ml and each sample mixed thoroughly. Two tablets containing alkaline salicylate and a chlorine catalyst were added to the solution, crushed and mixed until dissolved. Samples were left to stand for 10 minutes at room temperature to allow for colour development. After 10 minutes 2.5ml of each solution was decanted into cuvettes and placed into a Walden Precision Apparatus S106 digital spectrometer with the wavelength set to 640nm. Readings of absorbance and transmittance were recorded and compared to a calibration provided with the test kit to derive the ammonia content of each sample. Samples whose ammonia content was beyond the detection range of the test kit, typically because they were too high, were omitted from the results.

#### 7.2.2.3. Phosphate

Phosphate concentrations in cattle faeces were investigated using a Quantofix Phosphate test kit. A chemical reaction involving nitric acid is used to induce a change in colour to a testing strip, which is then compared to a colour scale of different ortho-phosphate concentrations. The technique is semi-quantitative in that results are limited to the gradation of the colour spectrum, which ranges from white ( $0\text{mgL}^{-1}$ ) to blue-green ( $100\text{mgL}^{-1}$ ; Figure 7.1).



**Figure 7.1.** The phosphate experiment colour gradation spectrum. The test kit allowed for the detection of phosphate concentrations between 0 and 100 milligrams per litre.

60 samples of wet cattle faeces weighing between 0 and 1.811 grams were placed into test tubes and mixed thoroughly with distilled water to a volume of 5 millilitres. For each of the 60 samples the following procedure was followed.

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Five drops of  $\text{PO}_4^{3-}$ -1 were added to the sample and mixed. In a separate vessel, six drops of  $\text{PO}_4^{3-}$ -2 were added. A test strip was placed into the sample and left for 15 seconds, after which the test strip was removed. The test strip was then placed into the vessel containing  $\text{PO}_4^{3-}$ -2 and left for 15 seconds, after which it was removed. After a further 60 seconds the colour on the test strip indicator was compared to the colour spectrum and the concentration of phosphate recorded. Where the test strip indicator fell between two grades of phosphate concentration an intermediate value was given (e.g. if the colour fell between grades  $50\text{mg l}^{-1}$  and  $100\text{mg l}^{-1}$ , a concentration of  $75\text{mg l}^{-1}$  was recorded). As such, results from this study were the least precise of all the nutrients investigated as the phosphate test kit was: relatively insensitive to changes in phosphate; only semi-quantitative; and subject to human error in the allocation of concentration grade. The weight of faeces at each grade was averaged and a graph of faeces weight against phosphate concentration was produced.

#### *7.2.2.4. Potassium*

Potassium concentrations in cattle faeces were investigated using a Palintest Potassium test kit. The kit detected potassium concentrations between 0 and  $12\text{mg l}^{-1}$ , and was precise to variations in ammonia concentration of  $0.01\text{mg l}^{-1}$ . 100 samples of wet cattle faeces weighing between 1.4mg and 200mg were placed into a test tube, which was then filled with distilled water to a volume of 10ml and the sample mixed thoroughly. A tablet containing sodium tetraphenylboron was added to the solution, crushed and mixed until dissolved. Samples were left to stand for five minutes at room temperature to allow for turbidity development. After five minutes, 2.5ml of the solution was injected into a cuvette and inserted into a Walden Precision Apparatus S106 digital spectrometer with the wavelength set to 520nm. Readings of absorbance and transmittance were recorded and compared to the potassium calibration chart provided with the test kit to derive the potassium content of each sample. Samples whose potassium content was beyond the detection range of the test kit, typically because they were too high, were omitted from the results.



#### *7.2.2.5. Chemical oxygen demand*

The chemical oxygen demand (COD) of cattle faeces were investigated using a Palintest Chemical Oxygen Demand test kit. The kit detected COD between 0 and 300mg l<sup>-1</sup> O<sub>2</sub>, and was precise to variations in COD of 1mg l<sup>-1</sup> O<sub>2</sub>. 47 samples of wet cattle faeces weighing between 6.3mg and 91.8mg were placed into separate sample tubes and filled to a volume of 10ml with distilled water; each sample was mixed thoroughly. 2ml of each sample was decanted into separate test tubes containing an 84% sulphuric acid reagent that was pre-heated to 150°C. Test tubes were kept at 150°C for 2 hours and left to digest, after which time they were removed from the heat and allowed to cool to room temperature. Once cooled test tubes were inverted and mixed gently. 2ml of the solution from each test tube was injected into separate cuvettes and placed into a Walden Precision Apparatus S106 digital spectrometer with the wavelength set to 490nm. Readings of absorbance and transmittance were recorded and compared to the COD calibration chart provided with the test kit to derive the COD (mg l<sup>-1</sup> O<sub>2</sub>) of each sample. Samples whose COD was beyond the detection range of the test kit were omitted from the results.

Chemical oxygen demand was measured rather than biochemical oxygen demand as it is more representative of the total oxygen loss due to faeces and is easier to measure. It is not possible to distinguish between oxygen depletion due to chemical and biochemical processes using a test kit. For the purposes of this study is assumed that the difference between chemical oxygen demand and biochemical oxygen demand is negligible, as cattle faeces is unlikely to contain non-organic oxidizing compounds; the former term is used throughout as it more accurately describes the values measured.

### **7.2.3. Results**

#### *7.2.3.1. Cow pat weight*

The mean weight of the 100 cow pats collected from the Midlington sites was 1300g. The maximum weight recorded was 2008g, whilst the minimum was 526g. The standard deviation of cow pat weights was 445g. A Shapiro-Wilk normality test revealed cattle

faeces weights to be normally distributed, with no statistically significant skew ( $W = 0.943$ ,  $N = 100$ ,  $P = 0.171$ ), suggesting the samples collected were representative of the cow pat population.

#### *7.2.3.2. Dry and wet weight comparisons*

Wet faeces samples lost approximately 89% of their weight when placed in an oven at 65°C for 24 hours (Bratzler and Swift, 1959; Manoukas et al., 1964). Variability around this average value was minimal; only 5% of samples experienced weight loss beyond two standard deviations of the mean (Table 7.1).

|                             | Batch 1      | Batch 2       | Batch 3       | All           |
|-----------------------------|--------------|---------------|---------------|---------------|
| Wet sample weight range (g) | 0.45 to 8.07 | 1.58 to 15.13 | 1.23 to 18.42 | 0.45 to 18.42 |
| Dry sample weight range (g) | 0.05 to 1.03 | 0.08 to 1.78  | 0.11 to 2.34  | 0.05 to 2.34  |
| Maximum weight loss (g)     | 7.28         | 13.35         | 15.99         | 15.99         |
| Maximum weight loss (%)     | 90.4         | 96.52         | 91.06         | 96.52         |
| Minimum weight loss (g)     | 0.4          | 1.43          | 1.12          | 0.4           |
| Minimum weight loss (%)     | 86.79        | 87.30         | 85.21         | 86.79         |
| Mean weight loss (%)        | 88.63        | 90.80         | 88.71         | 89.41         |
| Standard deviation          | 0.92         | 2.54          | 1.49          | 2.06          |

**Table 7.1. Weight loss in cattle faeces following oven drying.**

#### *7.2.3.3. Chemical analysis: ammonia*

Chemical analysis of cattle faeces for ammonia revealed a statistically significant positive correlation between the weight of faeces in a sample and the concentration of ammonia ( $r = 0.664$ ,  $N = 43$ ,  $P < 0.001$ ; Figure 7.2).

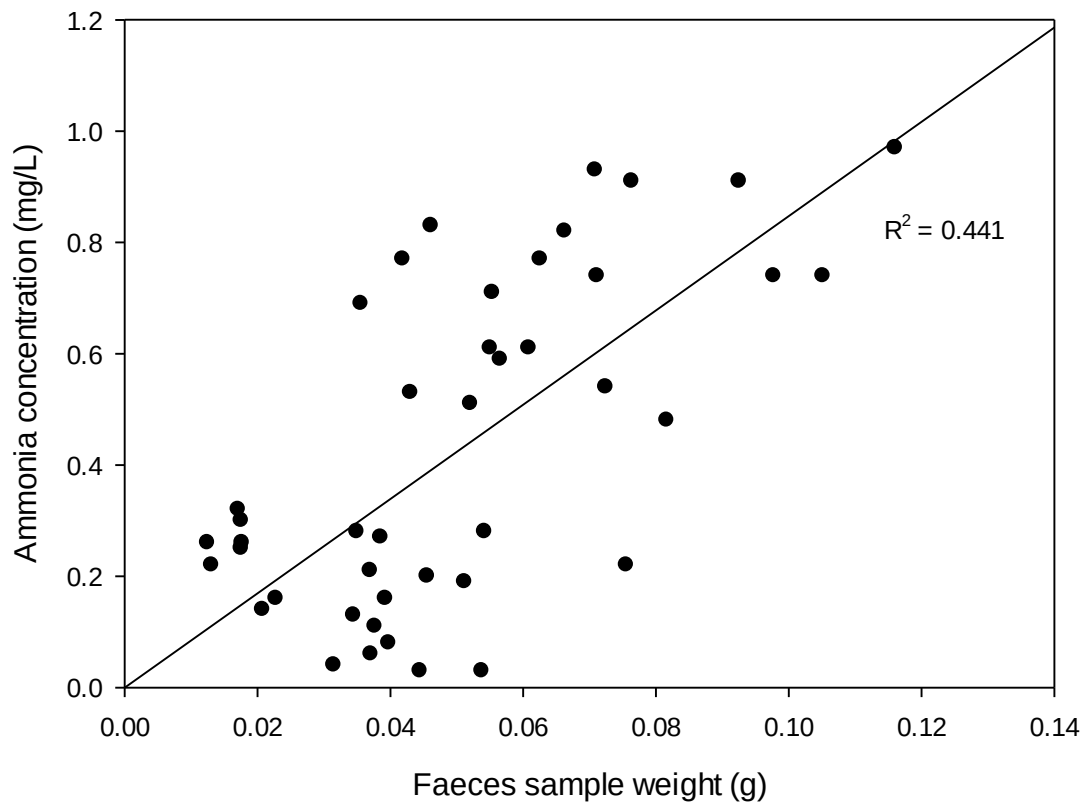


**Figure 7.2. Ammonia concentrations at different sample weights of wet cattle faeces. A linear regression line is displayed and an  $R^2$  value provided.**

It was discovered that adding 1 g of wet cattle faeces to 1 litre of river water would add 7.87 mg of ammonia (N); cattle faeces in this experiment contained approximately 0.79% ammonia. This equates to 10.23mg of ammonium ( $\text{NH}_4$ ) or 9.44mg of azane ( $\text{NH}_3$ ) per gram of faeces.

#### 7.2.3.4. Chemical analysis: phosphate

Chemical analysis of cattle faeces for phosphate revealed a statistically significant positive correlation between the weight of faeces in a sample and the concentration of phosphate ( $r = 0.903$ ,  $N = 51$ ,  $P < 0.001$ ; Figure 7.3).

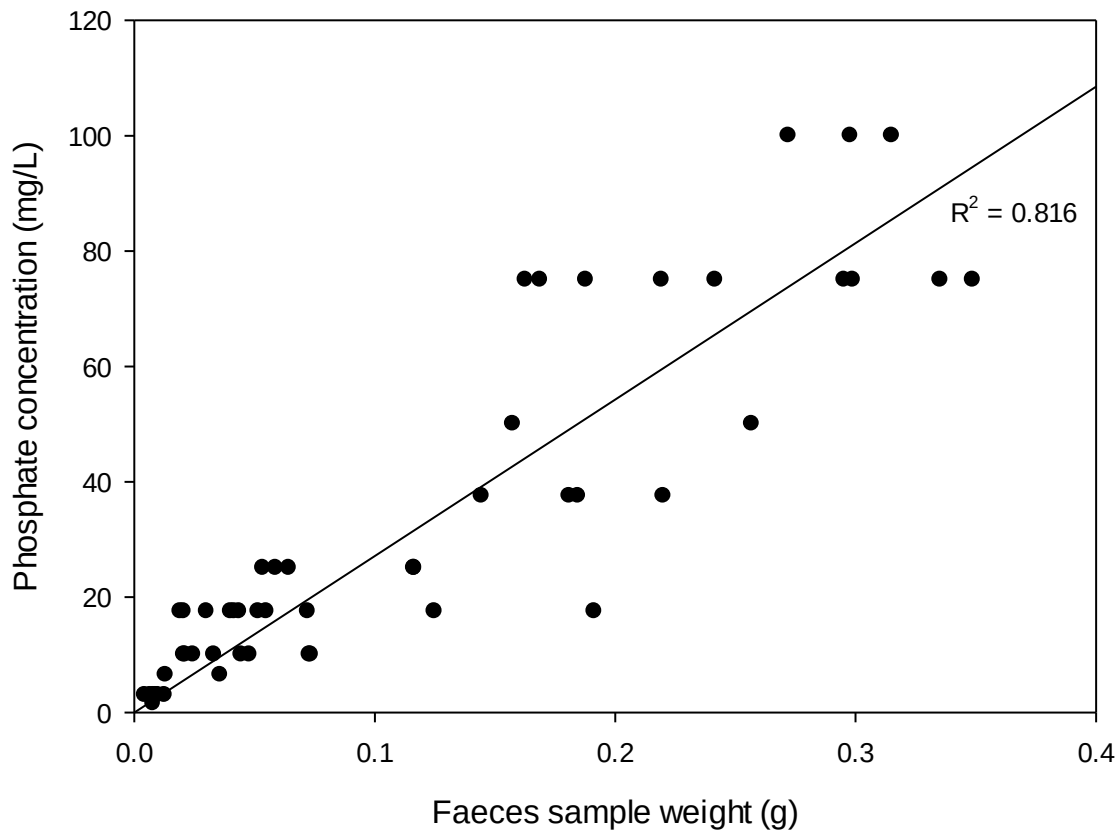


**Figure 7.3. Phosphate concentrations at different sample weights of wet cattle faeces. A linear regression line is displayed.**

It was discovered that adding 1 g of wet cattle faeces to 1 litre of river water would add 4.33 mg of phosphate ( $\text{PO}_4^{3-}$ ); cattle faeces in this experiment contained approximately 0.43% phosphate. This equates to 3.03mg of phosphorous oxide ( $\text{P}_5\text{O}_2$ ) per gram of faeces.

#### 7.2.3.5. Chemical analysis: potassium

Chemical analysis of cattle faeces for potassium revealed a statistically significant positive correlation between the weight of faeces in a sample and the concentration of potassium ( $r = 0.681$ ,  $N = 48$ ,  $P < 0.001$ ; Figure 7.4).

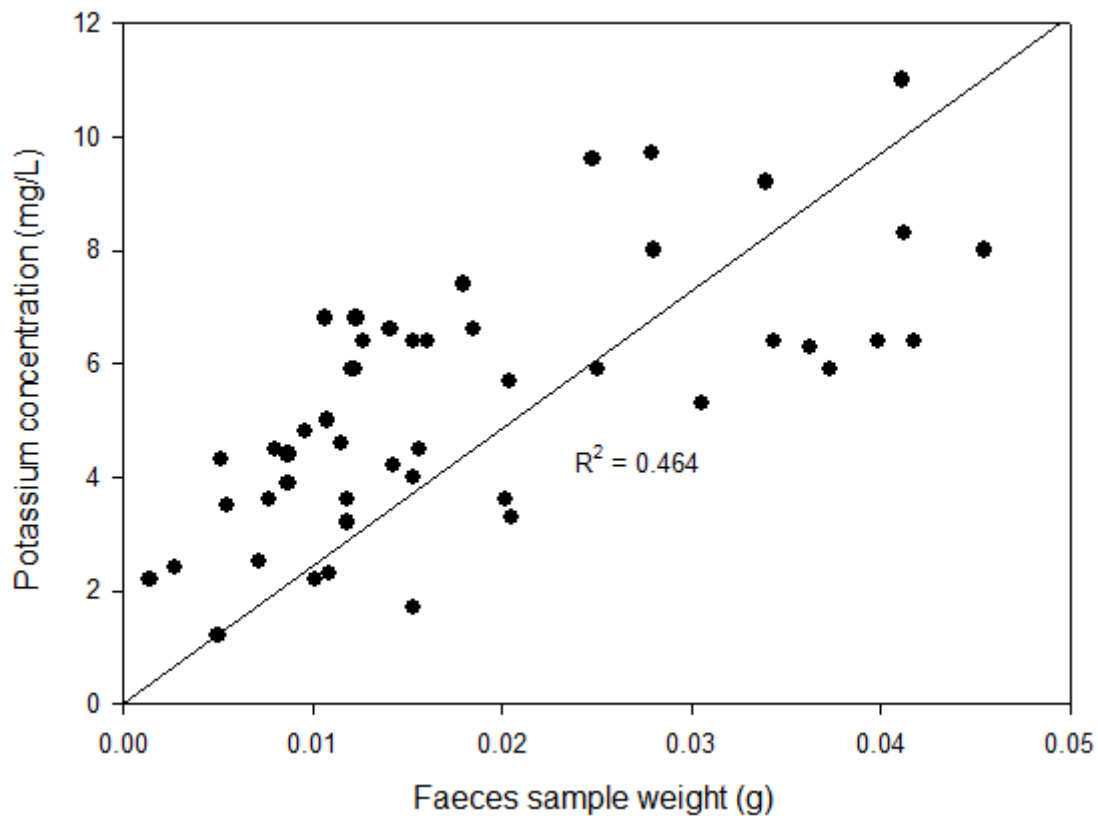


**Figure 7.4. Potassium concentrations at different sample weights of wet cattle faeces. A linear regression line is displayed and an  $R^2$  value provided.**

It was discovered that adding 1 g of wet cattle faeces to 1 litre of river water would add 4.27 mg of potassium; cattle faeces in this experiment contained approximately 0.43% potassium.

#### 7.2.3.6. Chemical analysis: chemical oxygen demand

Chemical analysis to determine the chemical oxygen demand of cattle faeces produced a statistically significant positive correlation between the weight of faeces in a sample and

its chemical oxygen demand ( $r = 0.849$ ,  $N = 25$ ,  $P < 0.001$ ; Figure 7.5).

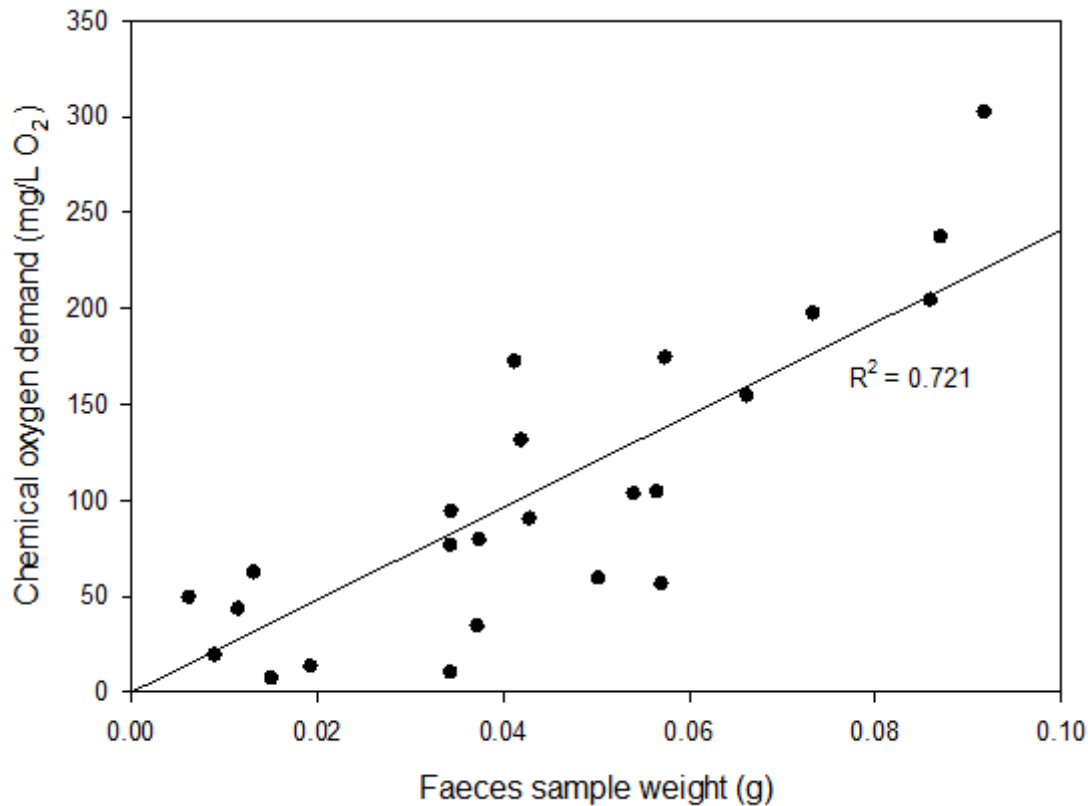


**Figure 7.5.** The chemical oxygen demand of different sample weights of faeces. A linear regression line is displayed and an  $R^2$  value provided.

The chemical oxygen demand of samples generally increased linearly with sample weight. It was found that for every gram of cattle faeces per litre of water, approximately 25 milligrams of oxygen were removed.

#### 7.2.4. Discussion

##### 7.2.4.1. Faeces consistency

It was evident from all of the chemical tests that increasing the amount of faeces in each sample increased the strength of the reaction from the reagents. However, it was also apparent that the chemical composition of faeces samples was dependent upon their consistency, and that the consistency of samples varied. Partially digested organic material in the form of leaves from trees and shrubs added weight to samples without

contributing soluble chemicals that could be detected by reagent tests. Hence, sample weight and chemical concentration were not perfectly correlated for any element tested.

The implication is that using the weight of faeces to infer its nutrient content will not necessarily accurately represent its true nutrient content. The diet of the animal, its age and hence its gut capacity, and the time spent ruminating will determine how well digested and homogenous faecal matter is. Nonetheless the statistically significant correlations recorded in the aforementioned experiments justify the use of the observed relationships to assess the chemical impact of cattle faeces upon chalk streams systems.

#### *7.2.4.2. Faeces weight*

It is clear from the oven drying experiment that the principle component of the cattle faeces taken from our subject animals is water. Physiologically the results suggest that cattle expel large volumes of water through faeces (Bentley, 2002). As a comparison, whereas the water content of human faeces is typically 75% (Wrick *et al.*, 1983) and sheep between 45-75%, the average water content of faeces taken from cattle grazing at the chalk stream sites was  $89.4\% \pm 2.1\%$  (Bentley, 2002). Yet, from the observational study conducted at the two Midlington sites it is known that cattle spend a very small fraction of their time drinking (Bond *et al.*, 2012). Thus it can be assumed that the high water content of their faeces is derived from their grass based diet and that the majority of the water that cattle require to survive is sourced from their food (Lysyk *et al.*, 1985). This concurs with the result that cattle spent only 0.46% of the observational study period drinking.

With respect to the impact upon the chalk stream environment, the high water content of cattle faeces is also significant. Unlike horse and sheep manure (Bentley, 2002), cattle faeces is particularly soluble due to its high water content, and is therefore more susceptible to movement and dispersion by hydrological and fluvial processes (Dickinson *et al.*, 2006). Moreover, the water in cow faeces is likely to bind with nutrient components such as nitrogen and phosphorous, making such materials more mobile and soluble than they would be in isolation or prior to digestion (Chapuis-Lardy *et al.*, 2003)

#### 7.2.4.3. *Ammonia*

Ammonia concentrations in faeces samples were greater than those recorded previously in the literature. The mean nitrogen content in beef cattle faeces was 0.59% in a study by Hubbard *et al.* (2004), whilst Smith and Frost (2000) noted a consistent 0.5% nitrogen concentration, irrespective of animal weight or cattle type (i.e. beef or dairy). Although there are likely to be small discrepancies between previously recorded values and values from this study owing to differences in the techniques used, the relatively high concentration in our animals likely reflects the comparative quality of forage available to cattle in chalk stream environments, which is greater than in the semi-arid grasslands in which many of the existing studies regarding cattle faeces nutrient concentrations have been conducted.

It should be noted that the values obtained may be an underestimate given that the time that elapsed between the collection of samples and their analysis, which has been shown to affect measurements of nitrogen concentration in faeces (Emmet and Grindley, 1909; Falvey and Woolley, 1974; Hinnant and Kothmann, 1988; Jacobs *et al.*, 2011). Although all samples were fresh at the time of collection it was not possible to conduct all of the chemical analyses simultaneously. Consequently the samples prepared for nitrogen analysis were kept in cold storage (~4°C) and not used until several weeks after collection, and it is probable that over this time a small proportion of the faeces nitrogen content (between 5-10% based upon existing estimates from the literature) was lost to the atmosphere prior to analysis (Adriano *et al.*, 1974; Hinnant and Kothmann, 1988). In future studies, greater technical human resources could reduce sample processing time and provide a more accurate estimate of faecal ammonia concentrations.

#### 7.2.4.4. *Phosphate*

The phosphate test kit used in this experiment has several limitations. The derivation of phosphate concentration using the colour spectrum does not produce a series of distinct results. The grouping of results around arbitrary grades of phosphate concentration limits the potential for statistical analyses. The experiment is limited further by intermediate



colouration of test strips (i.e. when results fall between two spectrum grades) and the potential for human error in determining test strip classification.

Nonetheless, and despite sizeable variance in the range of absolute results at each gradation, the average phosphate concentration correlates strongly with faeces weight. The derivation of an accurate phosphate concentration for cattle faeces is a key output of this experiment given the previously discussed role of phosphates in moderating primary productivity.

With respect to previous research into the phosphate content of cattle faeces, estimates from our study are in-between existing values from the literature. Morse *et al.* (1992) and Hubbard *et al.* (2004) recorded lower phosphorous concentrations than observed in our study. Conversely, Barnett (1994) recorded total phosphorus content of feeder cattle faeces as 0.67% of faeces weight, which is greater than in our study. In all of the aforementioned studies the methods employed to derive phosphate concentrations from cattle faeces were different, suggesting a broad consistency in faecal phosphorous concentrations.

#### 7.2.4.5. *Potassium*

For cattle the principle means of excess potassium excretion from the body is via urination (National Research Council, 2001). Hence the potassium content of faeces is dependent not only upon the dietary intake of potassium, but also the amount of potassium excreted via urination. Resultantly, variability in faeces potassium content may be higher than variability in the occurrence of other nutrients, whose main excretion pathway is faeces.

The potassium content of cattle faeces within our experiment appears similar to those values recorded previously. Hubbard *et al.* (2004) discovered an average potassium concentration of 0.36% in fresh manure, whilst Barker and Zublena (1996) recorded concentrations of 0.49%.

#### 7.2.4.6. Chemical oxygen demand

One of the complicating factors in measuring chemical oxygen demand is that it is not necessarily representative of biochemical oxygen demand, which refers to the amount of oxygen required by a waterbody's biota, and which changes according to water temperature, seasonality and the species composition of the river (Davie, 2008).

Biochemical oxygen demand is typically measured within watercourses as the change in dissolved oxygen content over a given period due to the break down of organic matter by organisms (UNEP, 2008). However, it would not have been appropriate to measure the difference in dissolved oxygen content between control samples and samples containing cattle faeces and record it as the biochemical oxygen demand, as the change measured includes everything that could be chemically oxidized; the chemical oxygen demand. In practice biochemical and chemical oxygen demand can be similar, depending on the abundance of non-organic oxidizing compounds (e.g. heavy metals) within a waterbody, and it is assumed that the chemical oxygen demand of cattle faeces recorded in this study is representative of its biochemical oxygen demand.

Assessing whether the chemical oxygen demand of cattle faeces recorded in this study is representative or typical is difficult. Hubbard *et al.* (2004) recorded a COD of 7.8kg for beef cattle, although what this equates to in  $\text{mgL}^{-1}$  is unclear. Møller *et al.* (2004) identify slurry from cattle as having a COD of  $56.5\text{mgL}^{-1}$  but do not mention the amount of slurry required to induce this COD. Gregory *et al.* (2000) prescribe a COD of approximately  $400\text{g animal}^{-1}$  for cattle faeces derived from animals at pasture, although again there is no context or explanation of this value.

In the absence of any interpretable comparisons to other faeces studies, the chemical oxygen demand of our samples is difficult to contextualise. Our observation that 1 gram of faeces has a COD of  $25\text{mgL}^{-1}$  suggests cattle faeces have a higher COD than a number of compounds (such as glucose [ $18.6\text{mgL}^{-1}$ ], starch [ $16\text{mgL}^{-1}$ ] and acetic acid [ $18.8\text{mgL}^{-1}$ ]) tested by Hejzlar and Kopáček (1990) but a lower COD than the sewage effluents (treated trade waste:  $340\text{mgL}^{-1}$ ) tested by Barker *et al.* (1999).

### **7.2.5. Conclusion**

Oven drying of cattle faeces revealed that cattle excrement is predominantly water, which accounted for  $89.4\% \pm 2.1\%$  of cattle faeces weight. Chemical analysis of faeces, undertaken to determine the nutrient loading due to excrement inputs from cattle, revealed nitrogen, phosphorous and potassium concentrations largely consistent with previously recorded values. Cattle faeces contained 0.79% nitrogen, 0.43% phosphorous and 0.43% potassium by wet mass. The chemical oxygen demand of cattle faeces was  $25\text{mg l}^{-1}$  per gram of wet faeces.

As well as providing the basis for calculations into likely nutrient loading to chalk streams, these values provide essential information about the composition of cattle faeces. Consisting principally of water, cattle faeces are relatively mobile compared to less soluble animal excrement such as that produced by sheep or horses. Consequently, indirect pollution pathways such as via surface runoff or throughflow may be important routes for allochthonous nutrient inputs. Although the nutrient content of faeces appears small as a percentage of faeces weight, further research (section 7.3) is necessary to establish whether cattle contribute significant quantities of phosphates, nitrates and potassium given the known frequency and magnitude with which they defecate.

## **7.3. Nutrient loading to chalk streams**

### **7.3.1. Introduction**

In section 7.2 chemical analyses of cattle faeces was undertaken to ascertain the nutrient content of excrement with respect to a number of key elements. However, prescribing values to the chemical content of faeces alone does not quantify the nutrient loading to chalk streams due to cattle.

By combining the findings of section 7.2 with the observational data chronicled in section 6.1 it is possible to calculate the total nutrient loading due to cattle over the period of this study. Moreover, by adding contextual information regarding the geomorphological characteristics of the river, as well as data from the academic literature relating to species

tolerances of specific nutrients, a detailed assessment of the chemical effects from cattle faeces can be undertaken.

### **7.3.2. Methods**

Calculations incorporating observational data and river characteristics data were undertaken for three sites: the North and South Midlington sites (section **Error! Reference source not found.**); and the Tichborne site (section **Error! Reference source not found.**).

River characteristics were derived from field observations and remote sensing. Reach length and enclosure size were calculated using georeferenced aerial imagery (section 7.7). At each site, 10 river cross-sections were measured using a Leica total station and the average river volume calculated. Average stream discharge was derived from proximate Environment Agency gauging stations at Mislingford (the North and South Midlington site: Environment Agency, 2012a) and the Cheriton Stream (the Tichborne site: Environment Agency, 2012b), as well as in-field measurements from a flow meter. The summed reach discharge was calculated by multiplying the average discharge by the period of exposure.

Defecation frequency was derived from Bond *et al.* (2012), with the total number of in-stream defecations at each site calculated by multiplying the number of cattle, the average defecation frequency and the period of exposure. The total defecation weight was calculated by multiplying the average faeces weight (section 7.2.3.1) by the total number of defecations (Bond *et al.*, 2012).

Total loadings were calculated by multiplying the proportion of each nutrient in cattle faeces (section 7.2.3) by the total weight of faeces. In-stream concentrations of faeces-derived nutrients were calculated by dividing the summed reach discharge by the total in-stream loading for each nutrient.

### 7.3.3. Results

The calculations in Table 7.2 show that although the net contribution of cattle faeces and faeces associated nutrients may be large, the overall effect, once considered over an appropriate temporal and spatial scale, may be less substantial.

|                                                                                | North Midlington        | South Midlington        | Tichborne               |
|--------------------------------------------------------------------------------|-------------------------|-------------------------|-------------------------|
| <u>Site characteristics</u>                                                    |                         |                         |                         |
| Enclosure size (ha)                                                            | 29                      | 19                      | 9                       |
| Reach length (m)                                                               | 1200                    | 770                     | 700                     |
| Reach volume (m <sup>3</sup> )                                                 | 3920                    | 2541                    | 2296                    |
| Average stream discharge (m <sup>3</sup> s <sup>-1</sup> )                     | 0.98                    | 0.99                    | 0.82                    |
| Summed reach discharge over the period of exposure to cattle (m <sup>3</sup> ) | 18.12 x 10 <sup>6</sup> | 18.30 x 10 <sup>6</sup> | 13.04 x 10 <sup>6</sup> |
| <u>Cattle characteristics</u>                                                  |                         |                         |                         |
| Period of exposure (days)                                                      | 214                     | 214                     | 184                     |
| Number of cattle                                                               | 35                      | 33                      | 20                      |
| Defecation frequency (animal <sup>-1</sup> day <sup>-1</sup> )                 | 8.46                    | 7.8                     | 8.28                    |
| Average defecation weight (kg)                                                 | 1.3±0.445               | 1.3±0.445               | 1.3±0.445               |
| <u>Defecation calculations</u>                                                 |                         |                         |                         |
| Total defecations                                                              | 63365                   | 55084                   | 30360                   |
| Total faeces weight (tonnes)                                                   | 82.4±28.2               | 71.6±24.5               | 39.5±13.5               |
| % of defecations in-stream                                                     | 12.3                    | 11.7                    | 12                      |
| Total in-stream defecations                                                    | 7794                    | 6445                    | 3643                    |
| Total in-stream faeces weight (tonnes)                                         | 10.1±3.5                | 8.4±2.8                 | 4.7±1.7                 |
| <u>Ammonia calculations</u>                                                    |                         |                         |                         |
| Total ammonia in faeces (kg)                                                   | 650.9±222.8             | 565.6±193.6             | 312.1±106.6             |
| Ammonia from in-stream faeces (kg)                                             | 79.8±27.7               | 66.4±22.4               | 37.1±11.9               |

|                                                                                       |              |             |            |
|---------------------------------------------------------------------------------------|--------------|-------------|------------|
| In-stream ammonia concentration due to direct faeces input ( $\text{mg l}^{-1}$ )     | 4.4±1.3      | 3.6±1.3     | 2.8±0.96   |
| <u>Phosphate calculations</u>                                                         |              |             |            |
| Total phosphorous in faeces (kg)                                                      | 356.8±118.78 | 310.0±103.2 | 171.0±56.9 |
| Phosphorous from in-stream faeces (kg)                                                | 43.7±14.8    | 36.4±11.9   | 20.4±6.9   |
| In-stream phosphorous concentration due to direct faeces input ( $\text{mg l}^{-1}$ ) | 2.4±0.8      | 2.0±0.6     | 1.6±0.5    |
| <u>Potassium calculations</u>                                                         |              |             |            |
| Total potassium in faeces (kg)                                                        | 351.8±120.5  | 305.7±104.6 | 168.7±57.6 |
| Potassium from in-stream faeces (kg)                                                  | 43.1±15.0    | 35.9±12.1   | 20.1±7.1   |
| In-stream potassium concentration due to direct faeces input ( $\text{mg l}^{-1}$ )   | 2.4±0.8      | 2.0±0.6     | 1.5±0.6    |
| <u>Chemical oxygen demand calculations</u>                                            |              |             |            |
| Chemical oxygen demand of in-stream faeces ( $\text{mg l}^{-1}$ )                     | 4.5±1.6      | 3.9±1.4     | 3.0±1.1    |

**Table 7.2 The chemical effects of cattle grazing in chalk streams.**

The greatest nutrient loadings for all nutrients occurred at the North Midlington site, where the high density of cattle contributed the greatest quantity of faeces. The Tichborne site, with a lower period of exposure and less cattle, experienced the least nutrient loading, despite having the lowest discharge. As with the results of the faecal analysis, concentrations of ammonia in terms of nutrient loading were nearly twice as high as concentrations of phosphate and potassium, with marginally higher concentrations of phosphate than potassium.

#### **7.3.4. Discussion**

##### **7.3.4.1. Ammonia**

In their long-term study of water quality in the River Frome, Bowes *et al.* (2011) report a contemporary nitrate concentration of  $6\text{mg l}^{-1}$ , with similar values recorded for the River Pang and River Lambourn by Jarvie *et al.* (2006b). In groundwater aquifers, Jackson *et al.* (2008) suggest values between  $2\text{--}4\text{mg l}^{-1}$  are typical, whilst Limbrick (2003) cites a mean nitrate concentration of  $6.37\text{mg l}^{-1}$  for chalk streams in south Dorset.

As with other elements, nitrogen availability varies temporally over the course of a day and through the seasons (Whitehead *et al.*, 2002). Moreover, nitrogen concentrations have increased markedly over the last 50-100 years in many chalk streams as a consequence of fertilizer use, effluent from sewerage works and runoff from urbanised areas (Casey *et al.*, 1993; Neal *et al.*, 2002; Whitehead *et al.*, 2002; Casey and Clarke, 2006).

Contributions of between  $2.8$  and  $4.2\text{ mg l}^{-1}$  of ammonia equivalent recorded across our study sites suggest that excrement inputs from cattle faeces do increase in-stream nitrogen availability. However given the relative abundance of nitrogen within chalk streams compared to other essential nutrients, increased nitrogen inputs may have negligible effects upon biota. With respect to algal blooms and eutrophication in chalk streams, phosphorous availability is often the limiting factor (Smith *et al.*, 1999; Neal *et al.*, 2002; Iriarte and Purdie, 2004) and it has been shown that high nitrogen concentrations, relative to phosphorous, can improve water quality (Smith, 1983; McQueen and Lean, 1987).

##### **7.3.4.2. Phosphate**

In their study of three rivers across southern England, Young *et al.* (1999) found average phosphorous levels of  $0.99\text{mg l}^{-1}$ , with a maximum phosphorous level of  $6.7\text{mg l}^{-1}$  on the River Blackwater. In chalk streams such as the River Frome, average phosphorous concentrations are generally lower (Hanrahan *et al.*, 2003), having fallen over the past 20

years due to phosphorous stripping at sewage works; phosphorous concentrations in the Frome were measured at  $0.049\text{mg l}^{-1}$  between 2008 and 2009 (Neal *et al.*, 2010; Bowes *et al.*, 2011).

Phosphorous values are variable between rivers and over time, which hinders any assessment of typical or background values (Jarvie *et al.*, 2006a; Bowes *et al.*, 2008). The Department for the Environment (1993) and the Environment Agency (2000) set the water quality standard for phosphorous as  $0.1\text{mg l}^{-1}$ ; a value 16 times smaller than the smallest phosphorous loading attributed to direct cattle faeces inputs in our study. For chalk streams specifically, the Environment Agency (2000) prescribe a  $0.06\text{mg l}^{-1}$  target

Evidently at the densities of cattle considered in this study, phosphorous contributions from direct faeces inputs to rivers are not only higher than target water quality standards, but also higher than empirically measured concentrations of phosphorous in chalk streams (Department for the Environment, 1993; Young *et al.*, 1999; Environment Agency, 2000; Mainstone and Parr, 2002; Hanrahan *et al.*, 2003).

The principle implication of excessive phosphorous loading is the potential for nutrient-induced changes in riverine plant communities (Mainstone and Parr, 2002); more so in English chalk streams where phosphorous availability is often the limiting factor for plant growth (Hilton *et al.*, 2006). The entire river ecosystem, whose organisms rely upon macrophytes as primary producers, can be altered due to phosphorous loading (Mainstone and Parr, 2002).

In actuality these mechanisms for ecosystem change may not be manifest. Background or natural phosphorous concentrations, the existing species composition of both plant and animal communities, the timing of the nutrient loading (seasonally, diurnally), the occurrence of other, potentially mitigating compounds (e.g. calcium carbonate: Neal *et al.*, 2000) and the distribution of phosphorous throughout the water column and within the bed substrate, amongst other factors, will help determine the consequences of



excessive phosphorous loading (Environment Agency, 2000; Mainstone and Parr, 2002; Hilton *et al.*, 2006; Bowes *et al.*, 2011).

Nonetheless, with a maximum phosphorous concentration of  $2.4\text{mg l}^{-1}$  from direct inputs, as recorded in section 7.2.4.4, existing phosphorous contributions from cattle faeces have the potential to effect change in chalk stream ecosystems.

#### 7.3.4.3. *Potassium*

Casey and Farr (1982) recorded in-stream potassium concentrations of  $1.8\text{mg l}^{-1}$  during their study of spates on the Mill Stream in Dorset. Relative to the natural potassium content of chalk streams, the contribution of potassium from faeces is comparatively small. In the River Frome, recorded potassium concentrations varied from 0.6 to  $5.9\text{mg l}^{-1}$  between 1965 and 2009 (Bowes *et al.*, 2011), whilst values were between 3 and  $15.1\text{mg l}^{-1}$  across three non-chalk streams in Suffolk between 1981 and 2005 (Howden and Burt, 2009). As such, potassium contributions from cattle faeces are unlikely to have a significant effect upon chalk stream ecosystems; both because potassium is relatively unimportant compared to ammonia and phosphate, and because potassium loading from excrement is comparatively low relative to background levels (Mainstone and Parr, 2002).

#### 7.3.4.4. *Chemical oxygen demand*

Dissolved oxygen concentrations in chalk stream water can vary over the course of a day and at different locations along a river (Neal *et al.* 2006; Williams and Boorman, 2012). Hence, the effect of removing between 6.1 and  $1.9\text{mg l}^{-1}$  of oxygen, as suggested from the results, is uncertain. Simulated and background dissolved oxygen values at Ramsbury on the chalk stream River Kennet varied between 6 and  $14\text{mg l}^{-1}$  in a 14 month study by Williams and Boorman (2012), whilst on the River Brett in Suffolk, concentrations typically vary from 3 to  $11\text{mg l}^{-1}$  (Parr and Mason, 2004).

Physiologically, different organisms prefer different concentrations of dissolved oxygen, with many species having an optimum dissolved oxygen range for growth and reproduction (Irving *et al.*, 2004; Maes *et al.* 2007). However, large fluctuations in dissolved oxygen concentrations will not necessarily negatively affect fish populations, as shown by Forsberg and Bergheim (1996) in their study of post-smolt Atlantic salmon.

### **7.3.5. Conclusion**

Using calculations to combine behavioural cattle data with faecal analysis data, estimates of the direct nutrient loading due to cattle were calculated for an English chalk stream. It was estimated that a herd of 35 cattle deposited over 10 tonnes of faeces into a 1.2km river reach over a seven month period in 2010. Moreover, it was estimated that the loading of ammonia and potassium would have a relatively small effect upon background levels of these nutrients, compared to phosphate, whose in-stream concentration could be increased by an order of magnitude due to faecal inputs from cattle.

Our estimates suggest that cattle have the potential to change water quality significantly, with implications for chalk stream ecosystems. Phosphate loading, either directly through in-stream defecation or indirectly from surface runoff, is of particular concern. In the chalk streams observed within this study, apparently high phosphate loading had no obvious effect upon riverine ecology in the form of eutrophication, algal blooms or excessive plant growth. Further research looks to investigate whether these predicted values actually occur within chalk streams specifically and to establish what effect they have. If so, cattle access to rivers may require more stringent management, such as exclusion using fencing or the removal to faeces from defecation hotspots, to prevent the undesirable effects of nutrient loading in chalk streams.

The study has shown that by combining laboratory analysis of faeces with observational data of cattle behaviour, realistic estimates of nutrient loading can be calculated. Such calculations can tell us much about interactions between aquatic systems and external drivers without the need for extensive data collection. Furthermore it allows us to: compare the effects of cattle between sites; to foresee whether a given stocking density is

likely to cause deterioration in water quality; and to weigh-up the relative importance of nutrient loading from cattle faeces compared to other sources (e.g. sewage treatment works). Resultantly there is the potential for the use of these estimations in river and livestock management.

## **7.4. Terrestrial soil compaction and shear stress**

### **7.4.1. Introduction**

Soil properties modulate terrestrial hydrological processes, which subsequently partly determine allochthonous inputs to river channels (Chow, 1964; Dickinson, 1991; Davie, 2008). In particular, soil permeability and soil shear strength moderate runoff generation, soil erosion and rill and gully development (Jones, 1971; Mitchell and Soga, 2005). As geomorphic agents cattle have the capacity to modify these soil properties (Trimble and Mendel, 1995).

The role that cattle play in the compaction of soil has been well documented and in some instances quantified (Van Haveren, 1983; Monaghan *et al.*, 2005; Pietola *et al.*, 2005). Previous studies have shown that the degree of compaction is a function of numerous factors including stocking density, stocking duration, antecedent soil conditions, soil moisture content, soil structure and soil type (Thurow *et al.*, 1986). Further studies have also discussed the consequences of soil compaction by cattle, ecologically (Fleischner, 1994), geomorphically (Kauffman and Krueger, 1984) and hydrologically (Warren *et al.*, 1986).

Cattle activity has also been shown to effect soil erosion: compaction reduces soil infiltration capacity, increasing runoff; vegetation mortality reduces soil cohesion in the absence of root systems (Trimble and Mendel, 1995). A study by Thurow *et al.* (1986) conducted over six years in Texas reported greater inter-rill erosion and reduced infiltration in heavily stocked pastures compared to moderately and lightly stocked pastures, while Forsling (1931) observed that erosion and runoff in grazed alpine slopes fell by half following the cessation of grazing.

In practice the effects of soil compaction and erosion by cattle are not uniform. As seen in the results of this study and those before it, cattle preferentially use some areas and avoid others. As a result, there may be heterogeneity in soil compaction and erosion due to cattle that is not represented in existing studies. Specifically, cattle trail soils are thought to be more erodible and more compacted than soils not subject to cattle transit.

In order to test these hypotheses a cohesive strength meter is employed within this study to measure the critical shear stress required to induce erosion in cattle trail and non-cattle trails soils. The cohesive strength meter (CSM), which has been used in previous studies of cohesive sediments and soils, particularly in estuarine environments, is easy to use, transportable and automated, providing consistent measurements of shear stress between different surfaces (e.g. Watts *et al.*, 2003; Tolhurst *et al.*, 2006; Darby *et al.*, 2010; Chen *et al.*, 2012).

The experiment detailed herein explains how a CSM was used to measure differences in the erodibility of soils affected by cattle within chalk stream environments. Additional data regarding the pressure exerted by cattle upon soils is also presented and compared to the pressure required to cause soil erosion. The values obtained for shear stress in this experiment will provide the input variables for the modelling elements of this study. Specifically, the results will be combined with spatial data regarding the distribution of cattle trails (as derived from aerial photography) to generate a map of soil erodibility for the Tichborne site. Subsequent analysis within a diffuse risk modelling framework (SCIMAP) will produce outputs that illustrate the connectivity of the study area.

#### **7.4.2. Methods**

A 60 psi cohesive strength meter (CSM; as detailed by Tolhurst *et al.* 1999) was used for the experiment (Figure 7.6). The CSM was chosen for this experiment instead of other equipment (e.g. a penetrometer) principally because of its availability, although it does have a number of useful features including an automated procedure for data logging, high precision and reliable repeatability.



**Figure 7.6. The cohesive strength meter in the field.**

The CSM works by firing jets of air through a water-filled chamber onto an erodible surface. The pressure of the jet increases incrementally until the critical stress is achieved. The pressure required to induce erosion is determined by a device housed within the water-filled cylinder that measures the attenuation of light due to the suspension of material disrupted by the jet. A microprocessor on board the CSM takes regular recordings (a reading every 0.1 seconds) of the amount of light reaching the optical sensor and the jet pressure applied. The jet pressure required to induce erosion is indicated by a fall in detected light transmission to 90% of the starting value.

Calculations provided by the producers of the CSM were then used to convert critical jet pressure values into stress, horizontal stress and friction velocity for each sample; mean values and standard deviation for each surface type were also calculated.

The CSM was applied to three different surfaces (Figure 7.7): bare earth cattle trail soils approximately 20 metres from a cow ramp, bare earth cattle trail soils approximately 10 metres from a cow ramp, and vegetated non-cattle trail soils (grasses were clipped to a uniform height of 10mm).

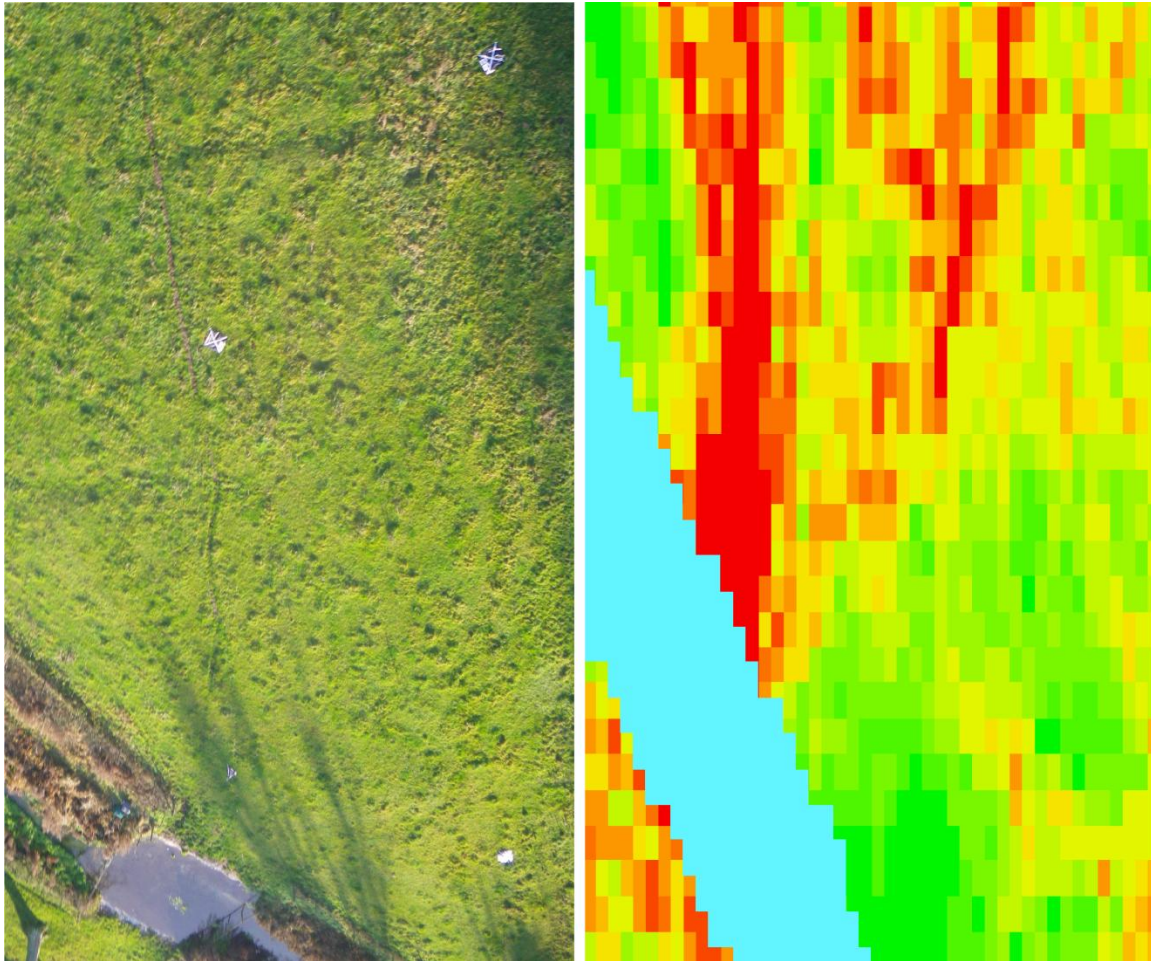


**Figure 7.7.** Aerial photography (left) and a GIS raster layer (right) for the Tichborne site. The GIS raster layer shows areas of high (red) and low (green) utilisation by cattle. Areas of high utilisation coincide with cattle trails and the cow ramp seen in the aerial image.

### 7.4.3. Results

A total of 33 CSM samples were taken: 15 on a cattle trail approximately 10m from a cow ramp; nine on a cattle trail approximately 20m from a cow ramp; five on vegetated soils of uniform grass height; and four that were discarded because the water-filled cylinder drained prior to the detection of a critical shear stress.

| <i>Sample number</i>      | <b>ID16</b> | <b>ID17</b> | <b>ID18</b> | <b>ID19</b> | <b>ID20</b> |
|---------------------------|-------------|-------------|-------------|-------------|-------------|
| <i>Jet pressure (psi)</i> | 3.04        | 2.81        | 1.02        | 2.54        | 2.09        |

**Table 7.3.** The jet pressure necessary to induce erosion is given for samples 16-20 (cattle trail, approximately 10m from a cow ramp).

The jet pressure required to induce erosion was not constant between samples of the same surface type (Table 7.3). Within cattle trails the maximum jet pressure required to achieve shear stress was 4.01 psi while the minimum was 1.02 psi. By comparison the maximum jet pressure required to achieve shear stress in vegetated samples was 20.63 psi while the minimum was 19.36 psi.

| Surface type       | Number of samples | Pressure (psi) |       | Pressure (kPa) |        | Horizontal stress (Nm <sup>-2</sup> ) |      | Friction velocity (cms <sup>-1</sup> ) |      |
|--------------------|-------------------|----------------|-------|----------------|--------|---------------------------------------|------|----------------------------------------|------|
| Cattle trail (10m) | 15                | Mean           | 2.46  | Mean           | 17.17  | Mean                                  | 1.53 | Mean                                   | 3.82 |
|                    |                   | StDev          | 0.67  | StDev          | 4.66   | StDev                                 | 0.39 | StDev                                  | 0.53 |
| Cattle trail (20m) | 9                 | Mean           | 2.65  | Mean           | 18.26  | Mean                                  | 1.62 | Mean                                   | 3.92 |
|                    |                   | StDev          | 0.90  | StDev          | 6.23   | StDev                                 | 0.52 | StDev                                  | 0.65 |
| Vegetated          | 5                 | Mean           | 19.93 | Mean           | 137.43 | Mean                                  | 8.01 | Mean                                   | 8.84 |
|                    |                   | StDev          | 0.52  | StDev          | 3.60   | StDev                                 | 0.10 | StDev                                  | 0.05 |

**Table 7.4 Averaged critical values and standard deviations around those values for jet pressure, stress, horizontal stress and friction velocity.**

Greater variability in horizontal stress and friction velocity were recorded in samples from cattle trails than in samples from vegetated soils (Table 7.4). Mean values for all variables were also greater in cattle trail samples than in vegetated samples, with a statistically significant difference between cattle trail and vegetated critical horizontal stress ( $T = -73.46$ ,  $P = 0$ ,  $df = 5$ ); vegetated soils were significantly harder to erode than cattle trails. However, there were no significant differences between the shear stress of soil samples in cattle trails proximate to a cow ramp compared to soil samples relatively distant from a cow ramp ( $T = -0.45$ ,  $P = 0.659$ ,  $df = 13$ ).

#### **7.4.4. Discussion**

The principle finding of this experiment is that cattle trail soils were significantly more erodible than vegetated soils. Although this finding is supported by similar studies (Rich



and Reynolds, 1963; Chichester *et al.*, 1978; Thurow *et al.*, 1986), the erodibility of cattle trail soils has never previously been directly quantified in comparison to vegetated soils or otherwise.

It was also shown that the shear stress required to erode vegetated soils was less than the horizontal pressure applied by a moving cow (see section 4.2.2.1) and it is because of this that cattle trails form; repeated application of pressure perpendicular to the soil plane, and in excess of the shear stress, results in soil deformation, soil displacement and plant mortality. Even static cattle, applying a total vertical pressure of between  $0.25 \times 10^6 \text{ Pa}$  to  $1.25 \times 10^6 \text{ Pa}$ , depending on animal weight and basal foot area, would cause soil compaction of vegetated soils.

The observation that cattle can apply pressure several degrees of magnitude greater than the shear stress of vegetated soils underlines the potency of cattle as geomorphic agents in chalk stream environments. Furthermore it suggests that soil compaction and deformation do not occur solely in cattle trails; any terrestrial area with similar soils is liable to geomorphic agency in the presence of cattle. The implication is that cattle exert enough force to create not only micro-scale heterogeneity in soil properties (i.e. differences between the erodibility of cattle trail soils and vegetated soils within the same field) but also field-scale heterogeneity (i.e. differences between the erodibility of soils within grazed fields compared to ungrazed fields).

At the micro-scale the soils within cattle trails are significantly more susceptible to erosion than proximate vegetated soils. As illustrated by anecdotal evidence from the observational and GPS studies, and quantitative evidence from aerial photography, cattle trails connect the landscape and often directly link terrestrial and aquatic environments. Hence cattle trails act as both sources and pathways for eroded soil material. Furthermore, because cattle trails will be eroded by hydrological events that do not cause the erosion of vegetated soils (e.g. sheet or rill erosion caused by surface runoff from heavy rainfall events or overbank flow) their form may be maintained or enhanced in the



absence of cattle, particularly during the winter months when the likelihood of high rainfall events is greater.

Beyond this there is a need for further empirical research into the net runoff generated in cattle trails. In chalk stream environments, where flooding is seldom and high soil permeability limits saturation excess overland flow, highly erodible cattle trails may not enhance runoff significantly; measuring runoff directly would improve our understanding. Of potentially greater concern is the role cattle play in the relocation of soil material. Deformed soil from cattle trails can adhere to cattle hooves and be transported around the terrestrial environment and from the terrestrial environment to the aquatic environment. An assessment of the material lost from cattle trails to river channels, perhaps using a high-resolution laser scanner to record changes in cattle trail topography over time, would provide valuable information.

#### **7.4.5. Testable hypothesis**

The testable hypothesis for this section ( $H_4$ ), that soils in areas subject to greatest usage by cattle will have a lower horizontal shear stress than areas infrequently used by cattle, was proven with a statistically significant difference between critical horizontal shear stress in cattle trail and non-cattle trails soils.

#### **7.4.6. Conclusion**

A statistically significant difference was observed between the erodibility of bare cattle trails and proximate vegetated soils within a terrestrial chalk stream environment. The mean horizontal pressure required to induce erosion was  $1.58 \pm 0.45 \text{ Nm}^{-2}$  in cattle trails and  $8.01 \pm 0.1 \text{ Nm}^{-2}$  on vegetated soils. There was no statistically significant difference between the erodibility of cattle trail soils within 10m of a cow ramp and cattle trails within 20m of a cow ramp, suggesting that proximity to a watercourse is no indication of erodibility.

Evidently cattle can be important geomorphic agents within terrestrial chalk stream environments. Although previous work (e.g. Trimble and Mendel, 1995; Belsky *et al.*, 1999) has shown the potential for cattle to cause localised soil erosion, this study is the first to demonstrate the consequences of poaching across a chalk stream floodplain. The results illustrate the relatively high erodibility of soil within cattle trails, and the role of vegetation in retaining soil strength. The results also show the potential for cattle trails to form even when stocking densities are comparatively low and it has been shown that an individual cow may be able to exert sufficient force to induce erosion. In low-energy, groundwater-dominated fluvial systems that seldom experience overbank flows and are relatively inactive with respect to planform evolution, such as those in southern England, these findings regarding cattle activity are particularly significant.

Further research is required to ascertain whether the comparative erodibility of cattle trails contributes significant allochthonous inputs to the aquatic environment. Although anecdotally it appears that cattle trails connect the landscape, as yet no studies have considered their role in either producing or transporting eroded material. Moreover, the effect cattle trail features have upon soil permeability and catchment-scale runoff has not been researched and future work would evaluate not only the effect of cattle grazing upon soil erodibility but also upon hydrology.

## **7.5. Bank destabilisation and terrestrial laser scanning**

### **7.5.1. Introduction**

The destabilisation of river banks by cattle through the direct application of mechanical force represents a significant concern for land managers seeking to retain the morphological characteristics of their rivers (Trimble and Mendel, 1995). Chalk streams are particularly susceptible to cattle induced changes in stream morphology, as they naturally lack the energy required to undertake such geomorphic agency; discounting anthropogenically forced changes, the form of most chalk streams is a function of historic fluvial processes (Silvester, 1988; Mainstone, 1999; Sear *et al.*, 2005).

The bank-side landforms created by cattle, cow ramps, are discussed in the literature (Trimble and Mendel, 1995). They exist as features of relatively shallow relief that may hasten the delivery of surface runoff into rivers. Moreover, it is theorised that during overbank flows the increased surface roughness resulting from a spatially variable microtopography of hoof prints, and loose and compacted bank material, can lead to scouring, which in turn increases surface roughness further; a positive feedback mechanism (Trimble, 1994).

Overall, the existence of cow ramps is perceived to be detrimental to the river: channel form can be altered; surface runoff can more easily enter the aquatic environment; bank destabilisation contributes mineral and organic matter to the river channel; vegetation cannot establish on cow ramps; cow ramps experience scouring during overbank flows, with eroded material entering the river (Trimble and Mendel, 1995). Although many of these impacts have been qualified by simple observation, there has as yet been little quantification of their effects. Hence, it is not known, for example, whether the additional sediment contributed by the destabilisation of river banks at cow ramps is significant, either relative to other disturbance phenomena such as flooding, or in the context of the mortality and wellbeing of sediment-sensitive biota, such as salmonids (Kauffman and Krueger, 1984).

Although there are numerous ways in which river bank stability can be measured (e.g. *in-situ* shear stress tests: Docker and Hubble, 2008; measurements of long-term changes in channel morphology and planform: Kiss *et al.*, 2007; monitoring fluctuations in turbidity induced by river bank destabilisation events; Schaffelke *et al.*, 2005), few can offer the accuracy and precision afforded by terrestrial laser scanning (TLS). TLS technology has previously been used to observe a wide range of geomorphological phenomena in fluvial (e.g. Hodge *et al.*, 2009), aeolian (e.g. Nield *et al.*, 2011) and glacial (e.g. Schwalbe and Maas, 2009) environments. An increasing number of studies are employing TLS to monitor changes in river bank structure and size over time (Nasermoaddeli and Pasche, 2008; O'Neal and Pizzuto, 2010), and it is clear that, theoretically at least, bank destabilisation caused by cattle could be recorded and quantified using TLS.

The use of TLS to record changes in river bank topography compliments the monitoring of other process measurements throughout this study in the soil shear stress (section 7.4) and in-stream water turbidity (section 7.6) experiments. Moreover, TLS improves our understanding of cattle effects at the aquatic-terrestrial interface, and can be added to the soil shear stress data (terrestrial processes) and water quality data (in-stream processes) to generate an integrated overview of cattle effects within chalk streams.

Here we use a terrestrial laser scanner to quantify the amount of bank material lost throughout the grazing season. In addition, the terrestrial laser scanner allows for the generation of high resolution digital elevation models that can tell us much about cow ramp morphology and microtopography and how these change over time due both to cattle activity and hydrological processes.

## **7.5.2. Methods**

### *7.5.2.1. Terrestrial laser-scanner*

The terrestrial laser-scanner used in this study was a Leica HDS3000 Scanstation. scanner can collect up to 4000 points per second and has a 360° horizontal and a 270° vertical field-of-view. The scanner supersedes other methods of meso-scale topographical mapping (e.g. high precision levelling devices) in terms of its precision (up to 1mm), data capacity, automation and speed. The laser-scanning technique detailed herein was chosen because it was necessary to capture small (<1cm) changes in river bank topography caused by cattle across comparatively large areas (>20m<sup>2</sup>). When combined with a control station and fixed control points, the laser-scanner also afforded high precision in data collection over time, allowing for laser-scans taken months apart to be mapped in the same virtual space with no compromise in accuracy.

### *7.5.2.2. Fieldwork*

Two unfenced crossing points at the southern Midlington site and a fenced crossing point at the Tichborne site were laser-scanned. Sites were chosen on the basis of accessibility (land-owner's permission and proximity to a road; the laser-scanner is heavy and required

### *Studying the effects of cattle grazing in chalk streams*

two people to carry over difficult terrain) and how representative they were of typical chalk stream riverine environments.

The north-most crossing point at the southern Midlington site was relatively wide ( $>25\text{m}$  longitudinally) but shallow ( $<0.2\text{m}$  maximum river depth) with vegetated, low, steep-sided and vertical banks. Four laser-scans were taken in total, before, during and after cattle access: in March, May, August and October 2011. The south-most crossing point at the southern Midlington site was relatively narrow ( $\sim 10\text{m}$  longitudinally) and shallow ( $<0.4\text{m}$  maximum river depth) with partially-vegetated, shallow, gently sloping ( $\sim 10^\circ$ ) banks. Two laser-scans of the unvegetated areas of the river bank were taken in total, before and during cattle access: in March and May. The crossing point at the Tichborne site (Figure 7.8) had steeper river banks ( $\sim 30^\circ$ ) than those at the southern Midlington site but was narrower ( $<10\text{m}$  longitudinally) and deeper ( $<0.7\text{m}$  maximum river depth). Two laser-scans were taken in total, both after cattle access: in November and December.



**Figure 7.8.** The crossing point at the Tichborne site.

A control point system was set-up at each site where laser-scanning was to be undertaken; a minimum of six control points were used at each site (Figure 7.9). Control points are geostationary targets that allowed for the accurate comparison of scans taken at different times.

In addition to control points, four high-definition surveying (HDS) targets were used for each scanning session. HDS targets were not geostationary, and their position changed from session to session.

Control point and HDS target positions were measured prior to each terrestrial laser scanning session using a Leica total station. The maximum precision of the total station was +/- 1mm.

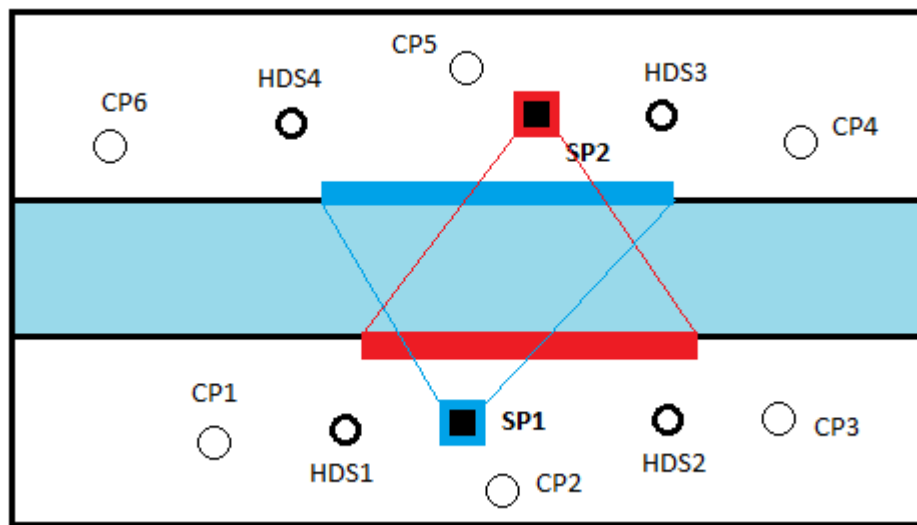


**Figure 7.9** A sketch of the laser-scanning set-up. HDS targets are numbered 1-4 and prefixed HDS. Control point targets are prefixed CP and numbered 1-6. The two scan positions (SP1 and SP2) and scan views are also shown.

The laser point spacing was 2mm in both the vertical and horizontal axis. The length, width and depth of river bank scanned for each session varied according to the attributes of the cow ramp and the elevation of the water surface.

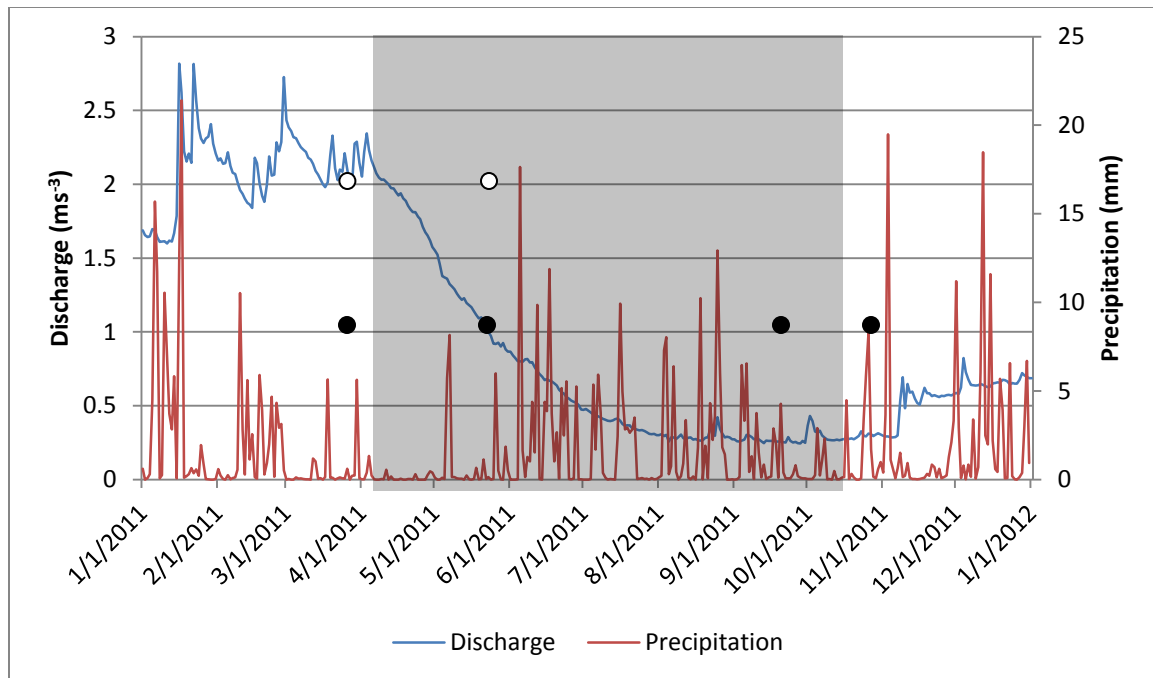


**Figure 7.10.** A hydrograph from the River Meon at Mislington. The period of exposure to cattle is shown in grey. White dots mark the dates of scans at the Southern Midlington site; black dots mark the dates of scans at the Northern Midlington site.

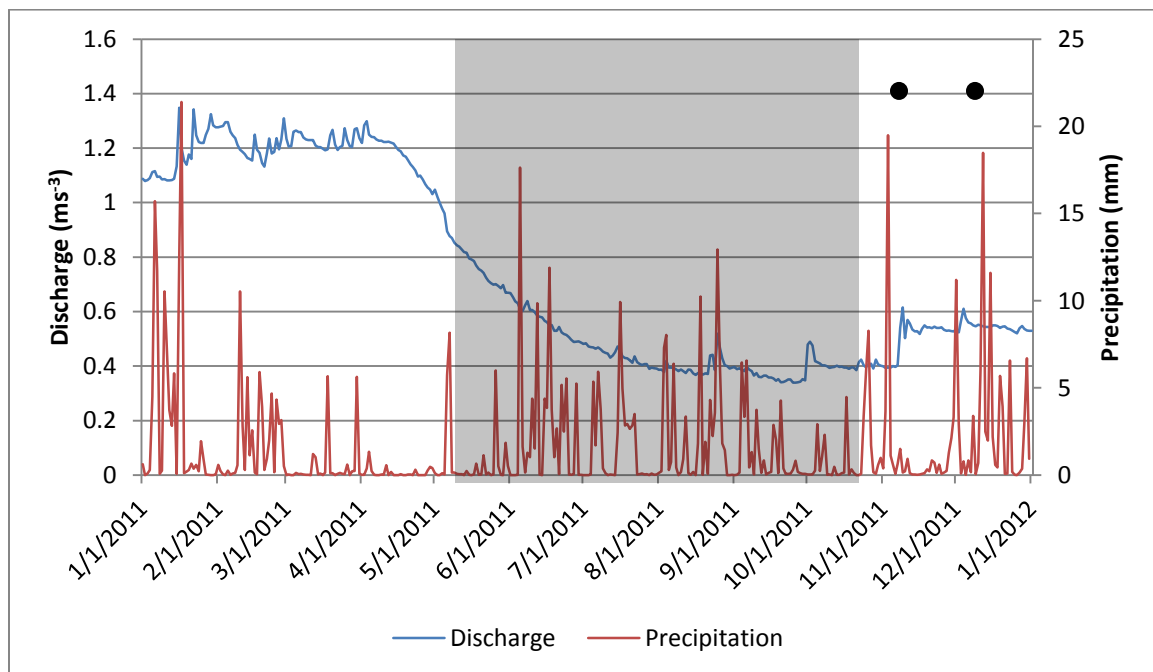


**Figure 7.11.** A hydrograph from the Cheriton Stream at Swards Bridge. The period of exposure to cattle is shown in grey. Black dots mark the dates of scans at the Tichborne site.

#### *7.5.2.3. Data processing and analysis*

For each scan session there were two scanner positions, one either side of the river bank; scans from different banks were conducted in separate Scanworlds™ (the displayed data set) and registered together subsequently in Cyclone (the bespoke data processing software for the Leica laser scanner) using the HDS targets. Once Scanworlds™ from the same session had been registered it was necessary to georeference these relative to the positions of the control points. This enabled all point clouds from the same location to exist within the same co-ordinate system such that data taken on different dates could be superimposed upon one another. Additionally it provided a means of assessing the positional accuracy of different Scanworlds™; Cyclone calculates the positional error of each registration (Table 7.5, Table 7.6).

Once all Scanworlds™ from the three locations were registered to their respective co-ordinate systems, the data in each Scanworld™ were cleaned by manually removing unwanted data points within Cyclone. The cleaning process had two stages. Water, mixed pixels and any other unwanted data, including pixels around control points, targets and vegetation, were removed; cleaned registered Scanworlds™ were then exported from Cyclone as text files and processed through a minimum elevation filter to remove any remaining vegetation. The filter works by finding the lowest elevation data point within a predefined area ( $0.02\text{m}^2$ ) and assigning this value to a newly constructed grid of minimum elevation points; the assumption made is that the lowest elevation point within a cell represents the elevation of the terrain (Figure 7.12).



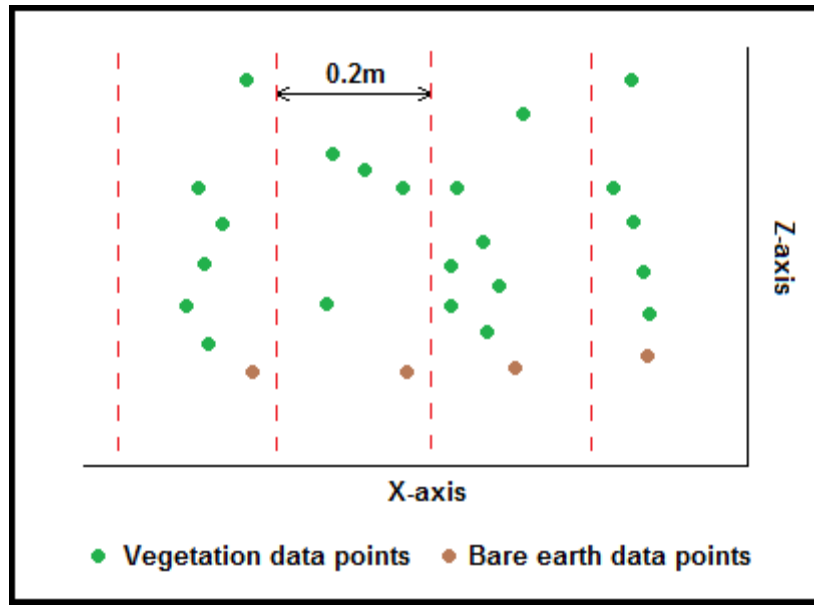


**Figure 7.12 Filtering method example.** Non-surface vegetation data points are omitted and data values derived from the lowest elevation point in each cell are reassigned to a  $0.2\text{m}^2$  grid (indicated by the dashed red lines).

Once processed through the filter, text files were imported into ArcGIS. Files were added as XY data, displayed and converted into shapefiles. Any remaining, clearly erroneous points were removed using the Editor Toolbar and the remaining data converted into raster output maps with a cell size of  $0.1\text{m}$  and the elevation (z component) as the output value; reducing the cell size from  $0.02\text{m}$  to  $0.1\text{m}$  improved the computational efficiency of processing.

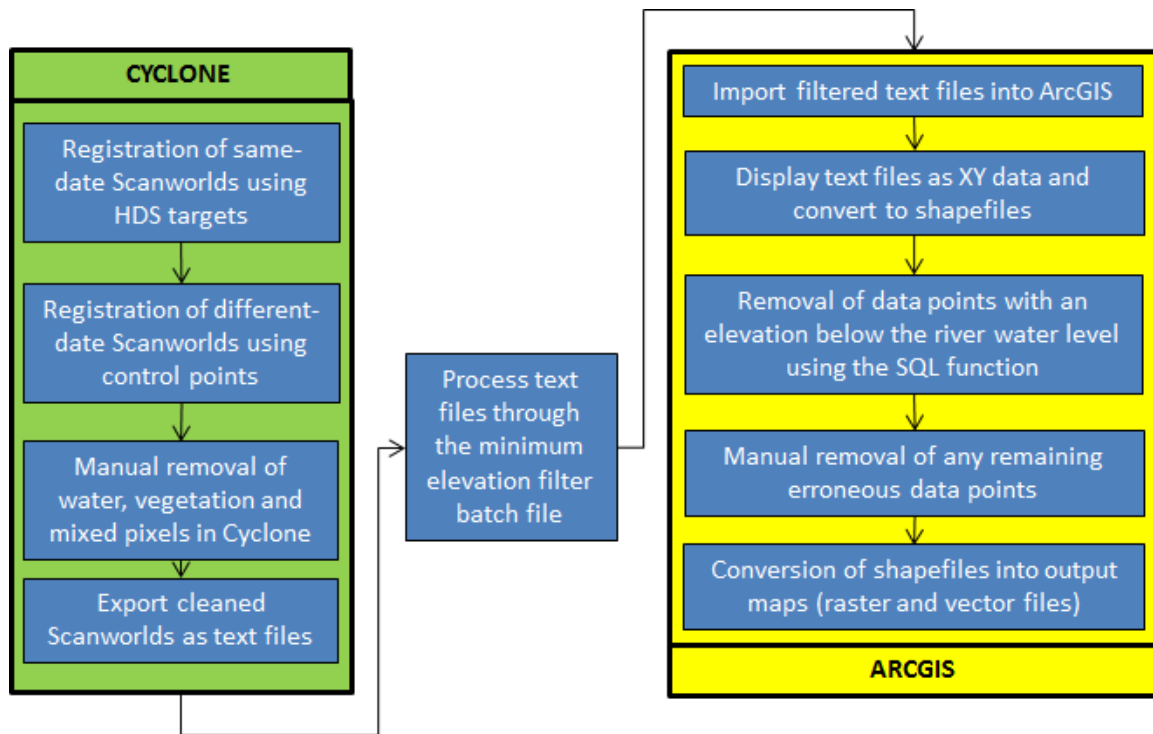


**Figure 7.13.** A workflow of the data processing phase for data derived from the terrestrial laser-scanner.

The ArcGIS raster calculator was used to generate anomaly maps of differences in river bank elevation before and after cattle access; a digital elevation map of difference over time. Absolute changes in the mass of river bank material were calculated using data from anomaly map attribute tables. This data was also used to create histograms of river bank elevation changes over the course of the study.

### 7.5.3. Results

#### 7.5.3.1. Errors

Positional errors resulting from the registration of separate Scanworlds™ using HDS targets were calculated (Table 7.5).

---

#### Same date bank-to-bank HDS target registrations

| Date and location | Minimum positional error (m) | Maximum positional error (m) |
|-------------------|------------------------------|------------------------------|
|-------------------|------------------------------|------------------------------|

---

|                            |  |  |
|----------------------------|--|--|
| <i>Northern Midlington</i> |  |  |
|----------------------------|--|--|

---

|                            |       |       |
|----------------------------|-------|-------|
| 22/03/11                   | 0.001 | 0.001 |
| 13/05/11                   | 0.001 | 0.002 |
| 31/08/11                   | 0.003 | 0.003 |
| 04/10/11                   | 0.001 | 0.002 |
| <i>Southern Midlington</i> |       |       |
| 22/03/11                   | 0.001 | 0.002 |
| 13/05/11                   | 0.000 | 0.000 |
| <i>Tichborne</i>           |       |       |
| 03/11/11                   | 0.045 | 0.123 |
| 01/12/11                   | 0.089 | 0.204 |

**Table 7.5. Positional errors in bank-to-bank registrations.**

The positional errors resulting from the registration of Scanworlds™ taken on different dates, and registered using fixed control points, were also calculated (Table 7.6).

| <b>Different date control point registrations</b> |                              |                              |
|---------------------------------------------------|------------------------------|------------------------------|
| Date and location                                 | Minimum positional error (m) | Maximum positional error (m) |
| <i>Northern Midlington</i>                        |                              |                              |
| 22/03/11-13/05/11                                 | 0.002                        | 0.002                        |
| 22/03/11-31/08/11                                 | 0.010                        | 0.053                        |
| 22/03/11-04/10/11                                 | 0.003                        | 0.006                        |
| 13/05/11-31/08/11                                 | 0.015                        | 0.042                        |
| 13/05/11-04/10/11                                 | 0.005                        | 0.007                        |
| 31/08/11-04/10/11                                 | 0.029                        | 0.043                        |
| <i>Southern Midlington</i>                        |                              |                              |
| 22/03/11-13/05/11                                 | 0.002                        | 0.007                        |
| <i>Tichborne</i>                                  |                              |                              |
| 03/11/11-01/12/11                                 | 0.000                        | 0.001                        |

**Table 7.6. Positional errors in control point registrations.**

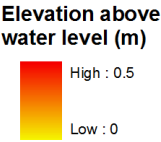
It is evident that there were different degrees of error between different scans. In particular, the positional errors of same date bank-to-bank registrations at the Tichborne site are relatively large and results derived from these scans contain a large degree of uncertainty. Conversely, errors at the northern and southern Midlington sites are small and results derived from these scans are likely to provide the most representative digital elevation models.

Positional errors occur for several reasons. Although HDS targets are static, if they are not properly secured they can move in the wind, creating inaccurate registrations. Rain and drizzle, which occurred during the laser-scanning conducted at the Tichborne site, can also affect the quality of registrations.

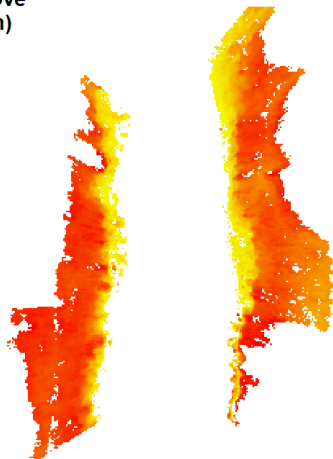
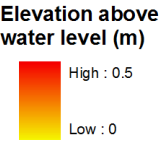
Errors are problematic not only in the initial analysis but in their propagation throughout analyses (Lichti, 2007; Wheaton *et al.*, 2010). A digital elevation model of difference incorporating two Scanworlds™ with pre-existing errors from control point registration will have a greater error than either Scanworld™ individually. Although it is not always possible to remove these errors, it is often possible to quantify them. In the subsequent sections, error margins for the net change in bank material volume are given. These are calculated by multiplying the maximum positional error values (Table 7.6) by the elevation values from each of the registered Scanworlds™ and then subtracting the original elevation values. Although simplistic in assuming a spatially uniform error, this method is less time consuming and computationally demanding than techniques involving probabilistic thresholding (e.g. Wheaton *et al.*, 2010).

#### *7.5.3.2. Northern Midlington site*

Terrestrial laser-scans of river bank topography were taken on four separate dates (Figure 7.14).



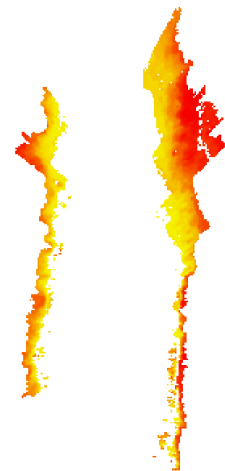
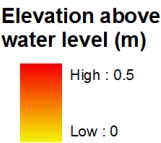
0 3 6 12 Meters



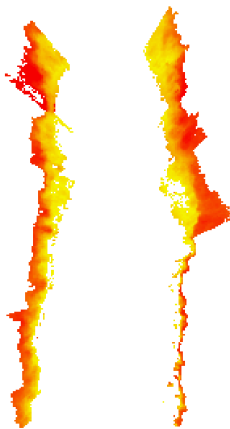
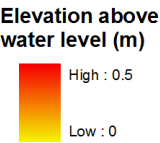
0 3 6 12 Meters

A

B



0 3 6 12 Meters



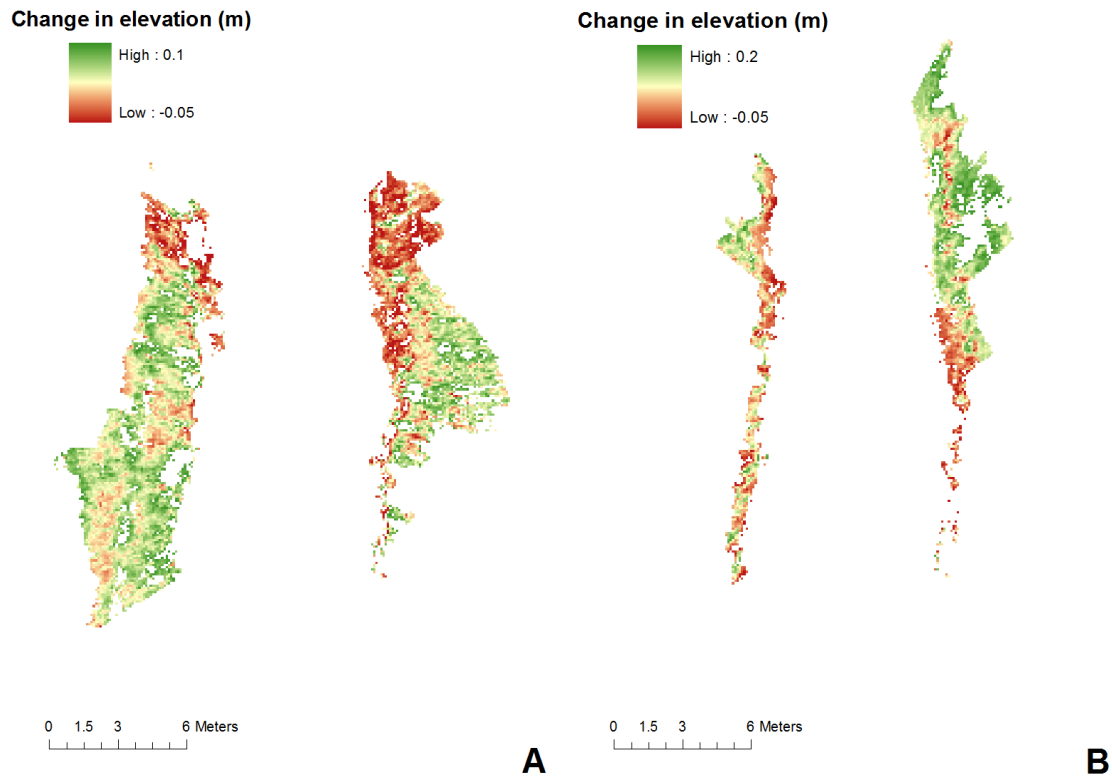
0 3 6 12 Meters

C

D

**Figure 7.14. Digital elevation models of river bank elevation as derived from a terrestrial laser-scanner. Elevation is given as the elevation above the level of river flow. Scans from four different dates are shown (A = 22/03/11, B = 13/05/11, C = 31/08/11, D = 04/10/11).**

Laser-scans from the four different dates, superimposed upon one another, revealed changes in river bank elevation over time (Figure 7.15).



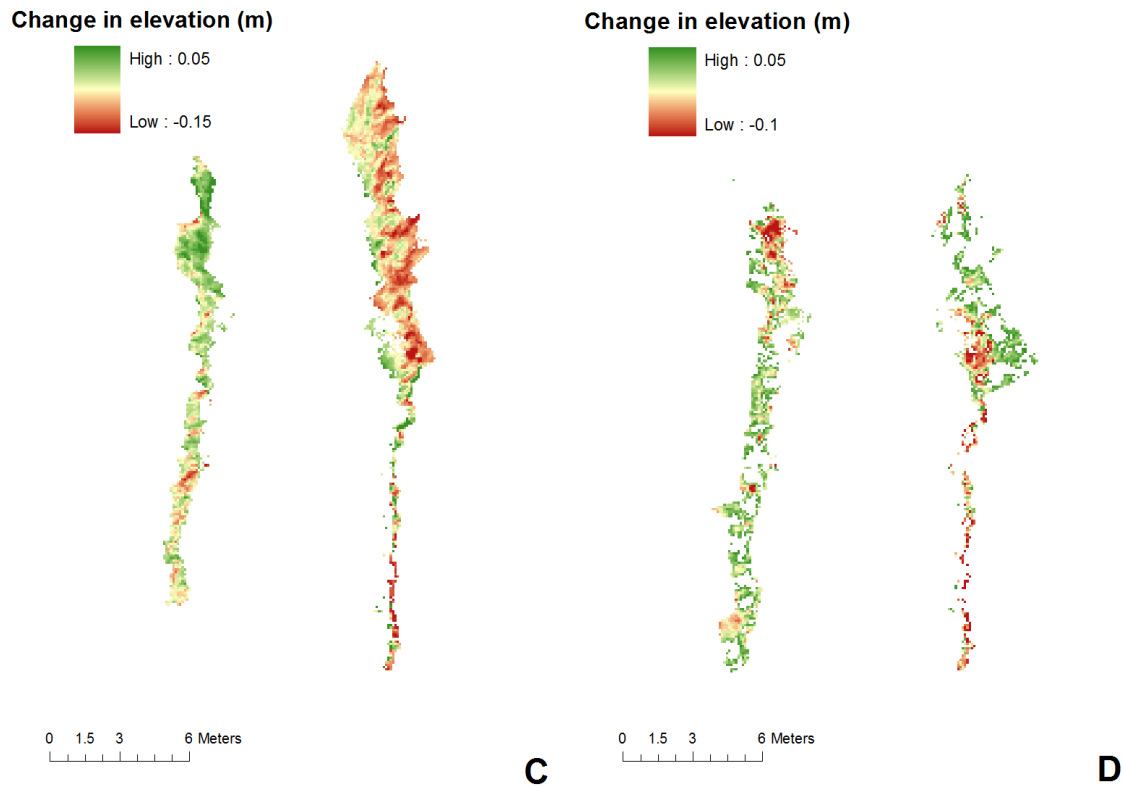
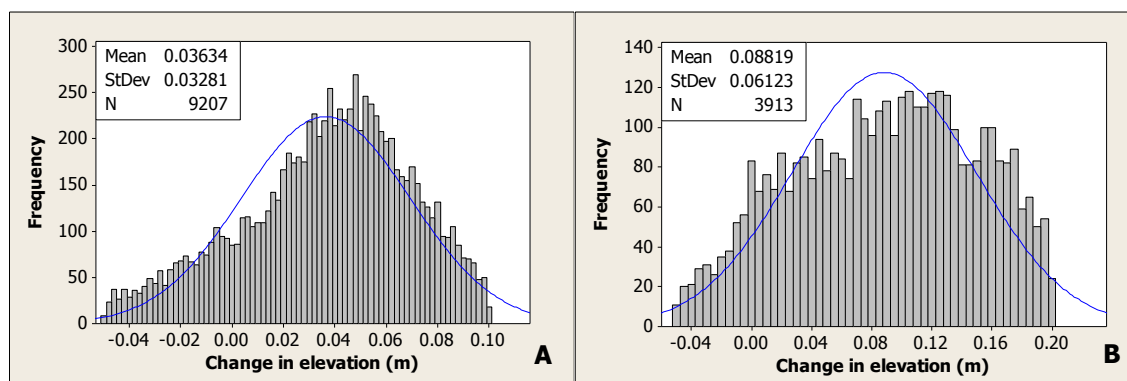


**Figure 7.15. Digital elevation models showing changes in river bank elevation over time as derived from a terrestrial laser-scanner. Scans of four different comparisons are provided (A = 22/03/11 to 13/05/11, B = 13/05/11 to 31/08/11, C = 31/08/11 to 04/10/11, D = 22/03/11 to 04/10/11).**

The changes in river bank elevation observed were spatially heterogeneous and variable over time. As well as showing changes in river bank morphology resulting from the displacement and removal of river bank material, laser-scans also revealed changes in the absolute mass of the river bank (Figure 7.16).



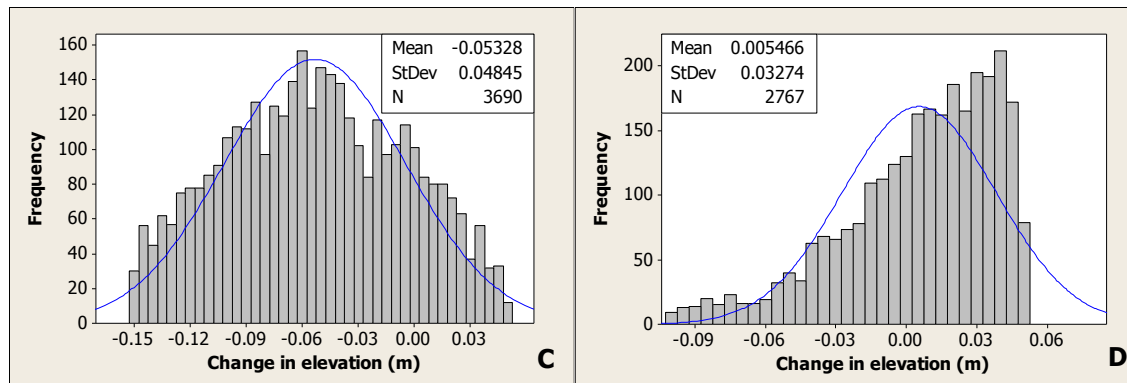


**Figure 7.16. Histograms of elevation change between Scanworlds™ taken on different dates. Data for four different comparisons are provided (A = 22/03/11 to 13/05/11, B = 13/05/11 to 31/08/11, C = 31/08/11 to 04/10/11, D = 22/03/11 to 04/10/11). Gaussian curves are displayed.**

The net change in raster map elevation between 22/03/11 and 13/05/11 suggests an estimated volume change of  $3.35 \pm 0.18 \text{ m}^3$ ; an average increase in elevation of approximately  $0.03 \pm 0.002 \text{ m}$  per pixel.

The net change in raster map elevation between 13/05/11 and 31/08/11 suggests an estimated volume change of  $3.45 \pm 1.64 \text{ m}^3$ ; an average increase in elevation of approximately  $0.09 \pm 0.042 \text{ m}$  per pixel.

The net change in raster map elevation between 31/08/11 and 04/10/11 suggests an estimated volume change of  $-1.97 \pm 1.58 \text{ m}^3$ ; an average decrease in elevation of approximately  $0.05 \pm 0.043 \text{ m}$  per pixel.

The net change in raster map elevation between 22/03/11 and 04/10/11 suggests an estimated volume change of  $0.15 \pm 0.167 \text{ m}^3$ ; an average increase in elevation of approximately  $0.005 \text{ m} \pm 0.006 \text{ m}$  per pixel.

### 7.5.3.3. Southern Midlington site

Terrestrial laser-scans of river bank topography were taken on two separate dates (Figure 7.17).



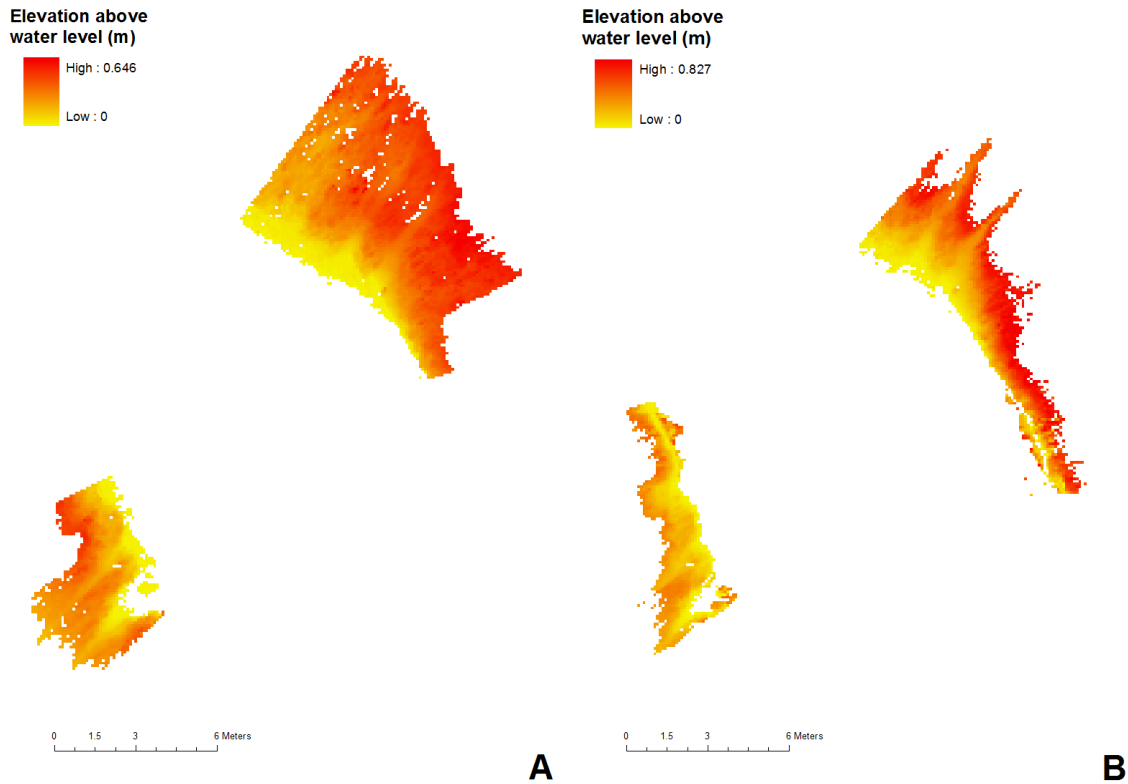


**Figure 7.17.** Digital elevation models of river bank elevation as derived from a terrestrial laser-scanner. Elevation is given as the elevation above the level of river flow. Scans from two different dates are shown (A = 22/03/11, B = 13/05/11).

Laser-scans from the different dates, superimposed upon one another, revealed changes in river bank elevation over time (Figure 7.18).



**Figure 7.18. Digital elevation model showing changes in river bank elevation between 22/03/11 and 13/05/11 at the Southern Midlington site.**

The net change in raster map elevation between 22/03/11 and 13/05/11 at the Southern Midlington site suggests estimated volume change of  $-0.18 \pm 0.11 \text{m}^3$ ; an average decrease in elevation of approximately  $0.01 \pm 0.007 \text{m}$  per pixel (Figure 7.19). As the only site where scans were taken without the effects of vegetation, these results are the most representative of the effects of cattle upon river bank topography.

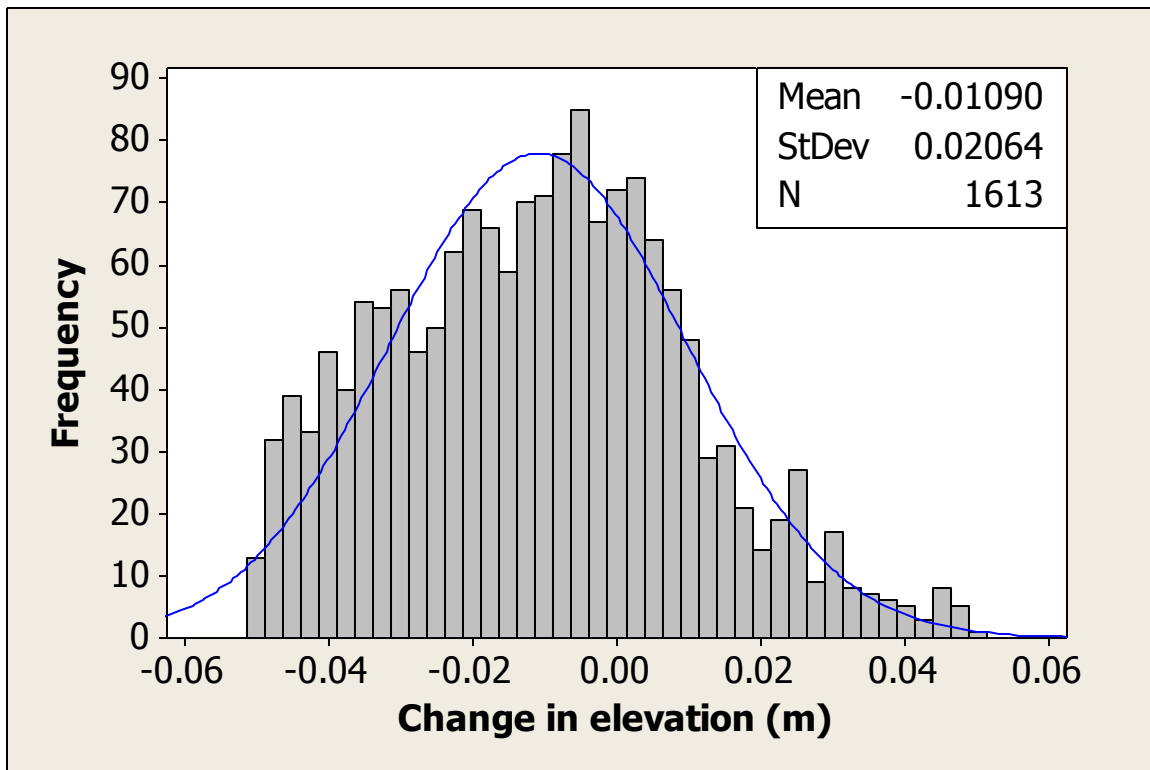


**Figure 7.19. Histogram of elevation change between 22/03/11 and 13/05/11 at the Southern Midlington site.**

#### 7.5.3.4. Tichborne site

Terrestrial laser-scans of river bank topography were taken on two separate dates (Figure 7.20).

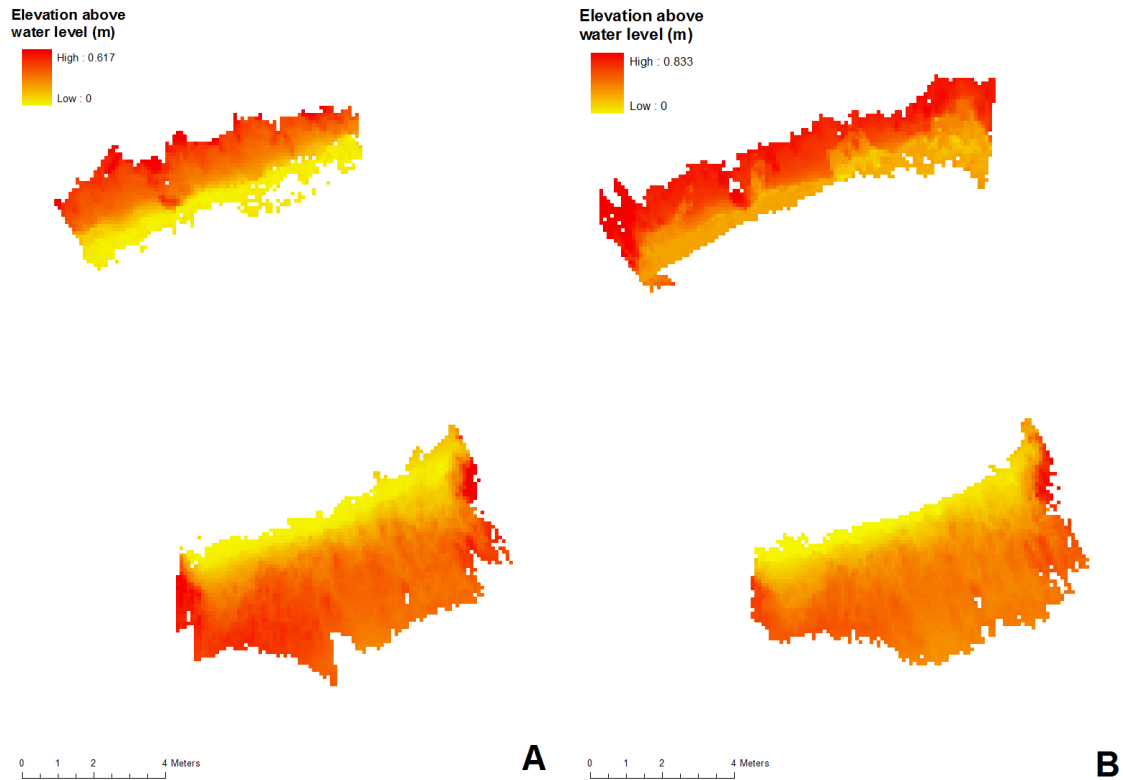


**Figure 7.20. Digital elevation models of river bank elevation as derived from a terrestrial laser-scanner. Elevation is given as the elevation above the level of river flow. Scans from two different dates are shown (A = 03/11/11, B = 01/12/11).**

Laser-scans from the different dates, superimposed upon one another, revealed changes in river bank elevation over time (Figure 7.21).

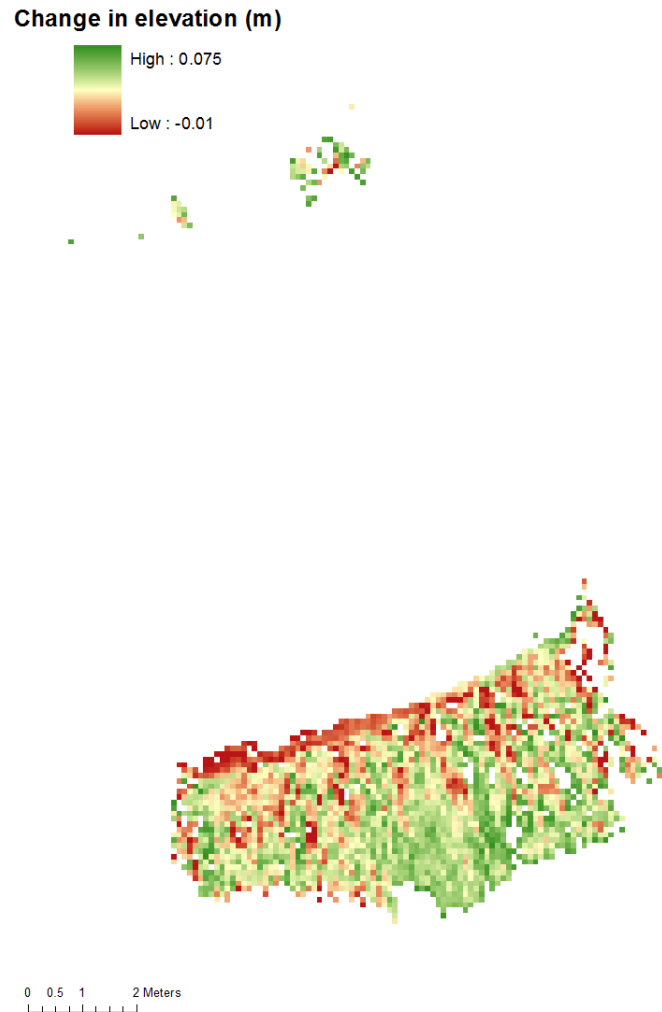


**Figure 7.21. Digital elevation model showing changes in river bank elevation between 03/11/11 and 01/12/11 at the Tichborne site.**

The net change in raster map elevation between 03/11/11 and 01/12/11 at the Tichborne site suggests an estimated volume change of  $1.13 \pm 0.03 \text{ m}^3$ ; an average increase in elevation of approximately  $0.04 \pm 0.001 \text{ m}$  per pixel (Figure 7.22).

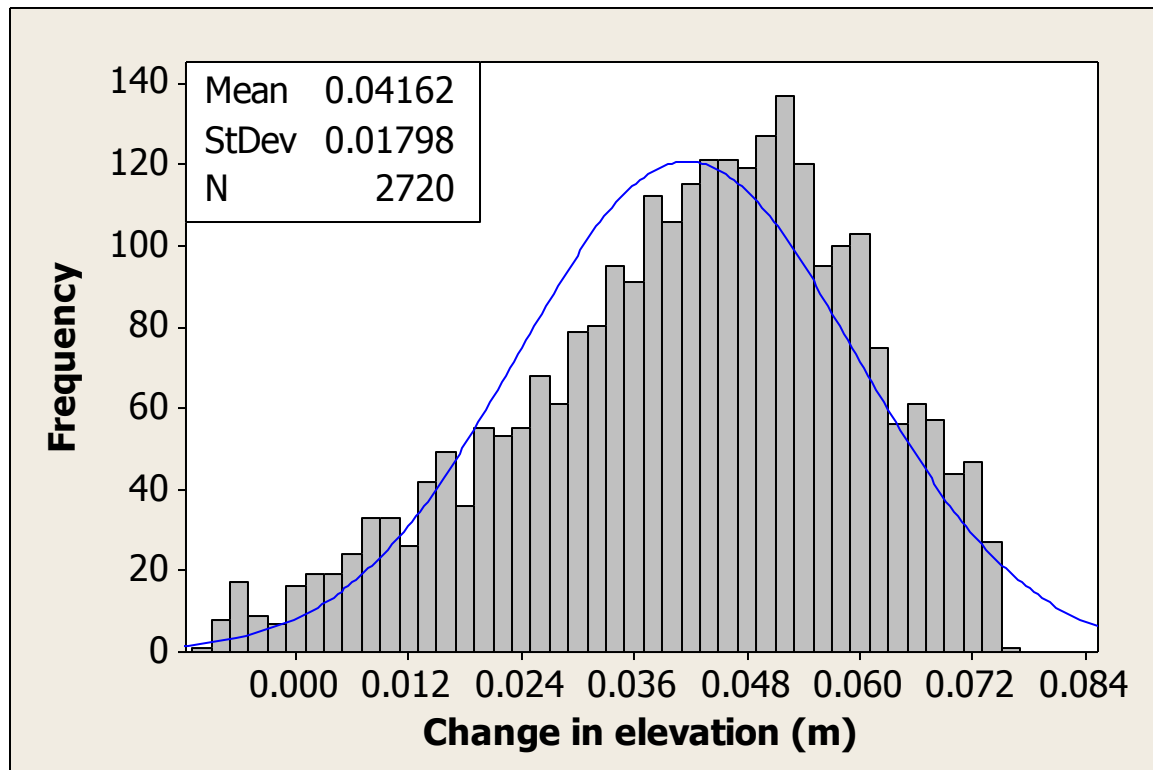


Figure 7.22. Histogram of elevation change between 03/11/11 and 01/12/11 at the Tichborne site.

#### 7.5.4. Discussion

##### 7.5.4.1. Positional errors

A minority of scans recorded high positional inaccuracies that inhibited the derivation of accurate digital elevation models. Scans taken on 31/08/11 had the greatest bank-to-bank positional error of any scans taken at the Northern Midlington site, with the largest date-to-date errors also. In some instances the maximum positional error exceeded the absolute change recorded between scans taken on 31/08/11 and other dates. As such the digital elevation models generated through the comparison of the 31/08/11 scan and scans from other dates are not necessarily accurate.

At the Tichborne site the maximum bank-to-bank positional error was 0.123m on 03/11/11 and 0.204m on 01/12/11. To negate these positional errors it was necessary to remove the majority of the elevation pixels on the northern bank. Although this led to the loss of over a third of the pixels from the original digital elevation models, the resultant output maps have reduced positional error.

#### *7.5.4.2. Vegetation effects*

The presence of vegetation limited the effectiveness of using the terrestrial laser-scanner for measuring changes in river bank elevation over time. Numerous studies have highlighted the problems caused by unwanted vegetation pixels captured within laser-scans (e.g. Jaselskis *et al.*, 2005; Lichti, 2005, Lim and Suter, 2009). Further studies have proposed methods and tools for vegetation removal from point clouds, including angle of repose filters (Nield and Wiggs, 2011), grid-based elevation filters (Coveney and Fortheringham, 2011) and slope-adaptive filters (Bremer and Sass, 2012). Nonetheless, unwanted, dense ground vegetation remains difficult to remove.

Despite the manual removal of unwanted pixels in Cyclone, the application of a minimum elevation filter, and the omission of elevation change outliers, the majority of laser-scans captured changes in vegetation height rather than bank elevation. This is particularly evident at the Northern Midlington site where between laser-scans taken on the 22/03/11 and 31/08/11 the estimated change in volume was  $6.8\text{m}^3$ . Such a large change cannot be confidently attributed to any geomorphic agent and likely represents growing vegetation and increasing sward height over this period. Similarly, the negative volume estimation between 31/08/11 and 04/10/11 is thought to be a function of grass and other vegetation dying back as the growing season ends.

The digital elevation model of difference at the Southern Midlington site, where only unvegetated areas of the river bank were laser-scanned, negated vegetation effects, and is the most representative of the effects of cattle upon river bank topography.

#### *7.5.4.3. Data conversion and changing scales*

The conversion of data from a laser-scanning resolution of 0.002m to an output raster resolution of 0.1m produced simplified river bank topography maps. The value of individual pixels is derived from the mean value of adjacent data points. Reducing the resolution of the data reduced the time taken for analysis by 80% and improved the

likelihood that analysis would be complete; a lack of computational power and data storage space caused ArcGIS to frequently crash when using the larger, original dataset. Although these maps still accurately quantify net changes in the absolute volume of scanned river banks, they lack the detail captured by the original laser-scans. Hence, the raster maps produced may underestimate the spatial variability in river bank elevation.

#### *7.5.4.4. Geomorphic agency by cattle*

Of those laser-scans in which a distinction can be made between changes in bank elevation and changes in vegetation height, there is evidence of geomorphic agency by cattle. Scans between 22/03/11 (prior to cattle introduction) and 13/05/11 (approximately one month after cattle introduction) at the Southern Midlington site suggest a net volume decrease of  $0.18 \pm 0.11 \text{m}^3$  across a  $16 \text{m}^2$  area of river bank. Whether such a change is solely attributable to cattle is unclear as hydrological and hillslope processes will have occurred concurrently. Although scans from the Tichborne site, taken in the absence of cattle, suggest that natural processes can cause detectable geomorphic change across cow ramps, the high positional inaccuracy means output maps from this location should be used with caution. Nonetheless, the inference that cattle activity may have removed up to  $0.18 \pm 0.11 \text{m}^3$  of river bank material is plausible, particularly given the capacity for cattle to cause shear stress (section 7.4).

The scans taken between 22/03/11 (prior to cattle introduction) and 04/10/11 (after cattle removal) at the Northern Midlington site suggest relatively little change in river bank volume over a six month period of cattle grazing. Contrary to the Southern Midlington site the net volume of river bank at the Northern Midlington site increased by  $0.15 \pm 0.167 \text{m}^3$ , albeit over a longer time period and in the presence of vegetation effects. Although identifying any clear pattern in elevation change is difficult, it appears the greatest erosion occurred near the water's edge whilst the greatest deposition occurred further away from the river. Cattle removed river-adjacent bank material by applying shear stress when moving between the aquatic and riparian zones and causing bank collapse. However, cattle also added material to the riparian zone by transporting it from the terrestrial zone and through defecating. The process of material movement induced by



cattle at this river bank is similar to mass movement due to hillslope processes, only accentuated (Figure 7.23).

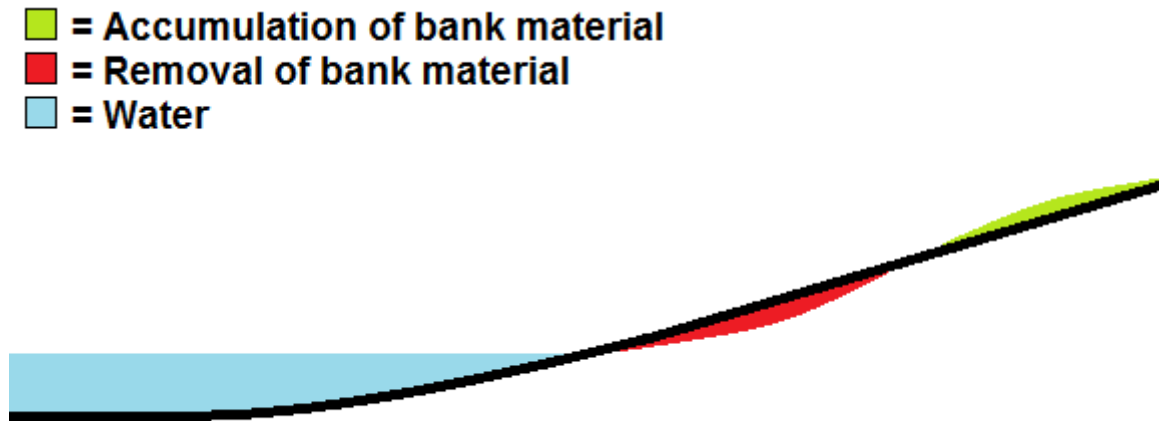


**Figure 7.23.** A sketch of general changes in river bank elevation due to cattle as informed by terrestrial laser-scans from the Northern Midlington site.

It is evident across all sites that the displacement and removal of bank material by cattle is not spatially homogeneous, and that the presence of cattle increases river bank elevation heterogeneity. Laser-scans show that cattle do not simply cause bank destabilisation, erosion and the removal of material from the river bank. Cattle can deposit mud and soil from the terrestrial environment along the river bank, as well as organic matter in the form of faeces.

### **7.5.5. Conclusion**

Limitations in using high spatial resolution laser-scanning for detecting changes in river bank topography were identified. Dense vegetation prevented the accurate derivation of digital terrain models, whilst the positional errors inherent in registering scans taken at different times hindered temporal comparisons. Care should be taken in the future employment of terrestrial laser-scanners when attempting to measure changes in channel morphology across vegetated surfaces.

Nonetheless, terrestrial laser-scans of river bank crossing points subject to cattle activity revealed changes in river bank topography over time. As well as absolute changes in the estimated river bank volume, periodic laser-scans also showed increased spatial heterogeneity in river bank elevation. Laser-scans from a location devoid of vegetation suggest a net decrease in river bank volume of  $0.18\text{m} \pm 0.11\text{m}^3$  over a six week period, whilst laser-scans from another, wider, vegetated crossing point suggest a net increase in river bank volume of  $0.15 \pm 0.167\text{m}^3$  over a six month period. It is suspected that in areas containing vegetation the laser-scanner was unable to distinguish between temporal changes in sward height and temporal changes in bank height, despite post-processing and the application of minimum elevation filters to the data.

The study suggests the principle geomorphic agency of cattle upon river banks is the removal, introduction and redistribution of river bank material. The over-riding implication is that cattle will enhance heterogeneity in river bank structure and morphology. In chalk stream environments, where there is relatively little background geomorphic work upon river banks, cattle could act as the dominant forcing locally. Although the amount of bank erosion caused by cattle may seem small, in the context of a river system in which overbank flows are seldom, the consequences of allowing cattle to graze at the river bank may accumulate over time. Given the inability of chalk streams to reassert their natural form, it is probable that many of the cow ramps observed during this study would maintain their form even if cattle were prevented from grazing in these locations in the future. The implication is that in the long-term cattle may alter channel planform, and river managers and graziers should be conscious of the potential geomorphological consequences of allowing cattle access to chalk streams.

## **7.6. In-stream turbidity and in-stream cattle activity**

### **7.6.1. Introduction**

One of the most often cited and relatively well understood impacts of cattle upon rivers is the changes that are induced in river water quality (Hubbard *et al.*, 2004; Neal *et al.*, 2006). Water quality is especially important in chalk stream environments, where the survival of native species is dependent upon specific in-stream conditions (Mainstone,

1999). Although many species will tolerate some variance in these conditions, significant changes in water temperature, dissolved oxygen content and turbidity have been demonstrated to induce mortality and changes in behaviour in aquatic chalk stream species (Greig *et al.*, 2005; Riley *et al.*, 2011; Dorts, 2012). Moreover, for many species the range of tolerable conditions, as well as the habitat optima, is known. For example, acceptable concentrations of fine sediment and dissolved oxygen, as well as temperature, have been quantified for the major chalk stream fish species (Kondolf, 2000; Armstrong *et al.*, 2003; Kemp *et al.*, 2011). Consequently, by measuring water quality it is possible to establish whether a particular river reach would provide suitable conditions for particular species (Neal *et al.*, 2000; Prior and Johnes, 2002).

Several studies have considered the differences in water quality between sites and reaches subject to cattle grazing and those that are not (e.g. Gary *et al.*, 1983). However, the effects of these differences in the context of grazing pressure (the number of cattle per unit area per unit time) are not known, and the changes immediately effected in water quality following an in-stream cattle event remain unknown. There has been no consideration of the antecedent conditions in the study environments, nor the role of seasonality and catchment-scale processes in influencing water quality.

It was therefore the aim of this study to accurately quantify the changes in stream conditions brought about by cattle access by focusing upon instances of in-stream activity. In-stream sensors were used to measure a number of water quality variables that were suspected to change during, and, in the aftermath of in-stream cattle events. By placing probes downstream of a cattle access feature, and then attributing changes in water quality to cattle (validation through the use of GPS collars), it was hoped that our understanding of the impact of cattle upon water quality could be improved.

## **7.6.2. Methods**

### **7.6.2.1. Fieldwork**

A turbidity probe, which was operational between September and November 2011, was installed downstream of the crossing point at the Tichborne site. Attached to a fence that

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bridged the downstream section of the crossing, the submerged probe was suspended 0.5m above the stream bed. The probe was connected to a data logger, which recorded in-stream turbidity once every minute.

At the same time, three cattle with access to the crossing point were equipped with individual AgTrax LD2 GPS collars. The collars, detailed in section 6.2, were used to determine when cattle were in-stream. By having the in-stream probe and the AgTrax LD2 GPS collars activated simultaneously, it was possible to identify any associations between water turbidity and cattle activity within the river i.e. does the timing of peaks in turbidity relate to instances of aquatic environment utilisation by cattle?

#### *7.6.2.2. Equipment*

An Analite NEP 390 series turbidity probe was used for the experiment (Figure 7.24). The NEP 390 probe, which measures between the range of 0 and 1000 NTU's (nephelometric turbidity units), uses a 90° infra-red technique (specification ISO7027) to measure turbidity. The probe is precise to  $\pm 0.6$  NTU, with an error of between <1% and 3%; error is generally greater with increased turbidity.

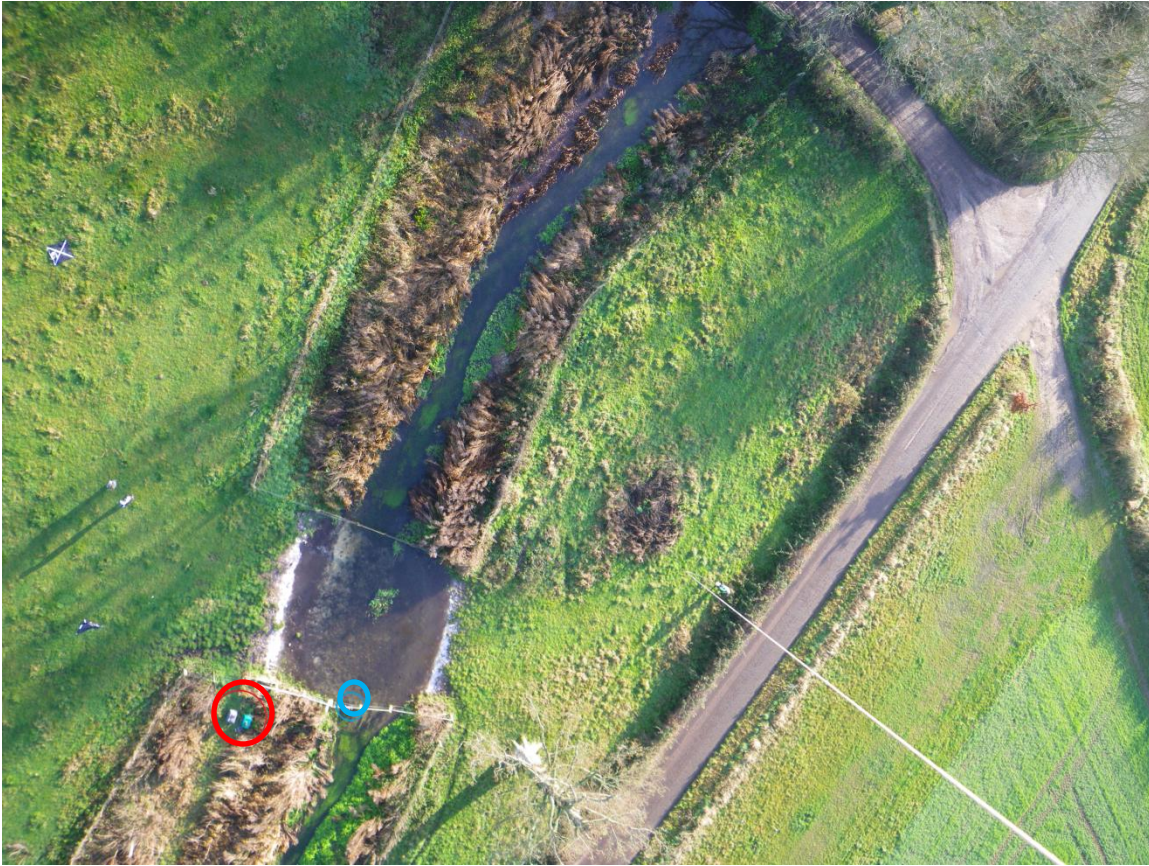


**Figure 7.24.** The cattle crossing point at the Tichborne site. The location of the data logger (circled in red) and the turbidity probe (circled in blue) are shown.

The turbidity probe was connected to a Delta-T DL2e data logger (Figure 7.25). The data logger was programmed to record a turbidity measurement once a minute, on the minute; the highest recording frequency possible with the Delta-T DL2e. Data were downloaded from the data logger once a week. For security and to prevent the data logger from getting wet, the Delta-T was housed in a padlocked, waterproofed casing.



**Figure 7.25. The Delta-T DL2e data logger.**

#### *7.6.2.3. Calibration*

The NEP 390 turbidity probe was initially calibrated using a formazin turbidity standard. Different concentrations of the standard, ranging from 1NTU to 250NTU, were placed into a litre amber container. Turbidity probes were inserted at each concentration and the output of the probes (in mV) measured. NTU and turbidity probe output were then plotted to produce a calibration curve that provided the basis for measuring in-stream fine sediment concentrations once the probes were installed (Figure 7.26).



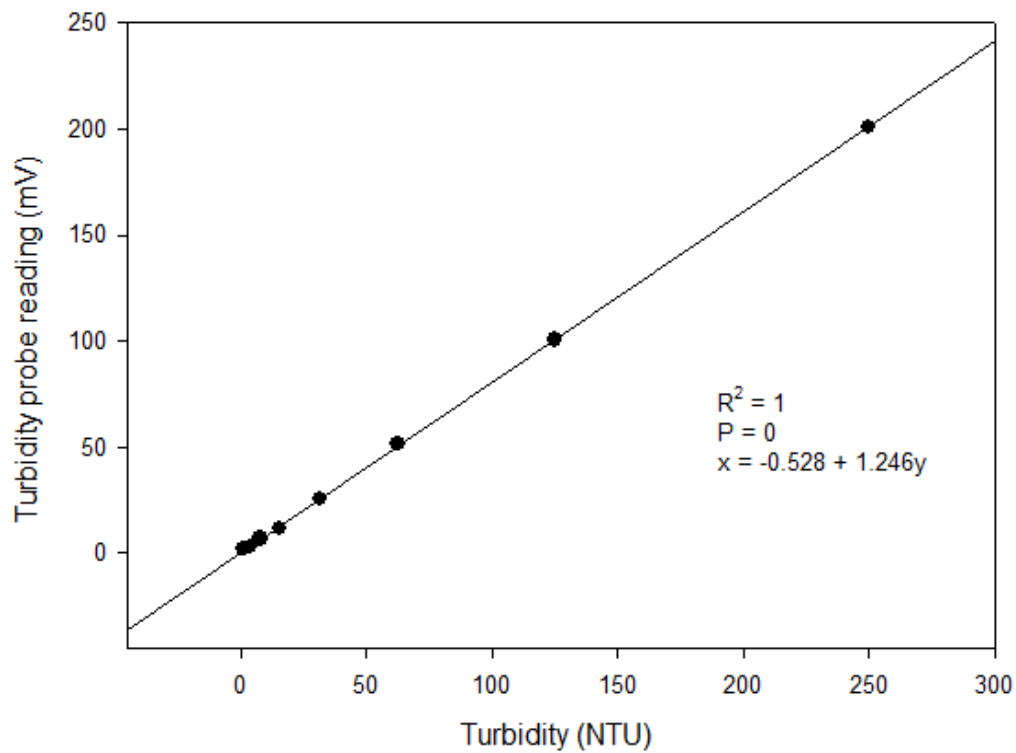


**Figure 7.26.** Calibration of the NEP 390 turbidity probe using known concentrations of a formazin turbidity standard.

To calibrate the probe for in-field usage, the NEP 390 was inserted into buckets with known concentrations of fine sediment, ranging from  $1\text{mg l}^{-1}$  to  $500\text{mg l}^{-1}$ , and output values were recorded. A calibration curve that links output values with fine sediment concentrations was produced (Figure 7.27)

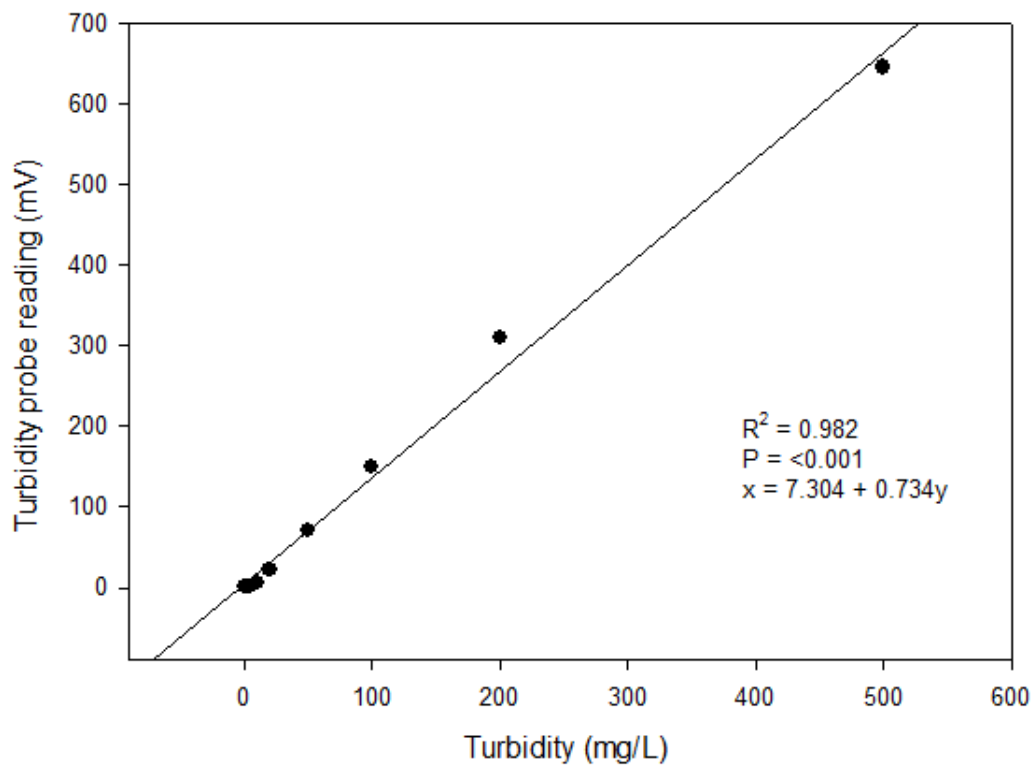


**Figure 7.27.** Calibration of the NEP 390 turbidity probe using known concentrations of fine sediment.

#### 7.6.2.4. Analysis

Turbidity in milligrams per litre was plotted against instances of in-stream cattle activity in mixed plot graphs. Discharge data for the Cheriton stream, recorded every 15 minutes at the Swards Bridge gauging station 500m downstream of the turbidity probe, were also plotted against turbidity and in-stream cattle activity events. Where data were clearly the function of noise resulting from the obstruction of the turbidity probe by weeds or other in-stream debris, they were omitted from the final analysis.

#### 7.6.3. Results

In total 109,570 turbidity readings were recorded between 13:33 BST 01/09/11 and 10:55 GMT 21/11/11. During this time cattle collars were active for two periods: between 12:30 BST 07/09/11 and 23:30 23/09/11; and between 09:00 BST 11/10/11 and 15:31 GMT 29/10/11. After the removal of data containing noise, 25,412 turbidity values remained.



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The total number of GPS fixes over the period of turbidity monitoring was 86616 for September and 13573 for October. Of these fixes, 67 occurred in-stream during the period of turbidity monitoring (Figure 7.28).

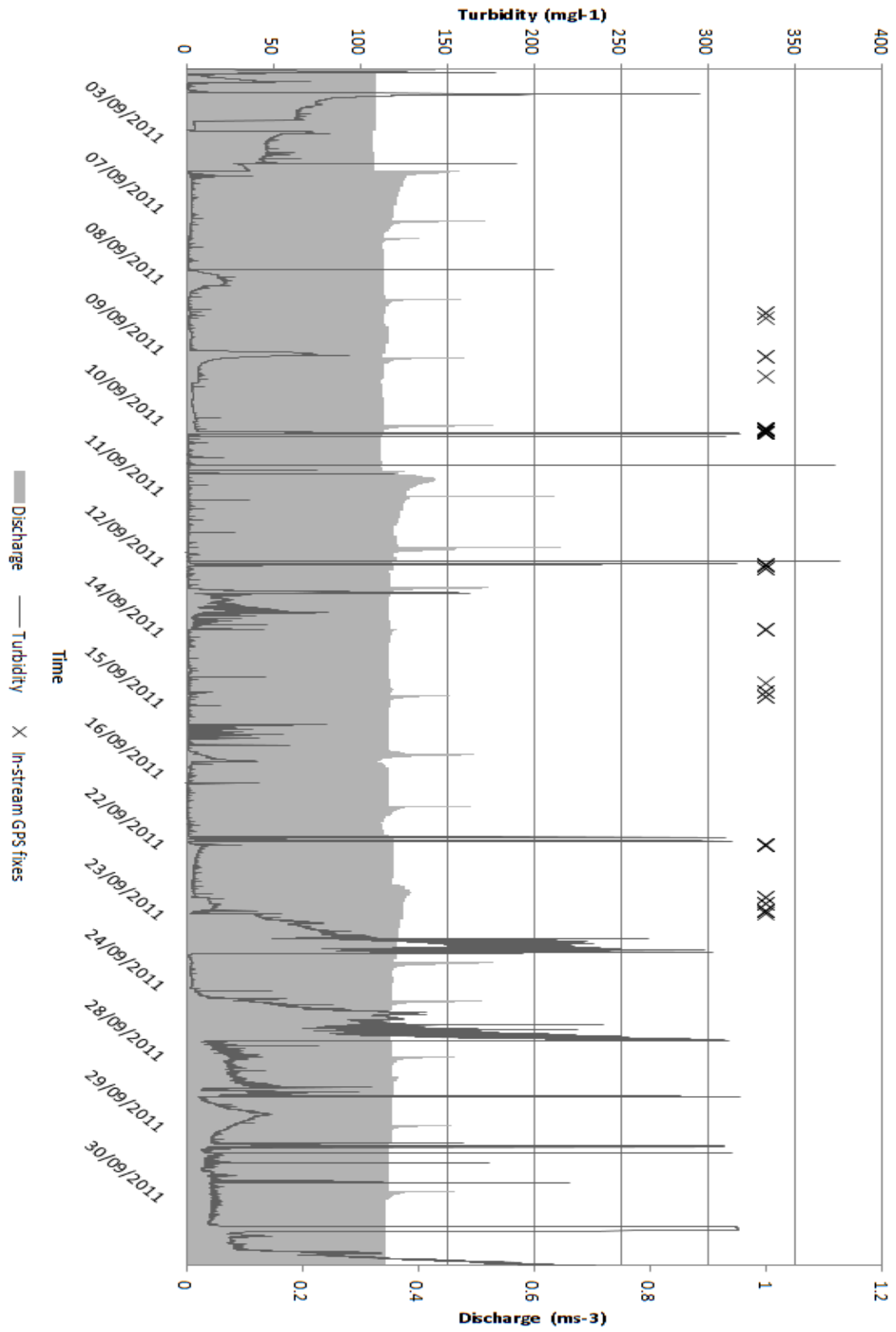


**Figure 7.28. Turbidity at the Tichborne study site between 07/09/11 and 23/09/11. Instances of in-stream cattle activity, as well as discharge values from the nearby Swards Bridge gauging stations, are shown.**

Turbidity readings varied within the limits of the equipment's range; between zero and  $370\text{mg l}^{-1}$ . Long periods of low turbidity were punctuated by comparatively short periods of high turbidity. A number of high turbidity events occurred immediately after peaks in discharge, such as the event on 13/09/2011, in which there was a seven minute lag between peak discharge and peak turbidity. However, there was not a statistically significant relationship between discharge and in-stream turbidity ( $r = -0.203$ ,  $N = 25412$ ,  $P > 0.05$ ).

A range of turbidity values were recorded during in-stream cattle events. However, the majority of in-stream cattle events were associated with relatively low turbidity values; over 80% of in-stream cattle events recorded turbidity concentrations of less than  $70\text{mg l}^{-1}$ . Of all the in-stream GPS fixes that correlated with an increase in turbidity, only one event is thought to be have been caused by cattle (Figure 7.29).

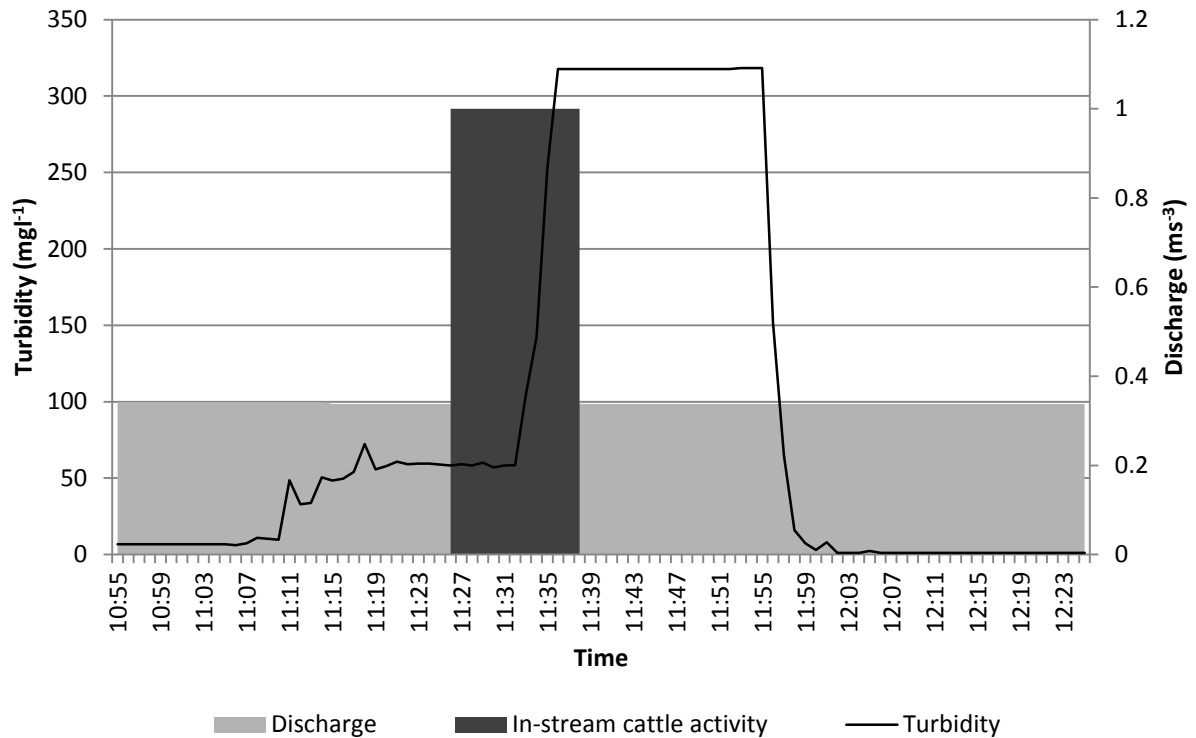


**Figure 7.29. A possible cattle-induced turbidity event on 10/09/2011.**

Turbidity rose sharply during the period of known in-stream cattle activity from an above base-value turbidity of approximately  $6\text{mg l}^{-1}$  to a peak of  $330\text{mg l}^{-1}$ . Peak turbidity was maintained for approximately 25 minutes, after which time turbidity fell as rapidly as it originally rose. Discharge was near constant at approximately  $0.342\text{ms}^{-3}$  during the turbidity event, and for 25 hours prior to the turbidity event discharge did not exceed  $0.349\text{ms}^{-3}$ .

#### 7.6.4. Discussion

Although there were a few instances of correlation between known periods of in-stream cattle activity and readings of high turbidity, generally turbidity did not increase with in-stream activity. More specifically, although there were correlations between known periods of in-stream cattle activity and high turbidity, there were many instances of apparent cattle access during which turbidity did not change at all.

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Whilst it is probable that in-stream cattle activity had no effect upon sediment mobilisation and hence turbidity in some instances, anecdotal evidence from the observational study suggests that a stronger association between turbidity and in-stream cattle activity should have been recorded. Nonetheless, there are a number of plausible explanations as to why this was not the case.

The experiment was limited methodologically. Because only a single turbidity probe was used there was no measure of sediment input into the experimental river reach. A second turbidity probe upstream of the first at the start of the cattle crossing would have simplified the process of correlating in-stream cattle access with turbidity, as well as provided useful quantitative data on sediment inputs and outputs within the reach. Although it was originally intended that two probes would be used in this manner, technical difficulties (a faulty connection) with the second probe prevented it from being used.

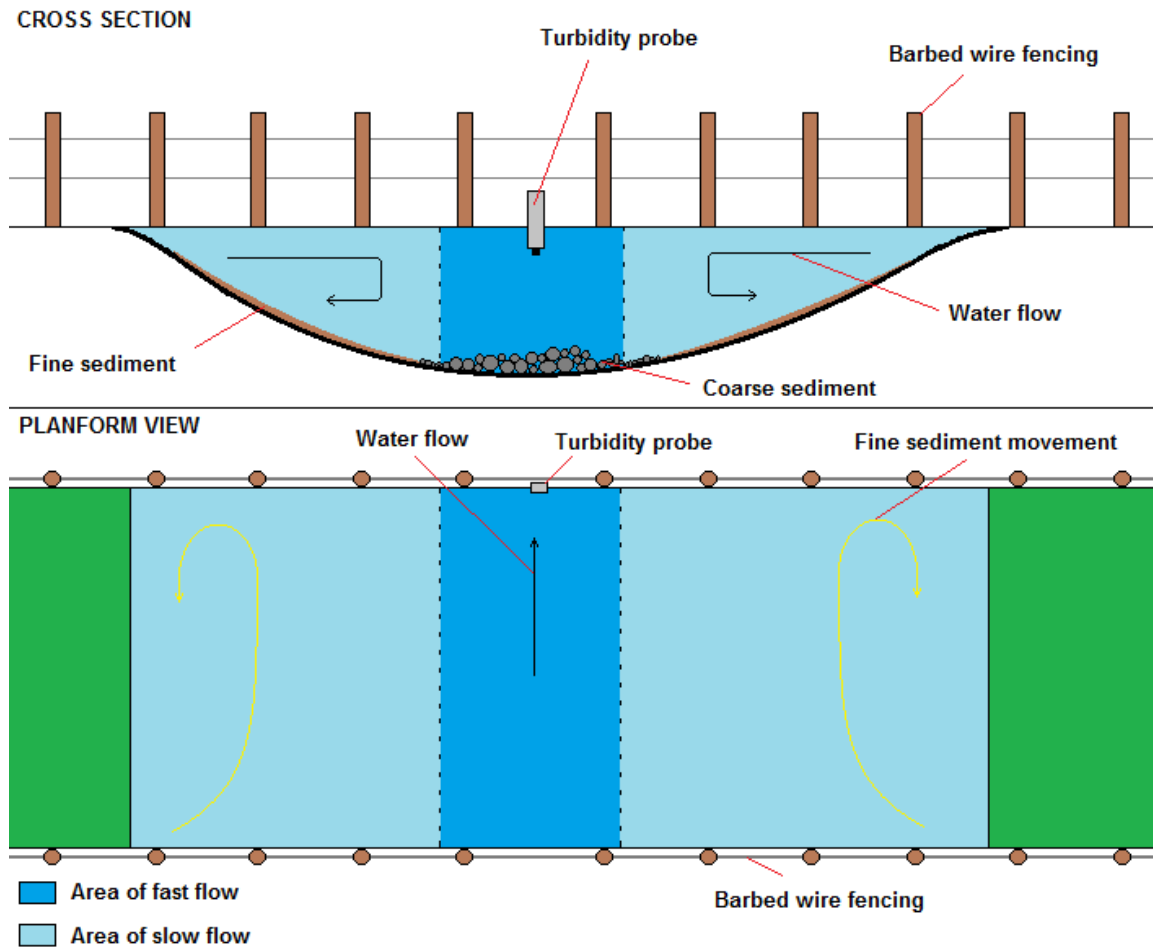


**Figure 7.30.** A schematic diagram of the River Tichborne cattle crossing point showing the location of the turbidity probe relative to in-stream features and processes.

The placement of the turbidity probe in the centre of the river channel 0.75m above the river bed was sub-optimal for measuring cattle-induced turbidity. Bed substrate, flow depth and flow velocity varied across the experimental reach such that areas of greatest fine sediment mobilisation were proximate to the river banks (Figure 7.30); only during large, prolonged cattle crossing events would there be sufficient bed substrate disruption and cattle-induced fluid mixing to entrain fine sediment in the area of fast flow. Moreover the effects of fine sediment suspension by cattle could be attenuated longitudinally. Sediment suspended by a small access event occurring in the upstream section of the reach would often become deposited before reaching the turbidity probe, whilst sediment disturbed by access events occurring near the river bank in the downstream reach often by-passed the turbidity probe.

A more effective methodology would have involved the installation of three probes in series along the downstream fence and three probes in series along the upstream fence. Such an arrangement would have captured a greater number of cattle access events providing useful data on the horizontal variability of turbidity and contingency in the likely event of debris interfering with turbidity probe readings.

Another limitation was horizontal accuracy of the GPS collars that were used to determine when cattle were in-stream. All data points with a horizontal accuracy of less than 10 metres were omitted from analysis and hence there are large periods of time when the turbidity probe was active but for which there is no reliable GPS data. Furthermore, it is possible that some turbidity events may have been caused by cattle but not attributed to cattle, either because GPS data for these events were unreliable and hence omitted, or because these events were caused by cattle without GPS collars.

It was evident from the data that cattle activity within the river channel was not the only cause of in-stream turbidity. There were several events whose turbidity profile mirrored a classic flood hydrograph, with a sudden peak in turbidity followed by a recessional limb. These events were associated with relatively high stream discharge and show that although chalk streams are comparatively unresponsive to rainfall, they do experience increased in-stream turbidity during elevated flows. Moreover, these events are associated with a greater net increase in turbidity over the course of the study than events thought to be caused by cattle.

#### **7.6.5. Conclusion**

Cattle caused relatively little in-stream turbidity in a combined GPS collar and turbidity sensor study. Evidence suggests that cattle can cause short-term (<30 minutes) increases in turbidity by mobilising fine in-stream bed sediment. Prolonged in-stream turbidity events were associated with increased stream discharge; a proxy for increased surface runoff suggesting that large turbidity events are caused by rainfall and subsequent overland flows. A number of in-stream turbidity increases were not attributed to a

specific cause and further research would attempt to establish the source of these. The results suggest that in-stream cattle activity has a minimal effect upon fine sediment mobilisation and that instead discharge events are the key cause of fine sediment transport in chalk streams.

This study has demonstrated the useful findings that can be obtained by correlating animal behaviour and environmental data sets; particularly where it is suspected there is a cause and effect relationship between two factors. Future work, which would incorporate additional logistical and ethical considerations (i.e. cattle welfare and finding an acquiescing livestock grazer), would involve the driving of cattle across a river and the measurement of water turbidity downstream at a number of points to capture both the absolute amount of suspended sediment and the attenuation of that sediment longitudinally.

Alternatively it may be possible to use one of several sediment tracing methods to identify the eventual sinks for the material mobilised by cattle during in-stream activity. It is possible that because cattle-induced fine sediment mobilisation is not necessarily associated with increased stream discharge, transport routeways for sediment moved in this way may be shorter, and sediment sinks closer, than sediment moved during elevated discharge events. Moreover, because of the tendency for cattle to defecate in-stream, any sediment moved due to cattle accessing the river may be combined with organic sediment from cattle faeces. As such understanding where fine sediment mobilised by cattle is deposited is important and should be the remit of further research.

## **7.7. Aerial photography**

### **7.7.1. Introduction**

Low-elevation, high-resolution aerial photography can be a useful research tool for geomorphologists (Marzloff and Poesen, 2009). Previous applications in fluvial (Lane, 2000; Vericat *et al.*, 2009), coastal (Richmond *et al.*, 2011) and glacial (Boike and Yoshikawa, 2003) geomorphology have demonstrated the potential of photogrammetry



and remote sensing to improve our understanding of form and process both quantitatively and qualitatively.

Recent developments in post-capture processing have reduced the time and effort required in georeferencing aerial images. Specifically, it is no longer essential to add a large number of control points in order to mesh two or more images together and create a map or digital elevation model (Xiang and Tian, 2011). A number of software programmes now exist in which it is possible to automatically generate an orthophoto without manual geocorrection (Xiang and Tian, 2011; Verhoeven *et al.*, 2012). Vision-based computer algorithms can search large image datasets to identify common points between images and even create high resolution digital elevation models (Verhoeven *et al.*, 2012).

Here we use low-elevation aerial photography taken from a Helikite-tethered blimp to generate composite images of cattle trails and cow ramps at the Tichborne site on the Cheriton stream.

### **7.7.2. Methods**

A Skyhook Helikite (Allsopp Helikites Limited) tethered, lighter-than-air blimp was used for this experiment (Figure 7.31). The blimp was filled with helium gas to provide lift. A programmed digital camera was secured to the base of the kite structure, facing downwards, so that low-elevation aerial photographs could be taken.



**Figure 7.31. The aerial blimp and kite with camera attached and trailing line visible (Photo courtesy of Simon Dixon)**



**Figure 7.32. An aerial photography target. Targets were held in place by a four three inch nails, one in each corner.**

40 white on black 1m<sup>2</sup> targets (Figure 7.32) were placed across the landscape in diagonal transects, with targets approximately 25m from each other (Figure 7.33). Targets were distributed into three patches, both to enhance the resolution of photo captures and to avoid overhead cables that inhibited the movement of the blimp and posed a risk to blimp pilots. In each patch the blimp was elevated to approximately 100 metres and walked in-between the targets. The digital camera was programmed to take 40 images in each patch, with an image taken once every 20 seconds (Figure 7.34). The camera was also programmed to delay for two minutes prior to the first photograph capture to allow time for the blimp to reach the desired elevation.

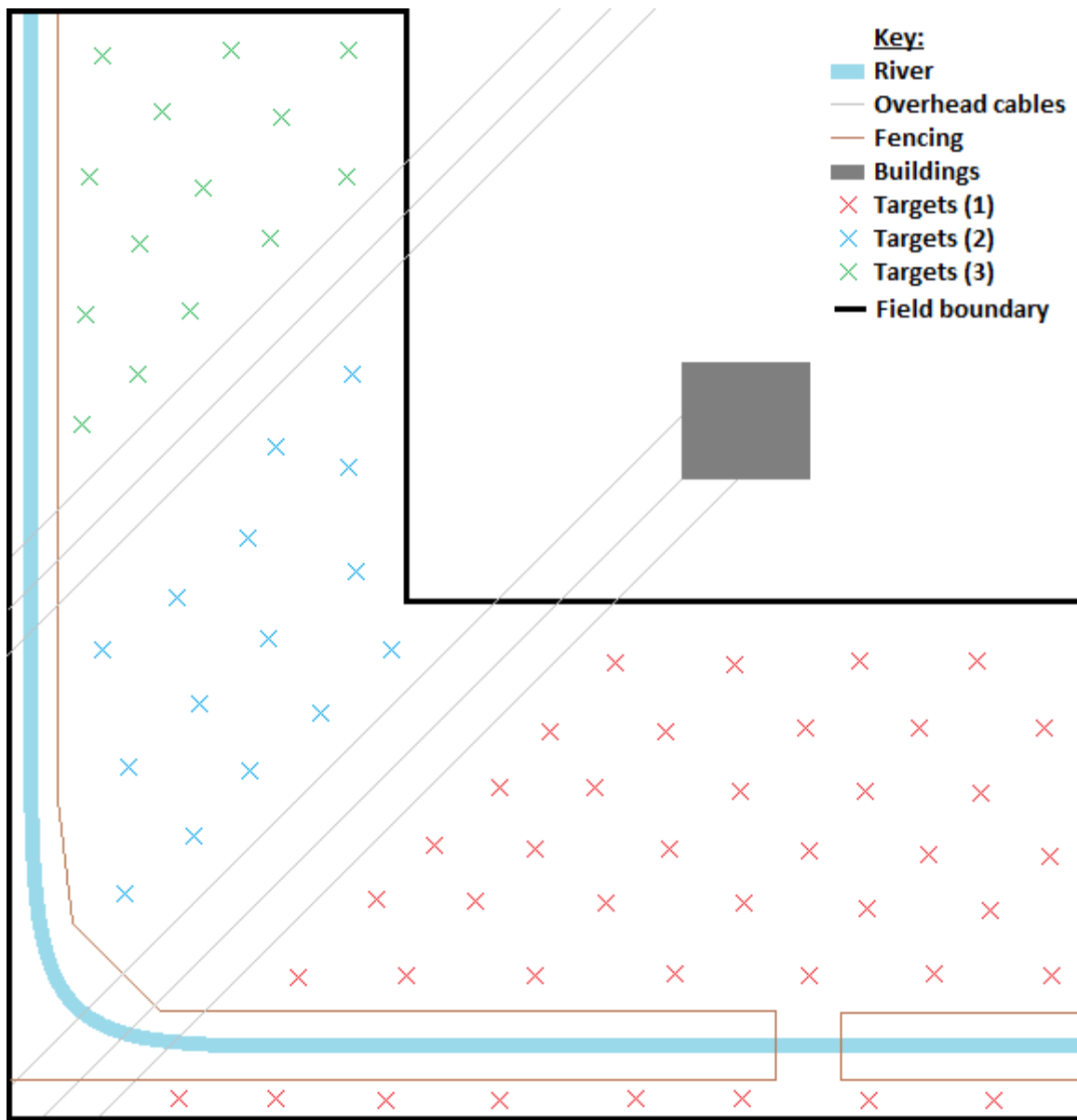


**Figure 7.33.** A sketch of target distribution for aerial photography at the Tichborne site.

Initial image processing involved the removal of poor quality photographs though visual inspection; blurred images and those without any targets were omitted. Thereafter, the remaining images were uploaded into the Agisoft PhotoScan (Professional Edition) software.





**Figure 7.34.** An example image taken from the helikite. Several black and white targets are visible.

Once uploaded, images within Agisoft Professional are placed into a three dimensional space relative to each other according to where the software thinks the images were taken from. A good collection of images taken from a consistent angle, height and orientation are arranged in alignment with each other along a similar spatial plane (Figure 7.35). A poor collection of images taken from different angles and heights are arranged haphazardly out of alignment with each other with no clear direction of orientation (Figure 7.36).

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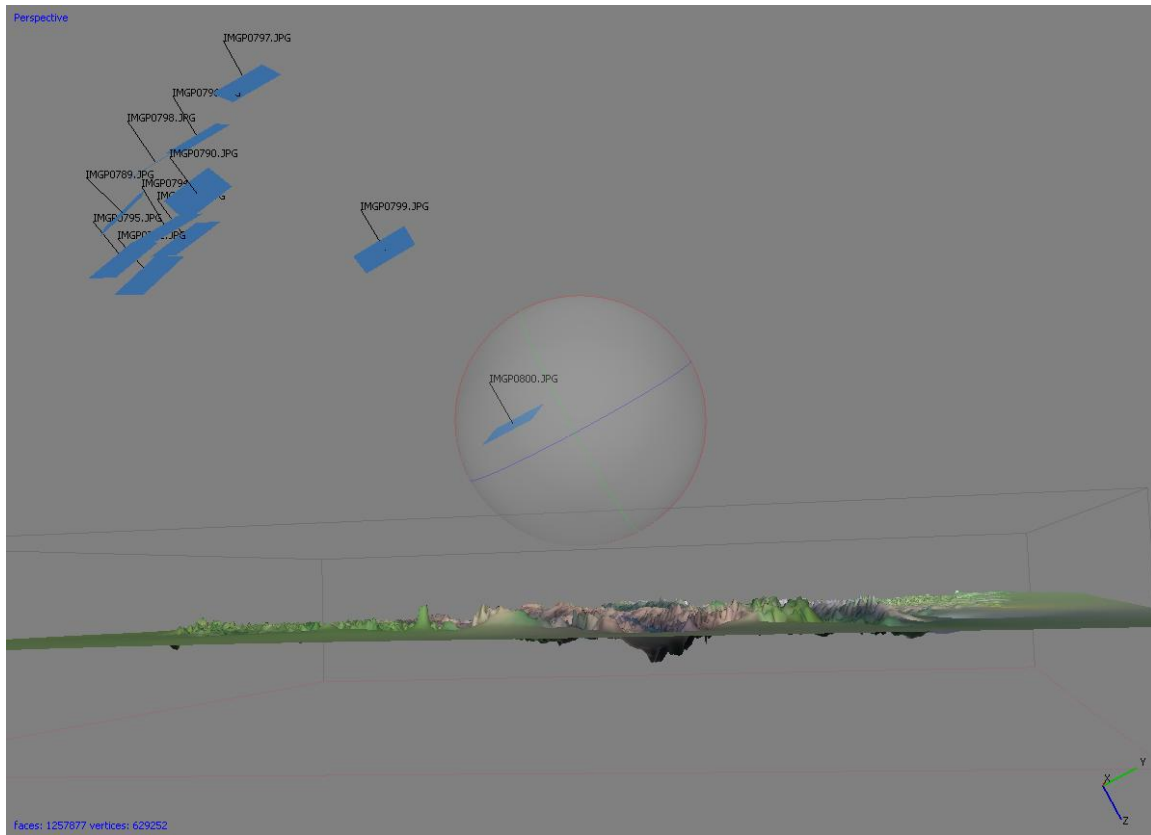


**Figure 7.35. A screenshot from Agisoft Professional. Images (blue squares) are arranged according to their relative positions at the top left of the figure. Note their consistent orientation and alignment.**

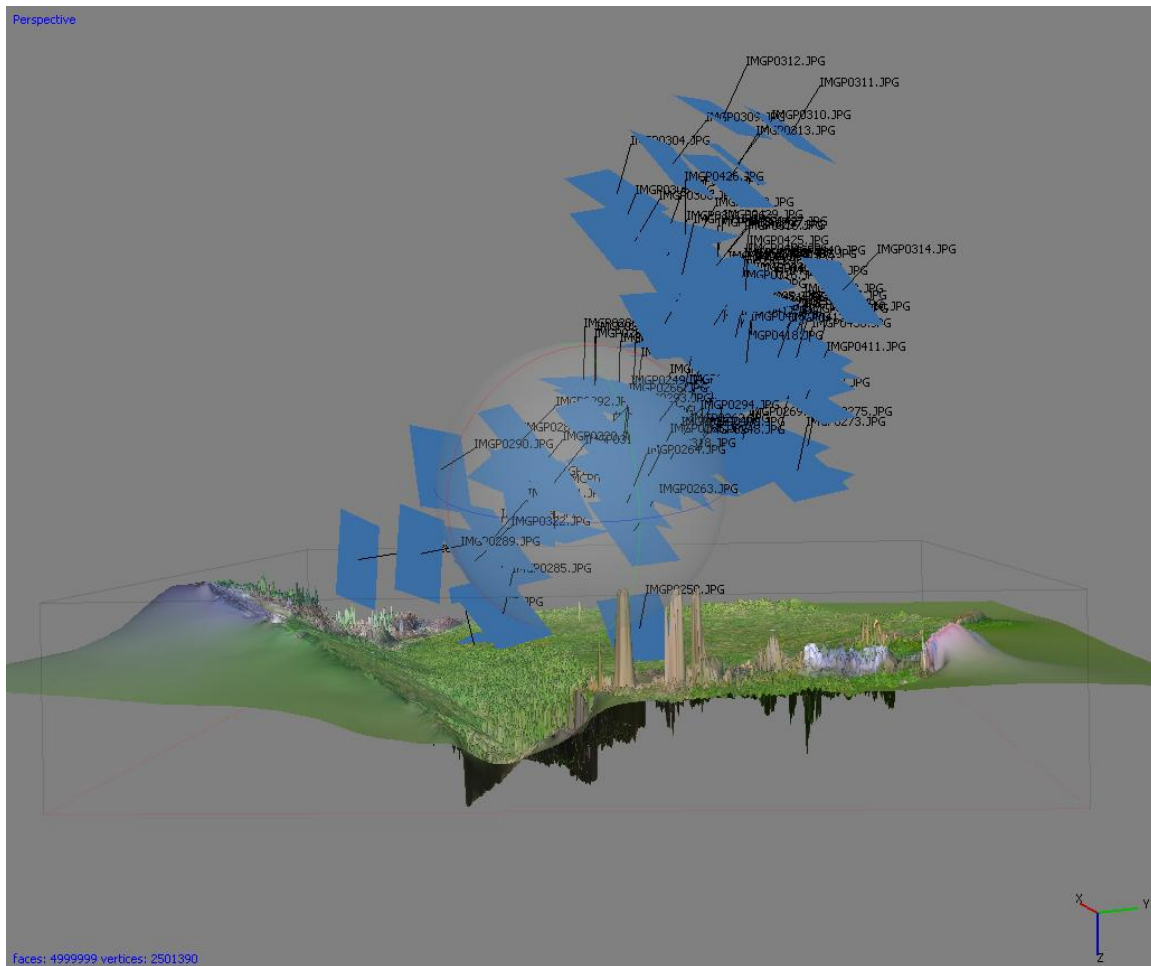


**Figure 7.36.** A screenshot from Agisoft Professional. Images (blue squares) are arranged according to their relative positions. A large number of the images are orientated similarly, although there are several that are not. As a consequence, the digital elevation model produced (at the base of the figure) is not representative of the landscape.

Although the model will omit incompatible or low quality images, the procedure by which it does this is determined by the input images, their degree of overlap and clarity. To account for this, a number of combinations of images were processed together initially, including using all of the images simultaneously to create an output.

Eventually it was determined that the most spatial representative outputs were generated when images were processed in batches of 25 consecutive photos, or wherever there was a break in the image collection (i.e. when the blimp was lowered to go under power lines or had stopped automatically taking photographs). The output of each batch was then

input into Agisoft Professional again and processed to create a map for the entire field; smaller maps comprising approximately 25 images were coalesced into a mosaic to produce the final output.

### **7.7.3. Results**

An insufficient number of high quality images were collected to produce a representative digital elevation model. However, a number of cattle-made features were visible in the landscape and several maps were produced (Figure 7.38).

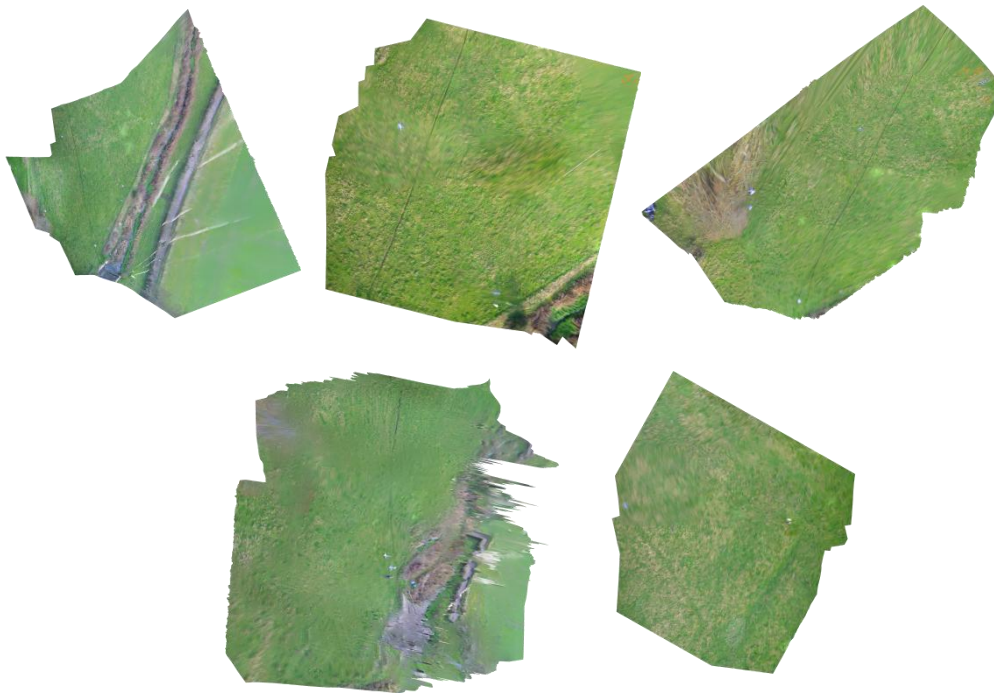


**Figure 7.37. Example map outputs of varying quality. Maps in this image have been reduced to one fifth of their original size.**

Of the outputs produced, one image (Figure 7.38) contained a number of cattle-made features. To the centre-right of the image is the cattle crossing point, with clearly exposed banks devoid of vegetation at the water's edge. The crossing point is noticeably wider than the adjacent, fenced-off channel, but also shallower; the river bed substrate of the crossing point is visible in this image.



### *Studying the effects of cattle grazing in chalk streams*

To the left of the crossing point the main cattle trail of the site can be seen.

Approximately three cattle hooves wide, the cattle trail shown in this image is 70m long and contains no vegetation. Other cattle trails that run parallel to the river can be seen towards the top of the image, originating at the cattle crossing point. In the top left of the image an area of disturbed earth created by cattle can be seen in between the river and the site boundary.

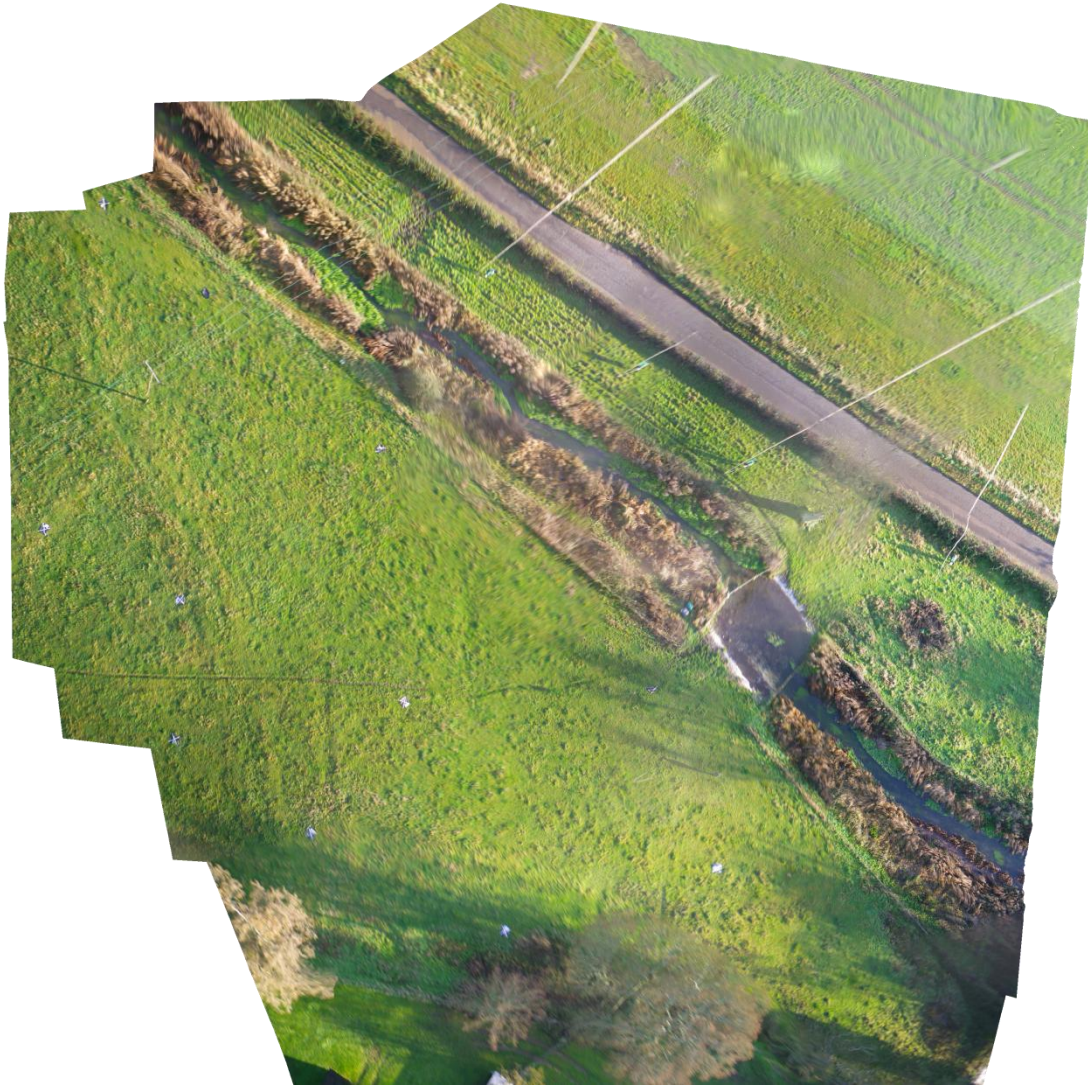


**Figure 7.38.** A composite image of 20 aerial photographs, showing the cattle crossing and the main cattle trail at the Tichborne site. The black squares with white crosses, used for georeferencing, are 1m<sup>2</sup> in diameter.

#### **7.7.4. Discussion**

##### *7.7.4.1. Limitations*

The novel approach used in this experiment to map landscape features created by cattle had a number of limitations. Firstly, maintaining the helikite in a stable position to ensure non-blurred imagery and a near-constant altitude was difficult. Constant uni-modal winds were less troublesome than variable complex winds, which reduced the stability of the photography platform. Secondly, although a constant length of tether could be maintained, helikite height was a function of wind strength, with strong winds causing the blimp to lose vertical height. Thirdly, although the camera platform was setup to remain perpendicular to the ground, strong winds caused the helikite to thrash around, changing the angle of the camera relative to the earth.

##### *7.7.4.2. Output maps*

Although the output maps produced by the Agisoft Photoscan software highlighted the location of cattle trails and cow ramps, the inability of the programme to generate accurate digital elevation models is a significant failing. Moreover, the output maps produced contain several signs of manipulation that detract from the maps purpose; including white lines showing the tether that linked the helikite to the operator, and a number of pictures of the operator themselves.

Nonetheless the maps highlight a range of different features that are of interest, including cattle trails, cow ramps, areas of disturbed earth, exposed bedrock on the river bank and in-stream vegetation. Through the comparison of features it is possible to make some useful observations. For example the cattle crossing point in Figure 7.38 makes the river noticeably wider here than in areas that cattle are unable to cross, showing the effect cattle have upon channel planform. Furthermore it can be seen from the map that on the river banks of the crossing point the chalk bedrock is exposed, suggesting that cattle cause bankside erosion and modify channel morphology by shallowing the river banks where they cross.

### *Studying the effects of cattle grazing in chalk streams*

The maps also provide a sense of relative scale and spatial proximity. For example the road at the top of Figure 7.38 is substantially wider than the cattle trail that is also visible in the image. Although it would be expected that both features could act as pathways for surface runoff, the map suggests that the road would have a greater effect than the cattle trail if only because of its greater surface area. However, the map also shows us that the cattle trail is spatially connected to the river channel whilst the road runs parallel to it, suggesting that the cattle trail may play a more significant role as a sediment transport pathway than the road. Whilst the maps do not tell us which pathway contributes the greatest surface runoff, they do allow us to link discrete landscape elements and to generally improve our understanding of connections between cause and effect at the reach scale.

#### *7.7.4.3. Future improvements*

A number of modifications to the methodology used within this study could be applied to enhance the data collected. Firstly, wherever possible the helikite should be used during calm conditions when wind speed is sufficient to keep the blimp buoyant but not too forceful that the stability of the kite is compromised. This makes it easier to maintain the kite at a constant altitude and reduces the movement of the camera, thereby generating better photographs.

Secondly, unique targets, possibly incorporating a clear numbering or colour system, should be used instead of homogeneous targets. The Agisoft PhotoScan software struggled to distinguish between the different targets used within this study as at the height images were taken from it was not possible to see the target number. Consequently when images were processed to generate larger maps, the software would occasionally mistake one target for a different target, causing the misalignment and reorientation of some images such that the output map produced could not be used

Thirdly, a small number of high quality photographs are more useful than a larger number of poor quality photographs. In this study approximately 20% of the photographs

taken were used, with the rest discarded because they were blurred, of insufficient resolution or lacking in discrete landscape features that connected them to other photographs within the set.

#### **7.7.5. Testable hypotheses**

Despite the aforementioned problems with this study, the hypothesis for this section ( $H_3$ ), that cattle-made landforms such as cow ramps and cattle trails form in areas used most regularly by cattle, as suggested by Trimble (1994) and Trimble and Mendel (1995), was proven by the occurrence of landforms in the same locations as high frequencies of GPS fixes from cattle collars (section 6.2).

#### **7.7.6. Conclusion**

This study has demonstrated that a helikite-mounted camera can be used to take low-elevation aerial photography of cattle-made landforms in chalk stream environments. By using the Agisoft PhotoScan (Professional Edition) software these photographs can be georeferenced to create a map of cattle-made features, which can be used in further analysis. However, the quality of map outputs is reliant upon the quality of input photographs; best results were achieved during still conditions when the helikite was most stable.

It was shown that the location of cattle, and the areas they use most frequently, relate directly to various features within the landscape. In particular it was seen that cattle trails develop in parts of the terrestrial environment most regularly used by cattle, whilst cow ramps form at river crossing points. Although intuitive, this is the first time low-elevation aerial photography has been used to map cattle-made features. Moreover, by combining aerial photography with GPS data from cattle collars it has been possible to correlate known areas of frequent usage by cattle with distinct geomorphological features.

Future work could improve upon the methodology used herein. A number of issues relating to the stability of the helikite severely limited the outputs of this study and if this research were to be conducted again a number of changes would be made. In particular, and given a sufficient budget, an untethered, unmanned aerial vehicle (UAV) would be used instead of the helikite blimp. Although relatively cheap, the erratic movement of the blimp greatly reduced the quality of images captured. UAV's, which have been employed to acquire aerial photographs for a number of applications (e.g. Hardin and Jackson, 2005), are an increasingly viable alternative when seeking to gather remotely-sensed landscape data.

## **7.8. Overview of the effects of cattle grazing in English chalk streams**

It was evident from the various studies in this chapter that the greatest short-term consequence of allowing cattle access to chalk streams is nutrient loading, and specifically phosphate loading (section 7.2). In otherwise naturally low phosphate concentration river water, allochthonous cattle faeces loading could increase in-stream phosphate levels by several orders of magnitude, with potential impacts upon ecology in the form of increased primary productivity, algal blooms and eutrophication (section 7.3). However, whether such consequences actually manifest is unclear; the calculations made in section 7.3 are estimates and further research is required, perhaps in a controlled environment, to assess the effect of faeces loading upon chalk stream ecology.

The greatest long-term consequence of allowing cattle access to chalk streams relates to their geomorphic agency. Cattle have been shown to exert sufficient shear stress to create cow ramps and cattle trails even on vegetated soils and at relatively low stocking densities (section 7.4). Data from the river bank topography study shows that cattle can erode stream banks, albeit slowly (section 7.5). In naturally low-energy chalk river environments, where there are rarely overbank flows, any changes in floodplain topography due to the creation of cattle trails and particularly cow ramps are likely to remain permanent; there is insufficient natural geomorphic agency at work for these streams to reassert their original form. As to whether the creation of cattle-made landforms is detrimental to chalk streams remains uncertain. Evidence from the turbidity

study (section 7.6) suggests that in-stream cattle activity has a small effect upon suspended sediment concentrations, whilst the principle finding of the terrestrial laser-scanning study was that cattle increased heterogeneity in river bank topography. Certainly cattle can create landforms within chalk stream environments that will remain for many years even after the cessation of grazing pressure.

When considered alongside observations made in chapter 0 and theoretical evidence (i.e. the intermediate disturbance hypothesis; Figure 4.6: Grime, 1973; Connell, 1978; Wilkinson, 1999), the findings of chapter 0 suggest a net benefit to chalk stream biodiversity in the presence of cattle at low stocking densities. The disturbance that occurs due to cattle is particularly important in chalk stream environments, where there are few other natural disturbance phenomena, such as flooding. Cow ramps, cattle trails, faeces hotspots and variable sward heights all create habitats that would not exist naturally without cattle. The key, as highlighted in previous studies (e.g. Mwendera *et al.*, 1997; Clary and Kinney, 2002), is that cattle do not create sub-optimal disturbance, either too little or too much, that could negatively affect biodiversity. Irrespective of the overall ecological role played by cattle, their capacity to conduct geomorphic work in relatively geomorphologically inactive landscapes, as shown in this chapter, is an important caveat if they are to be used as tools to maintain or improve biodiversity in chalk stream environments.

## 8. SCIMAP connectivity mapping

### 8.1. Introduction

One of the perceived effects of cattle grazing in temperate rivers is the input of nutrients and fine sediment from diffuse pollution sources (Collins and Walling, 2007; Larsen *et al.*, 2009). In chalk streams a number of species are especially susceptible to fine sediment and organic material inputs, particularly salmonids (Greig *et al.*, 2005; Greig *et al.*, 2007; Collins and Davison, 2009).

However, whether diffuse pollution sources ultimately affect an aquatic ecosystem is dependent upon the connectivity between the terrestrial and riverine environments (Baker *et al.*, 2003; Haygarth *et al.*, 2005). In chalk stream environments this connectivity is not guaranteed. Firstly, chalk streams have naturally low streampower owing to the shallow longitudinal gradient between their source and their mouth (Sear *et al.*, 1999). Secondly, because chalk streams are groundwater-fed by springs and aquifers (Sear *et al.*, 1999; Smith *et al.*, 2003) they lack the steeply-sloped and consequentially highly-connected headwaters that characterise many upland streams (Reid *et al.*, 2007; Cavalli *et al.*, 2012). Thirdly, overbank flows are important mechanisms for the transport of material from the river floodplain to the river channel; in chalk stream catchments overbank flows are seldom, due to the high soil infiltration capacity (Mainstone, 1999; Smith *et al.*, 2003). Finally, centuries of anthropogenic agency have significantly changed many chalk stream landscapes, with bank levees and the infilling of former channels reducing connectivity (Everard, 2005).

There are a number of conceptual models that consider river-floodplain connectivity in different environments (e.g. Hooke, 2003; Jain and Tandon, 2010). Built upon these are a number of computational models that have been used to assess landscape connectivity in different environments (e.g. Heathwaite *et al.*, 2005; McGuire *et al.*, 2007; Warren *et al.*, 2007). One model of particular relevance and use to this study because of its capacity to map diffuse pollution risk is SCIMAP.

SCIMAP uses three principle inputs: a digital elevation model, a land-cover map and a rainfall map. The model combines these different inputs to generate a map of fine sediment risk (Figure 8.1)

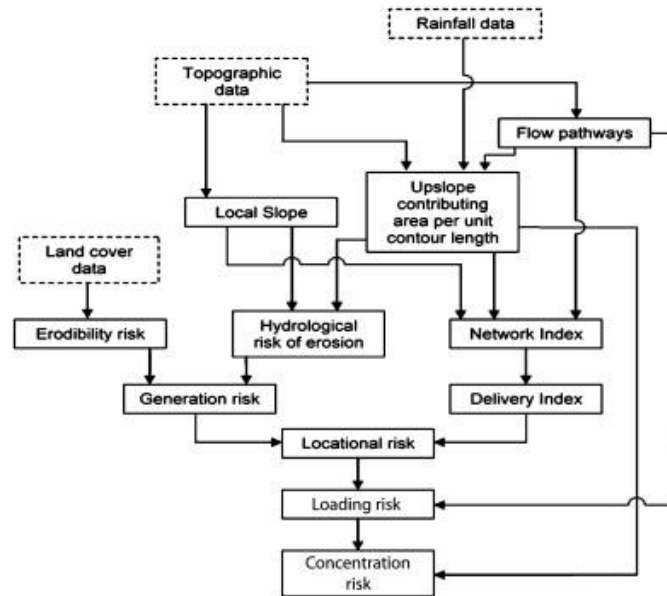


**Figure 8.1. Workflow of the SCIMAP model for fine sediment risk (after Figure 3 in Reaney *et al.*, 2011). Input data sets are shown in dashed-line boxes.**

A detailed explanation of how the model works can be found within Lane *et al.* (2009) but a simplified workflow is discussed herein. The model first considers the areas in which surface flow will accumulate based upon topography and rainfall inputs to generate a map of the drainage network. The erodibility of a given surface, derived from land cover data or other inputs, is subsequently determined to produce a map of erosion risk across the study area. The erosion risk map is then combined with hydrological data to identify those areas in which fine sediment will accumulate due to hillslope and hydrological processes. Finally, the accumulated erosion risk map is superimposed upon the drainage network map to produce a weighted output map of fine sediment risk in channels.



Previous studies have used such output maps in combination with other data to assess the effects of fine sediment risk upon ecological components of river systems, such as salmon and trout fry (Reaney *et al.*, 2011). This study will consider the importance of cattle trails and cow ramps in determining the location of fine sediment risk. Specifically, the study hopes to establish whether cattle trails and cow ramps act as pathways for the transport of fine sediment, or whether their principle role is as critical sediment sources. Additionally, SCIMAP outputs will enable us to see how well connected chalk stream environments are.

## **8.2. Methods**

Within this study the SCIMAP model is applied at two scales: at catchment-scale across a number of chalk stream watersheds (the Itchen, the Lee, the Meon and the Test); and at the field-scale at the Tichborne and Midlington sites.

The SCIMAP connectivity mapping was conducted using two geographical information systems. ArcGIS provided the tools to organise modify and ultimately display model outputs, whilst SAGA 2.0 was used to run the SCIMAP fine sediment risk model.

Three principle data sets were used for the SCIMAP connectivity mapping study; digital elevation models (for flow accumulation, slope calculations [streampower], etc), land cover maps (for soil erodibility) and annual rainfall maps (for discharge, flow accumulation, etc).

Two sources of raster data were used to create digital elevations models. For the catchment-scale modelling, 30m horizontal resolution topographic data from the ASTER GDEM sensor aboard the Terra satellite were used (NASA, 2012). For field-scale modelling, 1m horizontal resolution LiDAR data from the Geomatics Group (a subsidiary of the Environment Agency) were used (Geomatics Group, 2009). 1km horizontal land-use raster data were acquired from the Centre for Ecology and Hydrology (CEH, 2012). At the field-scale CEH land-use data were replaced by GPS cattle collar data acquired in section 6.2, with frequency of occupancy by cattle as a proxy for erodibility (higher

occupancy = higher erodibility), cattle trail and cow ramp mapping from aerial photographs (section 7.7), and digitised sketch maps based upon data from the observational study (section 6.1). UK Meteorological Office rainfall raster data with a 5km horizontal resolution were used at both the catchment-scale and the field-scale (UK Met Office, 2010).

It is a prerequisite of the SCIMAP model that all input data exist in the same grid system, with the same extent and the same spatial resolution. Using the ArcGIS Resample tool all catchment-scale data were downsampled to a resolution of 10m and all field-scale data were downsampled to a resolution of 1m. The ArcGIS Clip tool was used to give all datasets the same spatial extent so that they would exist within the same grid system.

In SAGA it was necessary to reclassify land cover classifications from the CEH data into values between 0 (low erodibility) and 1 (high erodibility) to produce an erodibility index based upon the categorisation by Reaney *et al.* (2011). Different severities of poaching, as taken from River Habitat Survey data (Figure 8.2; RHS, 2012), were also added to this index (Table 8.1). The severity of each poaching category was determined by calibration analysis (discussed in section 8.4.1) and with reference to the recommendations by Reaney *et al.* (2011).

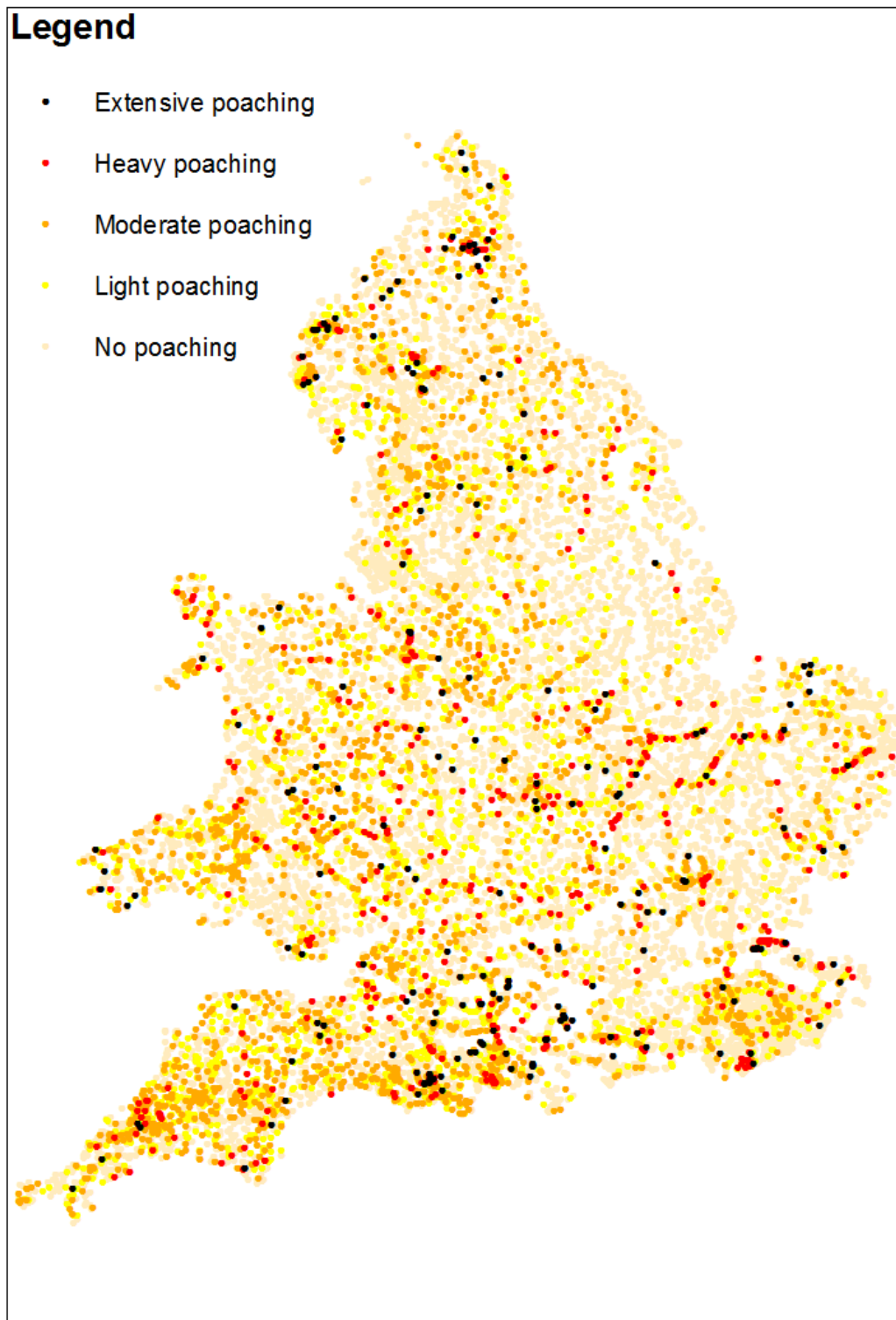


Figure 8.2. A national poaching map for the UK as derived from River Habitat Survey data. A high resolution version of this map was merged with the CEH data to produce catchment-scale land-use maps that incorporate cattle grazing data.

| Land-cover classification | SCIMAP erodibility value |
|---------------------------|--------------------------|
| <i>Land cover</i>         |                          |
| Horticulture              | 1                        |
| Arable                    | 1                        |
| Improved Grassland        | 0.2                      |
| Grassland                 | 0.1                      |
| Heathland/Peat/Bogs       | 0.05                     |
| Woodland                  | 0                        |
| Urban                     | 0                        |
| <i>Cattle poaching</i>    |                          |
| Light poaching            | 0.05                     |
| Moderate poaching         | 0.1                      |
| Heavy poaching            | 0.15                     |
| Intensive poaching        | 0.2                      |

**Table 8.1. Land cover classification index and conversion to soil erodibility inputs for the SCIMAP model. Values for poaching are absolute and were derived from calibration analysis (detailed in table 8.3). Values for land cover are taken from Reaney *et al.* (2011).**

### 8.3. Results

The SCIMAP fine sediment risk and landscape connectivity model produced a number of outputs for each catchment. Maps of slope, the surface wetness index, erosion risk and erosion risk in channels were produced, amongst other outputs. The key outputs and the ones used in the subsequent discussion, the concentrated erosion risk in channels maps, were converted from raster files in SAGA into shapefiles and then displayed in ArcGIS. Field-scale fine sediment risk maps of the Tichborne and Midlington study sites are also presented and discussed.

#### 8.3.1. Catchment-scale

All of the output maps generated from the SCIMAP model highlighted the disconnected nature of most chalk stream catchments. Many of the output areas of highest fine

sediment erosion risk were not connected to the main river channel of the catchment (Figure 8.3). Contiguous areas of connected risk were seldom longer than 1k, although there were no differences in connectivity between land-cover and cattle-based outputs; connectivity is a function of landscape elevation. Different catchments exhibited different trends with respect to the distribution, severity and connectivity of fine sediment risk, as explained below.

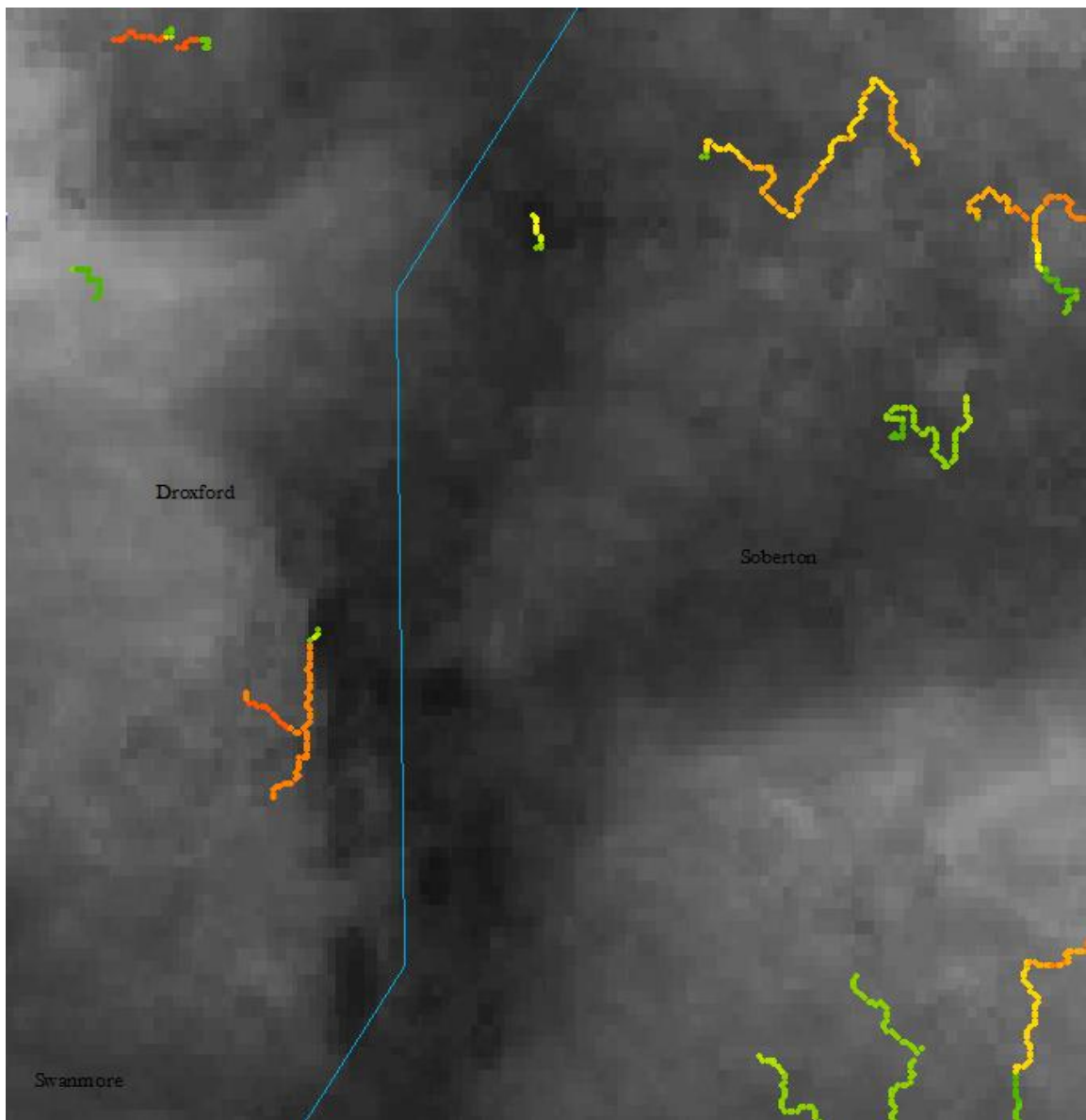


**Figure 8.3.** A snapshot of output from the Meon catchment, illustrating the disconnected nature of the landscape. Dots represent areas of fine sediment risk, whilst the blue line represents the centre channel of the River Meon; in this example the two are not connected.

*8.3.1.1. Itchen catchment*

The majority of fine sediment risk in the Itchen catchment was slightly above average; 0.17-0.5 standard deviations above the mean. Generally however, areas of risk were poorly connected to the main river channel of the River Itchen.

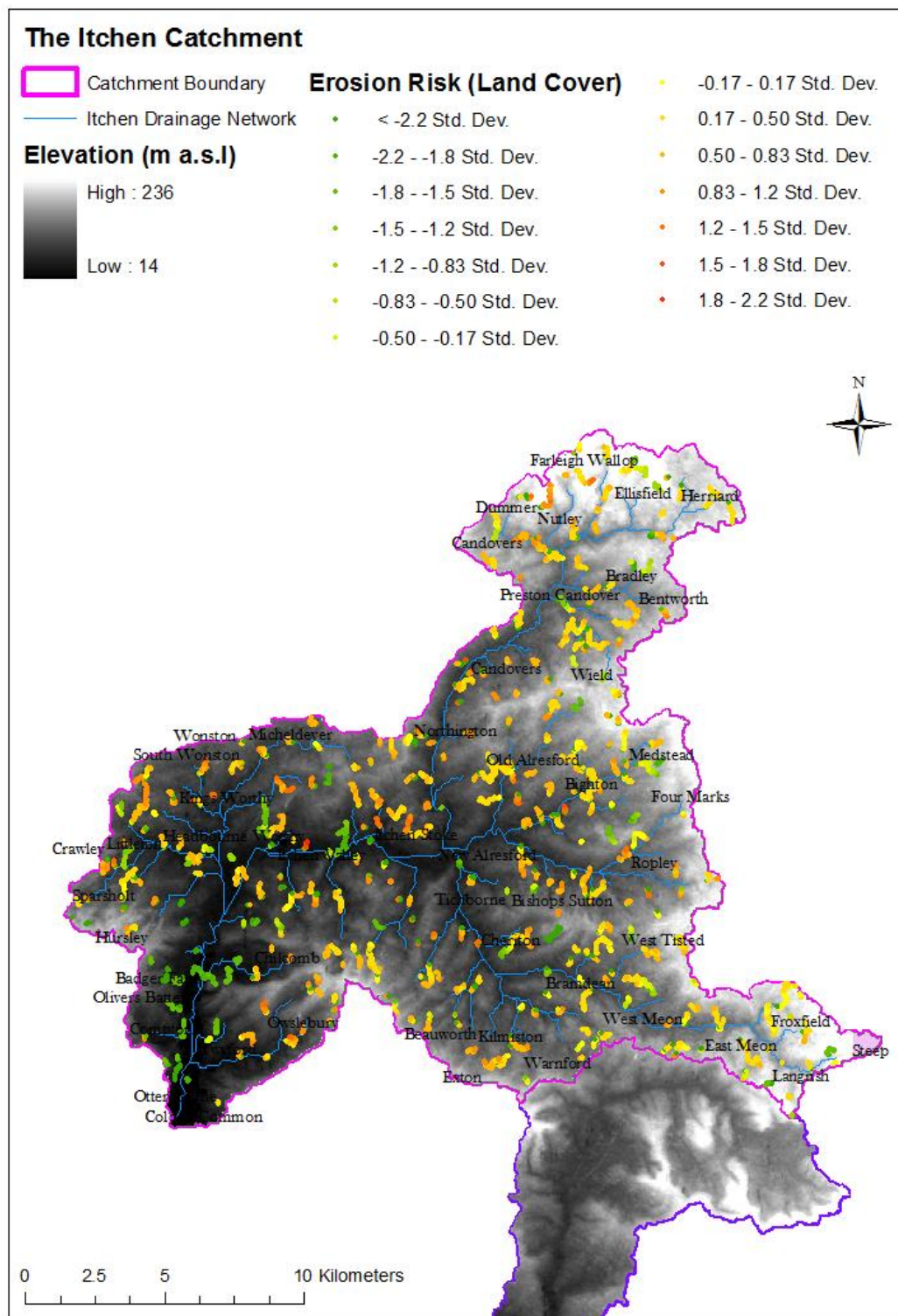


Figure 8.4. SCIMAP output map of fine sediment risk in the Itchen catchment based upon CEH land cover data. The dark purple line to the south-east outlines the adjacent Meon catchment.

The south-western most section of the catchment exhibited relatively low fine sediment risk compared to the rest of the watershed (Figure 8.4). The greatest fine sediment risk in the Itchen catchment was found around within the Itchen Valley area. There were comparatively few locations where fine sediment risk and the main river channel overlapped, with examples south of Northington, at Bramdean, and at the confluence of channels between Headborne Worthy and the Itchen Valley.



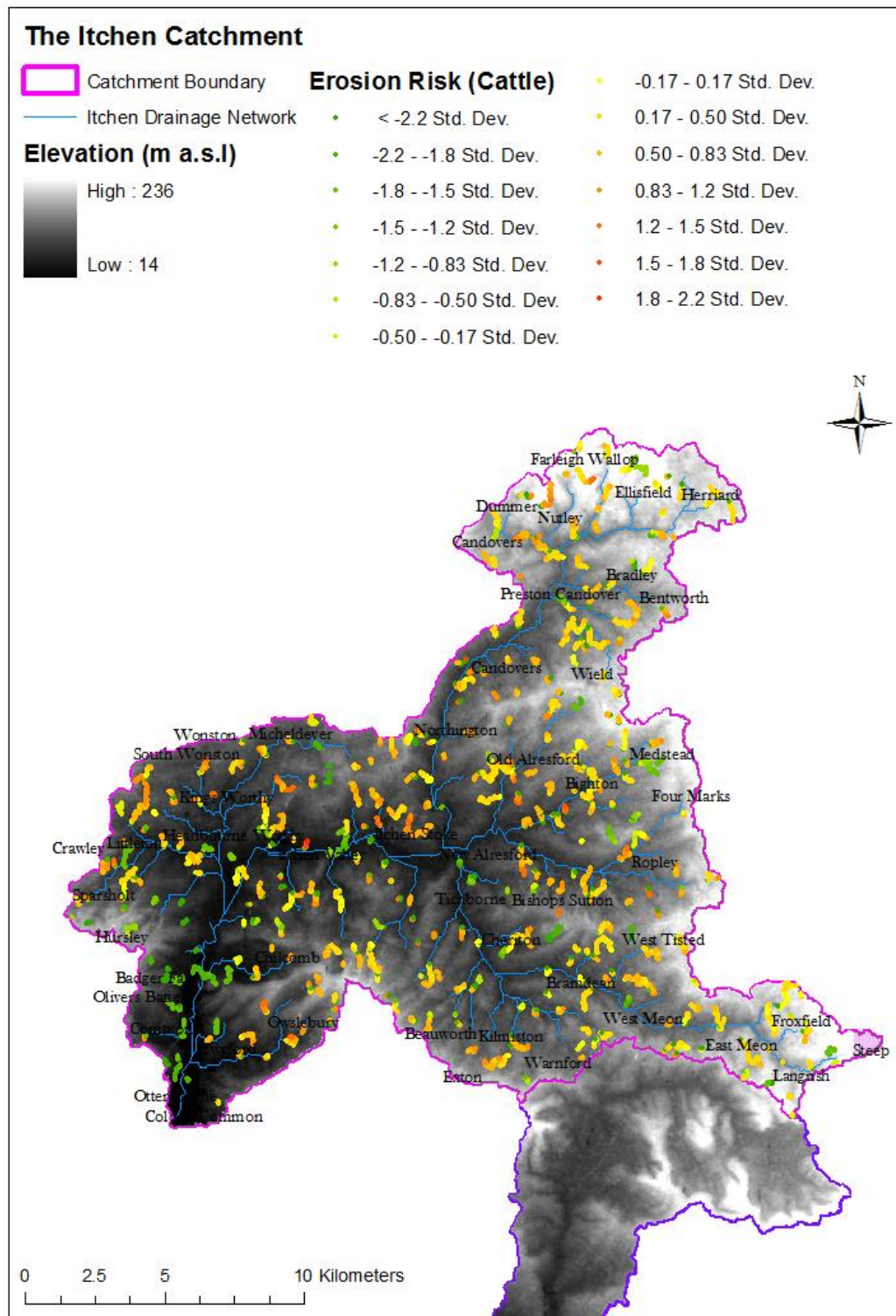


Figure 8.5. SCIMAP output map of fine sediment risk in the Itchen catchment based upon cattle poaching data superimposed upon CEH land cover data. The dark purple line to the south-east outlines the adjacent Meon catchment.

There was no net difference in fine sediment risk between cattle poaching and CEH land-cover output maps (Figure 8.5). However, spatial difference in fine sediment risk were evident, with greater fine sediment risk between Kings Worthy and the Itchen Valley in the cattle output map than the standard land-cover output map. Near Headbourne Worthy, fine sediment risk was less in the cattle output map than the standard land-cover output map.

#### *8.3.1.2. Lee catchment*

SCIMAP outputs from the Lee catchment reveal a relatively well connected catchment with many areas of moderate fine sediment risk. Moreover, contiguous channels of fine sediment risk were generally longer in the Lee catchment than any other catchment in this study.

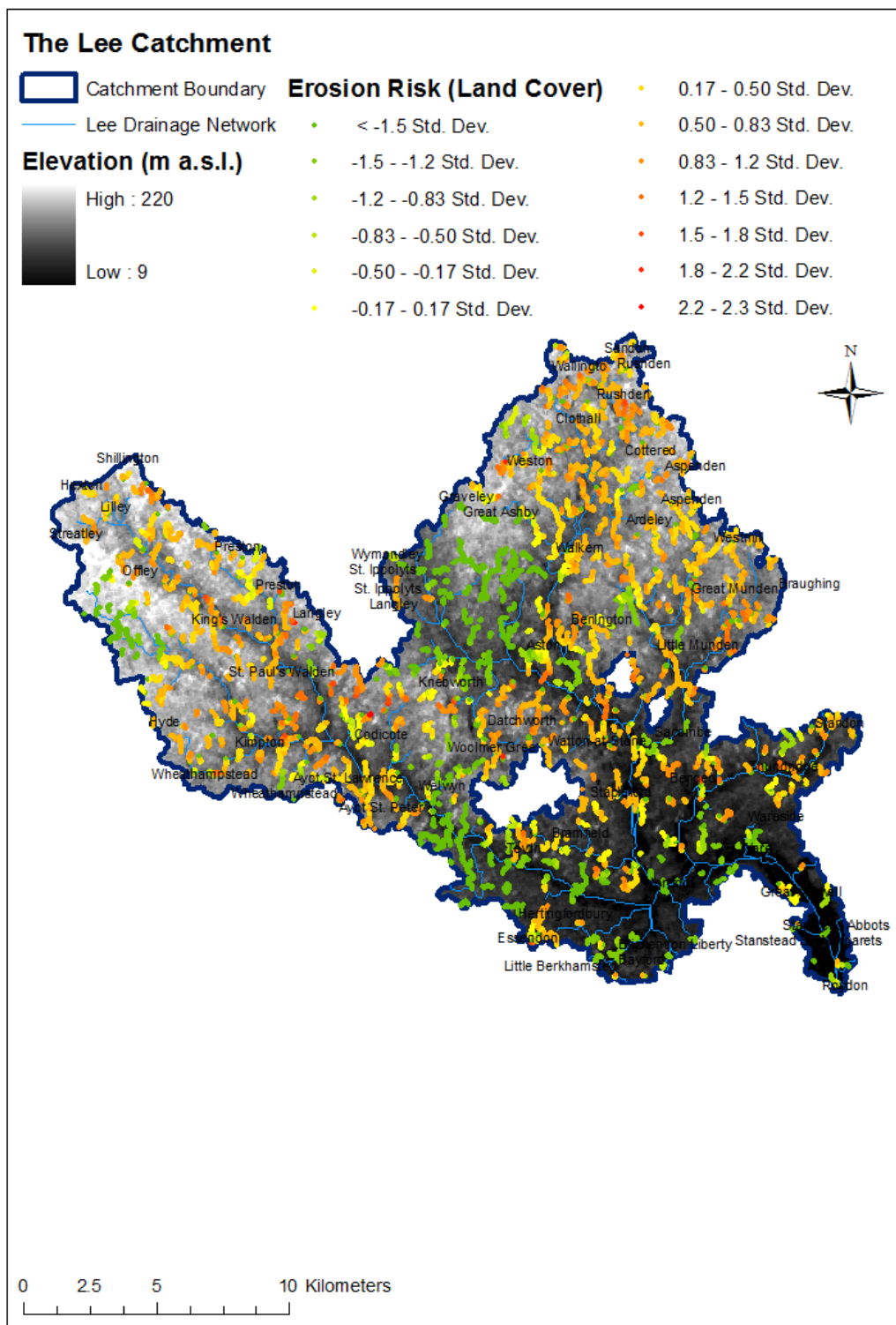


Figure 8.6. SCIMAP output map of fine sediment risk in the Lee catchment based upon CEH land cover data.

Areas of fine sediment risk in the Lee catchment are well distributed throughout the watershed (Figure 8.6). A number of places of greatest risk include the area around Rushden to the north of the catchment, the area between St. Paul's Walden and King's Walden to the west of the catchment, and the triangle of space between Datchworth, Watton-at-Stone and Benington in the centre of the catchment. Furthermore many of these areas of fine sediment risk are connected to the main river channel; at Aston, at King's Walden, south of Colthall and at Thundridge to the south-east.

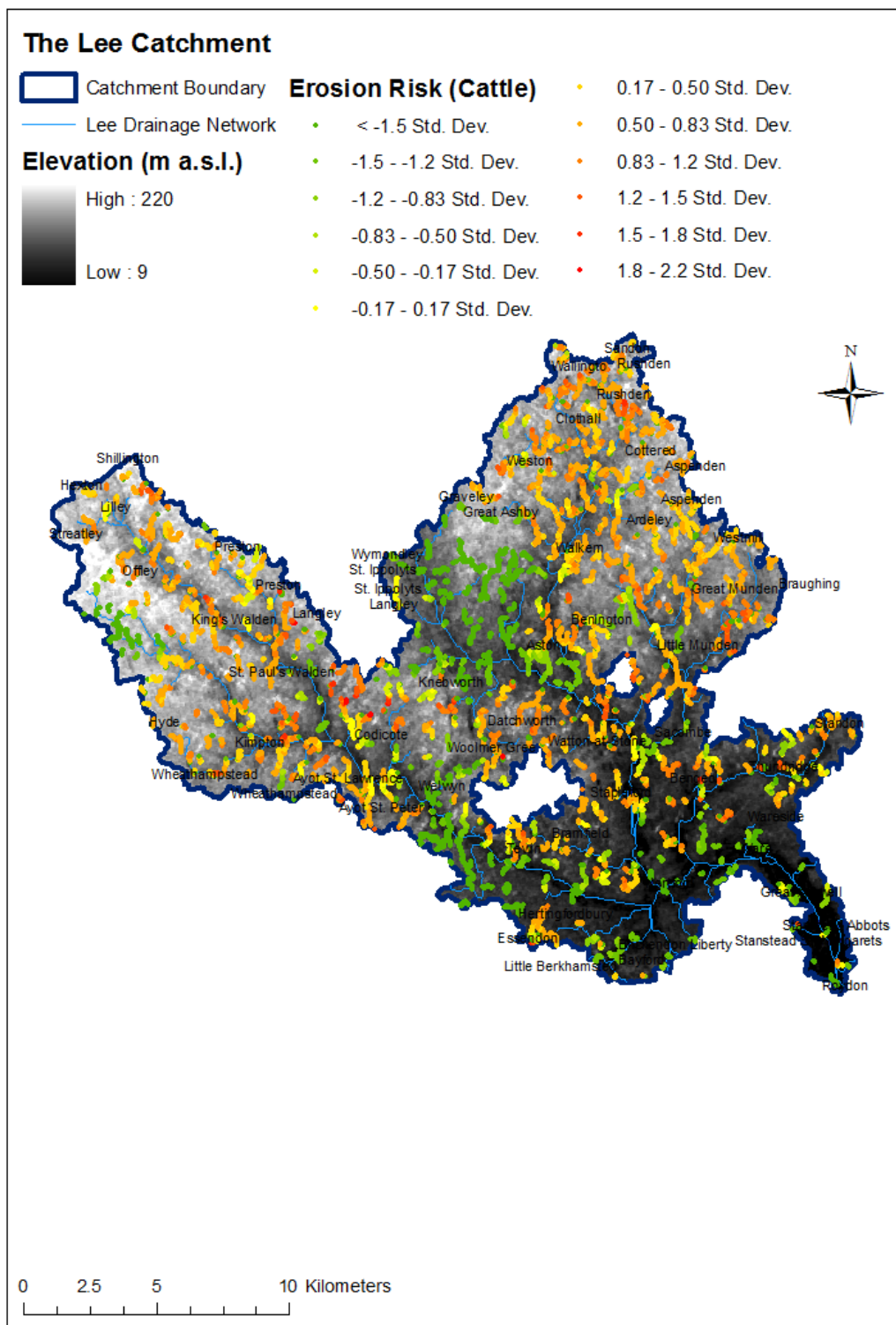


Figure 8.7. SCIMAP output map of fine sediment risk in the Lee catchment based upon cattle poaching data superimposed upon CEH land cover data.

In the map outputs that include a cattle grazing modifier, there was a small (<1%) but detectable increase in fine sediment risk across the catchment (Figure 8.7). There were also changes in the magnitude of risk in different location. The area to the south-east of King's Walden has greater risk with cattle than without, whilst the area around Aston was predicted reduced sediment risk in the presence of cattle as at this location the cattle overlay data reduced the erodibility value from 0.2 (improve grassland) to 0.05 (light poaching).

#### *8.3.1.3. Meon catchment*

SCIMAP outputs of fine sediment risk in channels across the River Meon identify numerous areas of high risk in both the standard land cover map and the modified cattle poaching map. However, compared to other watersheds within this study, overall fine sediment risk in the Meon catchment was low. Moreover, connected areas of risk were restricted to the north of the catchment.

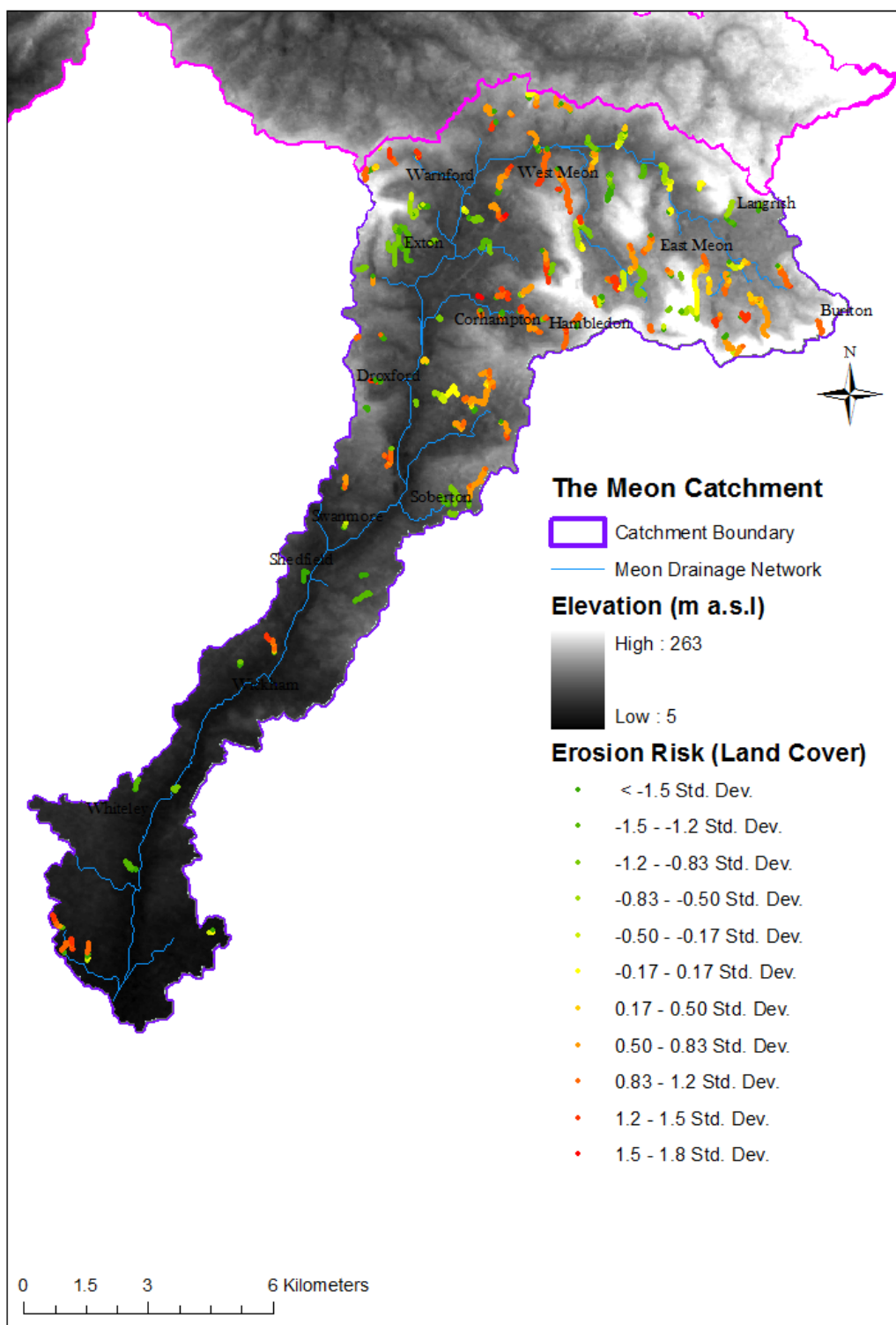


Figure 8.8. SCIMAP output map of fine sediment risk in the Meon catchment based upon CEH land cover data. The pink line demarcates the boundary of the adjacent Itchen catchment.

There are several areas of high fine sediment risk to the north of the catchment, particularly around Corhampton, Hambledon, West Meon and to the south of East Meon (Figure 8.8). The southern half of the catchment has comparatively low fine sediment risk relative to the north, where there is also far greater connectivity between areas of fine sediment risk and the main river channel. Fine sediment risk around the West Meon region was particularly well connected to the main river channel.



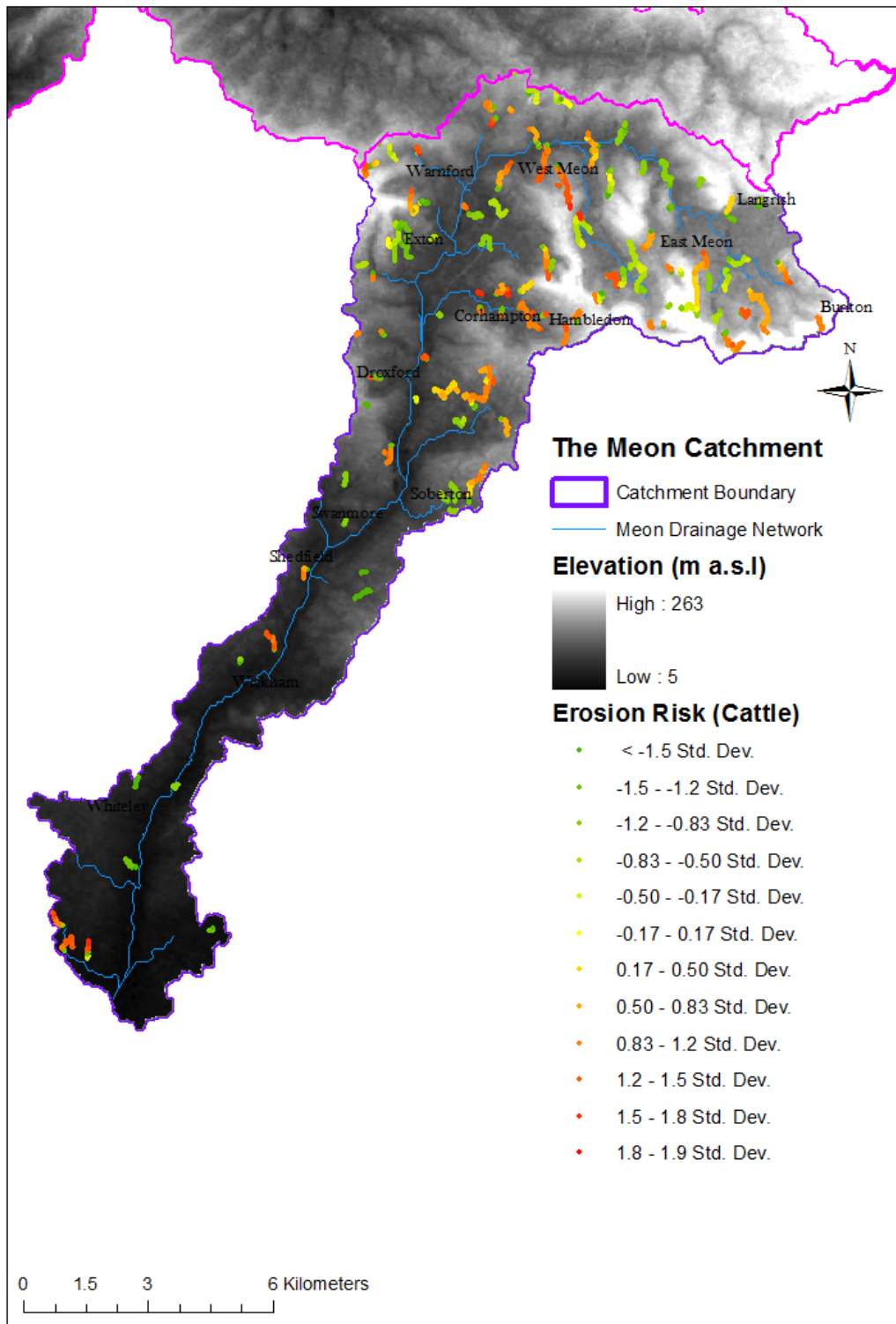


Figure 8.9. SCIMAP output map of fine sediment risk in the Meon catchment based upon cattle poaching data superimposed upon CEH land cover data. The pink line demarcates the boundary of the adjacent Itchen catchment.

There was less fine sediment risk in the cattle poaching output map, with a 7% decrease in fine sediment risk overall (Figure 8.9). In addition, there were spatial differences in risk between maps, with several areas, particularly the aforementioned region to the south of East Meon, exhibiting less fine sediment risk in the cattle poaching output map.

#### *8.3.1.4. Test catchment*

The largest watershed in the study, the Test catchment exhibited the greatest total fine sediment risk of all the catchments. Furthermore most of this risk was above average for the catchment, between 0.5-.083 standard deviations above the mean. The size of the catchment combined with the relatively extensive drainage network to produce numerous locations where fine sediment risk intersected the main river channel (Figure 8.10).

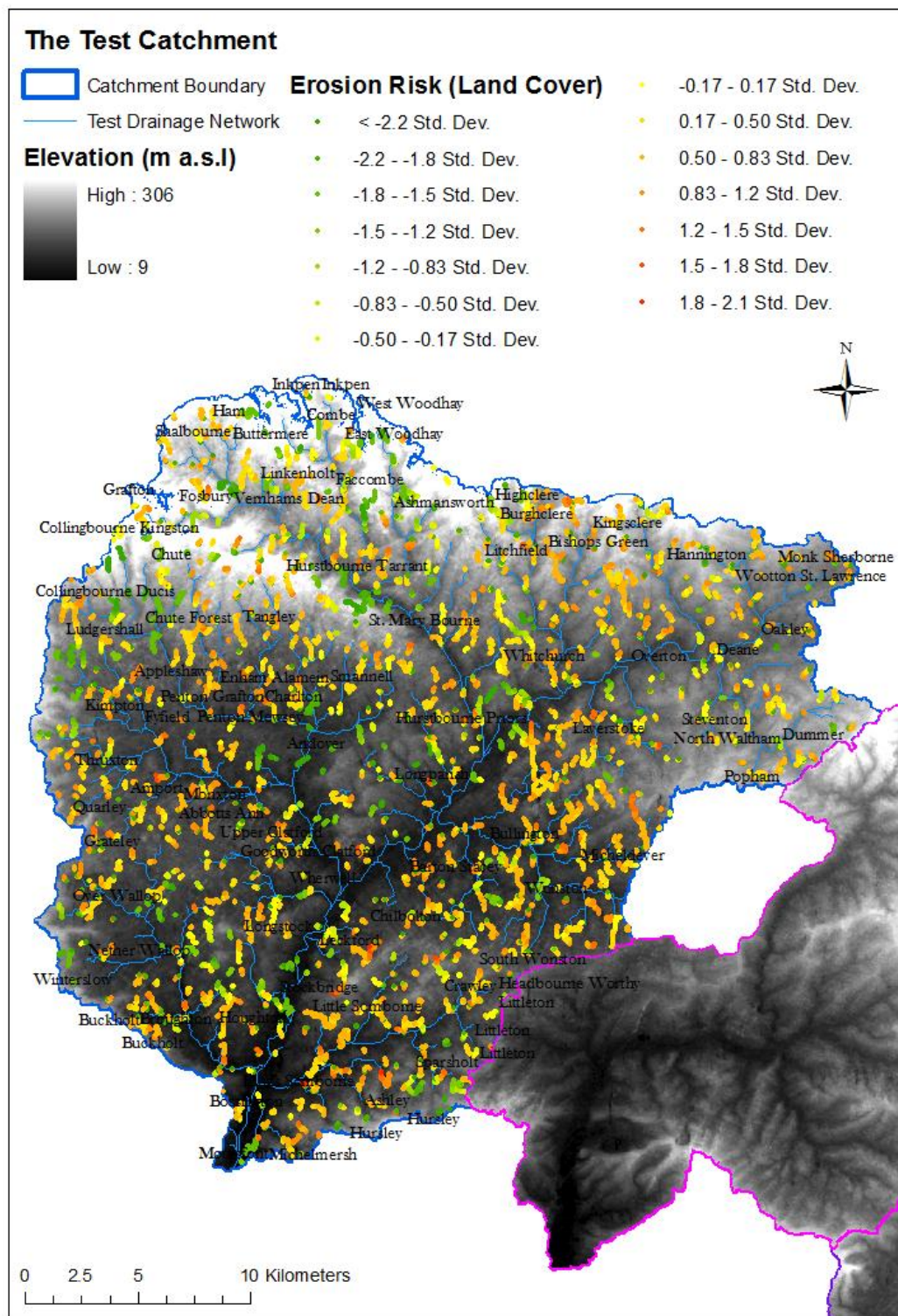


**Figure 8.10. SCIMAP output map of fine sediment risk in the Test catchment based upon CEH land cover data. The pink line demarcates the boundary of the adjacent Itchen catchment.**

Areas of fine sediment risk from the CEH land cover data outputs are evenly distributed across the Test catchment, although the severity of risk is not. There are several areas of high risk to the south of the catchment at Leckford, Stockbridge and Bossington. A number of low risk areas exist to the north and middle of the catchment at Hurstborne Tarrant, St. Mary Bourne and Andover. Although much of the fine sediment risk in the catchment was not connected to the main river channel, in some locations there were intersections, with examples at Overton, west of Houghton and between Faccombe and Linkenholt.

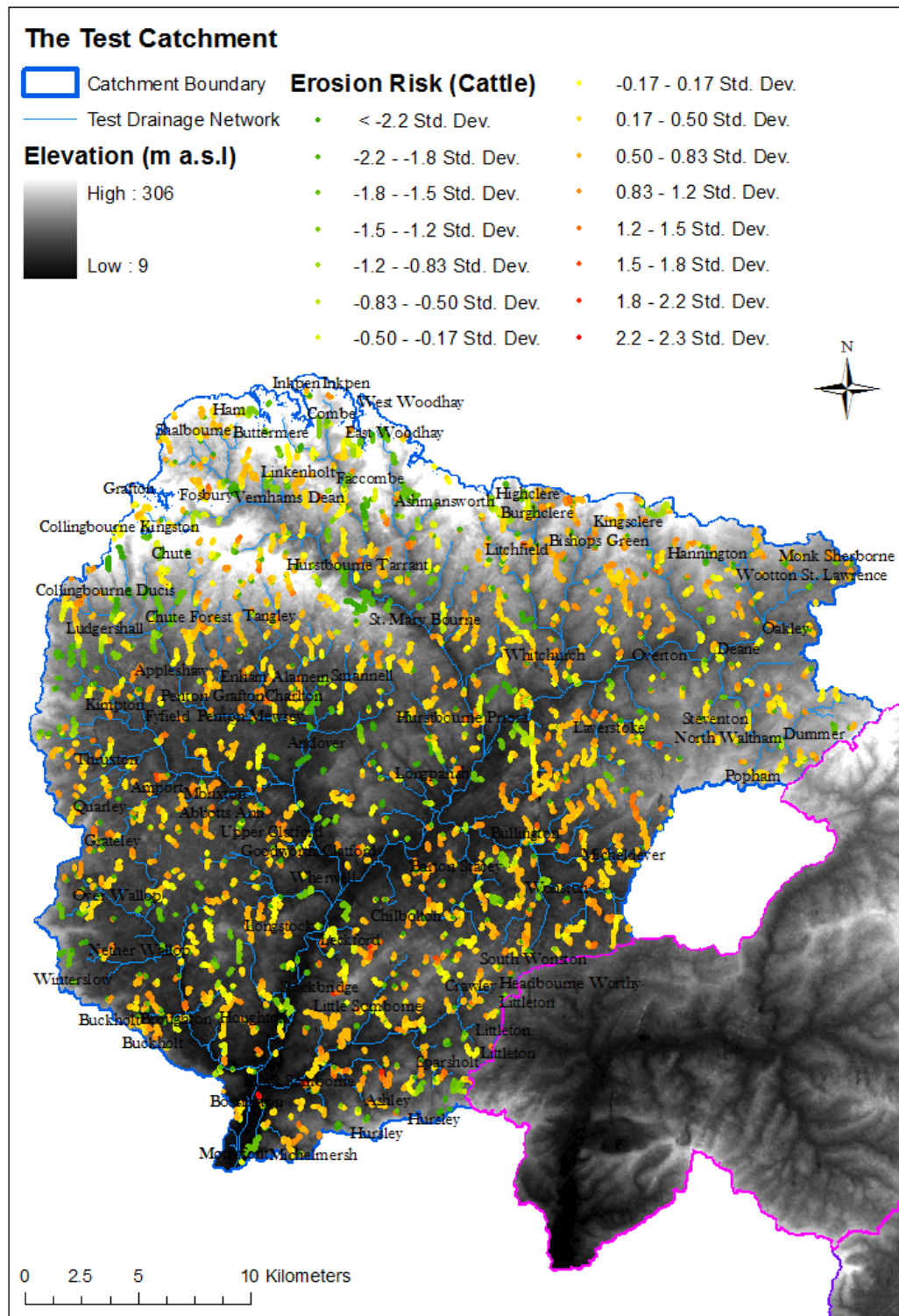


Figure 8.11. SCIMAP output map of fine sediment risk in the Test catchment based upon cattle poaching data superimposed upon CEH land cover data. The pink line demarcates the boundary of the adjacent Itchen catchment.

There was no overall difference in the total amount of fine sediment risk between output maps for the Test catchment (Figure 8.11). However, spatial differences in the intensity of fine sediment risk were observed, with some areas experiencing lower risk due to cattle (e.g. north east of Hurstbourne Tarrant) and some areas experiencing higher risk due to cattle (e.g. north west of Bossington).

#### 8.3.1.5. Catchment comparison

Numerical values from SCIMAP outputs allow for the comparison of the different catchments with respect to their fine sediment risk.

|                                            | Itchen | Lee   | Meon  | Test  |
|--------------------------------------------|--------|-------|-------|-------|
| <i>Catchment characteristics</i>           |        |       |       |       |
| Catchment Area (km <sup>2</sup> )          | 332    | 348   | 108   | 795   |
| Cumulative drainage network length (km)    | 243    | 272   | 70    | 587   |
| Drainage density (km/km <sup>2</sup> )     | 0.73   | 0.78  | 0.65  | 0.74  |
| <i>Output map characteristics</i>          |        |       |       |       |
| <u>Number of output dots</u>               |        |       |       |       |
| Standard                                   | 17121  | 37694 | 5328  | 50832 |
| Cattle                                     | 17121  | 37694 | 5328  | 50832 |
| <u>Maximum fine sediment risk value</u>    |        |       |       |       |
| Standard                                   | 0.18   | 0.18  | 0.16  | 0.19  |
| Cattle                                     | 0.18   | 0.18  | 0.16  | 0.19  |
| <u>Sum of fine sediment risk values</u>    |        |       |       |       |
| Standard                                   | 1600   | 3100  | 420   | 4900  |
| Cattle                                     | 1600   | 3100  | 390   | 4900  |
| <u>Mean of fine sediment risk values</u>   |        |       |       |       |
| Standard                                   | 0.093  | 0.083 | 0.079 | 0.096 |
| Cattle                                     | 0.093  | 0.083 | 0.074 | 0.096 |
| <u>Median of fine sediment risk values</u> |        |       |       |       |

|                                                        |       |       |      |       |
|--------------------------------------------------------|-------|-------|------|-------|
| Standard                                               | 0.11  | 0.10  | 0.97 | 0.11  |
| Cattle                                                 | 0.11  | 0.11  | 0.82 | 0.11  |
| <u>Standard deviation of fine sediment risk values</u> |       |       |      |       |
| Standard                                               | 0.041 | 0.047 | 0.48 | 0.043 |
| Cattle                                                 | 0.041 | 0.047 | 0.49 | 0.043 |

**Table 8.2. SCIMAP output data and catchment characteristics for the Itchen, Lee, Meon and Test catchments.**

Many of the numerical values produced from the SCIMAP outputs were identical between the standard maps and cattle maps; there was no difference between values within the Test and Itchen catchments (Table 8.2). The Meon catchment was the exception, where the output forecast reduced fine sediment risk due to cattle.

However, there were differences between catchments. The Test catchment had the greatest mean, maximum and sum fine sediment risk. The Test catchment also had the largest number of output dots overall, although the Lee catchment had the greatest number of fine sediment risk locations relative to its area. Indeed, despite being very similar in size to the Itchen catchment, the Lee catchment had nearly twice the sum fine sediment risk. Whilst the smallest catchment, the Meon catchment, had the lowest overall and mean fine sediment risk, it had the highest median fine sediment risk and the greatest standard deviation in fine sediment risk.

### **8.3.2. Field-scale**

Outputs from both the Tichborne and Midlington sites highlighted the importance of topography in determining landscape connectivity. In neither site were cattle trails or cow ramps pathways for fine sediment movement. Unlike the catchment output maps, areas of fine sediment risk at the field-scale were contiguous.

*8.3.2.1. Tichborne site*

SCIMAP outputs from the Tichborne site identified two main routes of fine sediment risk; one route connecting the floodplain to the main river channel and the main river channel itself (Figure 8.12).



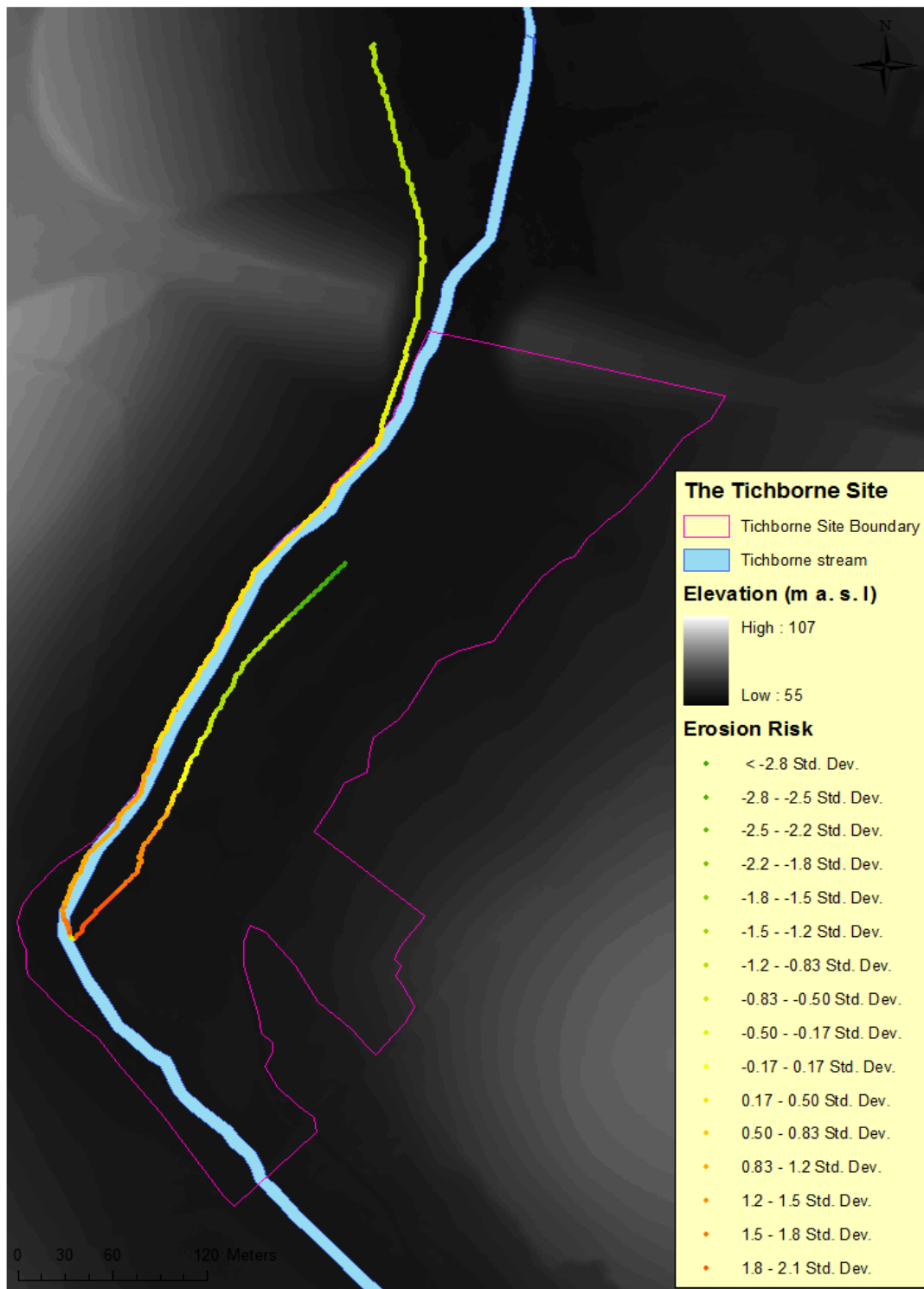


Figure 8.12. SCIMAP output of fine sediment risk at the Tichborne site. The area outside the site boundary was included in the analysis so that SCIMAP had a sufficient contributing watershed to produce a fine sediment risk output. The Tichborne stream flows from south to north.

The area of greatest fine sediment risk occurred at the riparian margin to the south-west of the site. In this location a former cattle crossing point exists (Figure 8.13).



**Figure 8.13.** The south-west corner of the Tichborne study site. A former cattle crossing point, demarcated by wooden fencing perpendicular to the direction of river flow, can be seen in the centre of the image. The contemporary crossing point is approximately 200m upstream.

There was no fine sediment risk within existing cow ramps or along existing cattle trails. This suggests these landforms do not act as fine sediment transport pathways at the Tichborne site, although they may still be sources of fine sediment.

The greatest fine sediment risk within the main river channel occurred within the site boundary, suggesting that the field containing cattle contributed more fine sediment than the area outside of the field. Fine sediment runoff from the field and the cattle trail that runs along the eastern boundary of the site appears to accumulate in the floodplain

pathway that flows from the north-east to the south-west, with increasing fine sediment risk with proximity to the main river channel. Moreover this fine sediment is then connected to the main river channel, which has above average fine sediment risk; this agrees with the catchment-scale modelling of the Itchen catchment.

#### *8.3.2.2. Midlington site*

The Midlington site contained numerous areas of potential fine sediment risk, with contiguous pathways from the north of the site to the south (Figure 8.14). As with the Tichborne site, there is no fine sediment risk in cattle trails or across cow ramps. In the northern section of the site, fine sediment risk is greatest within the main river channel, whilst to the south fine sediment risk is concentrated in a former channel that runs through the centre and along the western boundary of the site. This agrees with field observations and LiDAR data, which both suggest the presence of small levees either side of the River Meon at the Southern Midlington site.

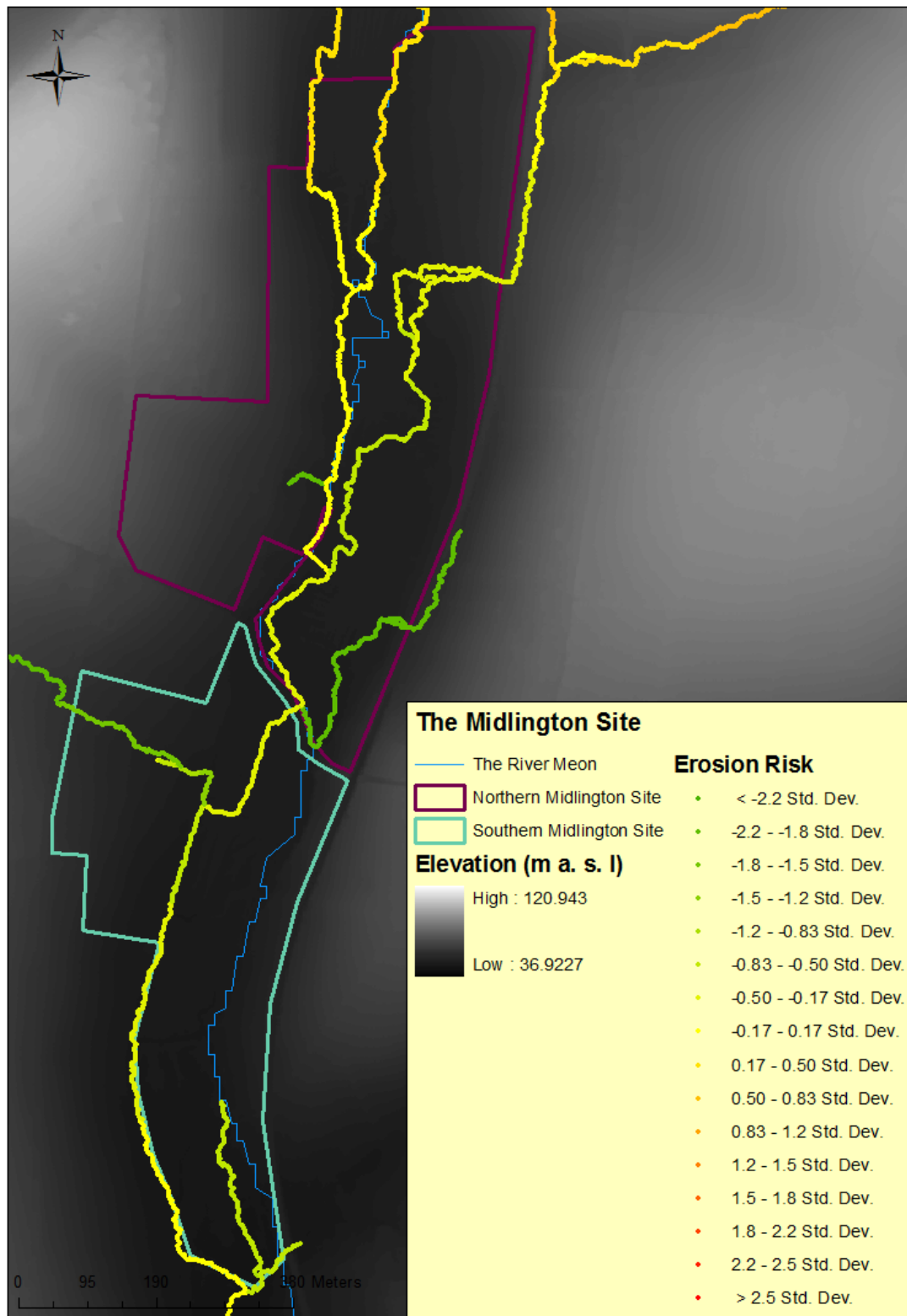


Figure 8.14. SCIMAP output from the Midlington site. The River Meon flows from the north to the south.

The severity of fine sediment risk is relatively consistent across the Midlington site, with areas of moderate risk throughout and three channels of low fine sediment risk: perpendicular to the main river channel to the south west of the Northern Midlington site; entering the Northern Midlington site from the east; and to the north west of the Southern Midlington site.

SCIMAP output from the Midlington site produced more channels than output from the Tichborne site. Output maps also suggest the Midlington site has greater landscape connectivity than the Tichborne site, although this may be partly due to differences in the size of the study sites. Additionally, overall fine sediment risk, as well as the mean sediment risk per output point, was greater at the Midlington site than the Tichborne site.

## **8.4. Discussion**

### **8.4.1. Catchment-scale**

There was no significant change in the overall amount of fine sediment risk in catchments due to cattle under the chosen parameters. Indeed, in some instances such as in the Meon catchment, including a cattle effect in the input variables for the SCIMAP model reduced overall fine sediment risk. However, we know from section 7.4 that soils subject to regular usage by cattle are more easily eroded than those that are not.

Several factors have contributed to this outcome. Firstly and most importantly, the erodibility of soils subject to poaching may have been underweighted. The weightings applied to cattle poaching inputs (Table 8.1) were based upon values in Reaney *et al.* (2011), who suggest that extensive pasture land could be given a SCIMAP erodibility value of 0.1, whilst intensive pasture land could be given a value of 0.2. Reaney *et al.* (2011) also note that any land cover that remains bare for part of the year could justifiably be given an erodibility value of 1.

| Poaching intensity | Run 1 | Run 2 | Run 3 (final values) |
|--------------------|-------|-------|----------------------|
| Low                | 0.25  | 0.125 | <b>0.05</b>          |
| Moderate           | 0.5   | 0.25  | <b>0.1</b>           |
| Heavy              | 0.75  | 0.375 | <b>0.15</b>          |
| Intensive          | 1     | 0.5   | <b>0.2</b>           |

**Table 8.3. The erodibility values used in the catchment-scale model runs were taken from the final calibration run (Run 3). These values appear in table 8.1 and were used as SCIMAP was either under of over responsive to other tested values. The calibration did not consider the land cover erodibility values prescribed by Reaney *et al.* (2011).**

Model calibration using different input values for poaching intensity (Table 8.3) revealed that the SCIMAP model was relatively sensitive to changes in input soil erodibility variables. Model runs one and two produced highly skewed fine sediment erosion risk maps in which more than 99% of all output points were within 0 and 0.17 standard deviations of the mean for the Itchen, Lee and Meon catchments.

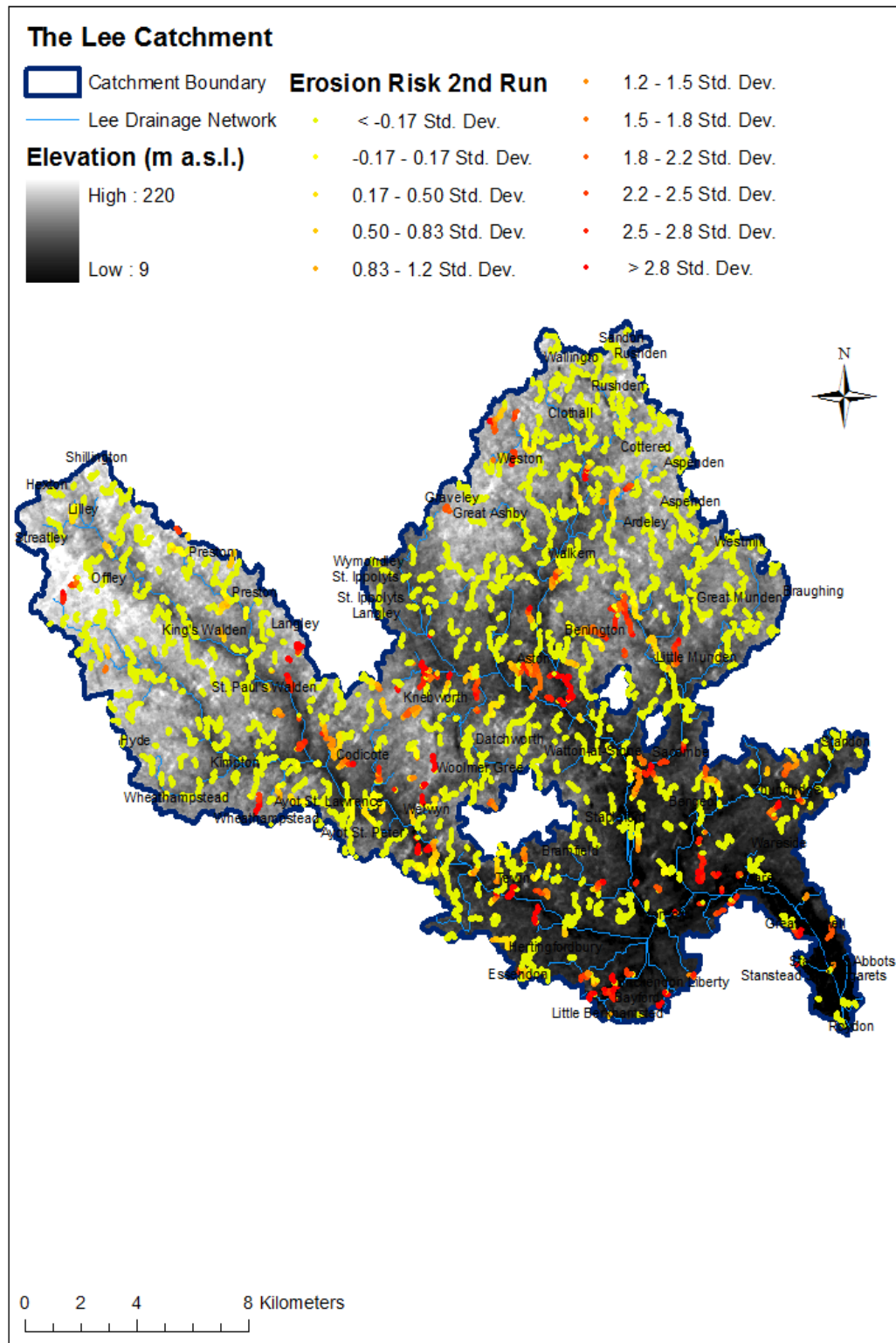


**Figure 8.15. Map output from Run 2 of SCIMAP using erodibility values listed in Table 8.3. Note the absence of green dots, which represented low fine sediment risk in previous figures, and the abundance of yellow dots, representing moderate fine sediment risk.**



In these output maps the modification of land cover to incorporate a cattle effect appears to overwhelm predictions of fine sediment risk (Figure 8.15). Changing the weighting of the poaching inputs influences fine sediment risk across the entire catchment, even in areas where there has been no change in land cover from the basic CEH map input. Furthermore, using weightings from Run 1 and Run 2 caused the intensity of fine sediment risk to be inverted, relative to using the final value weightings (Figure 8.16).

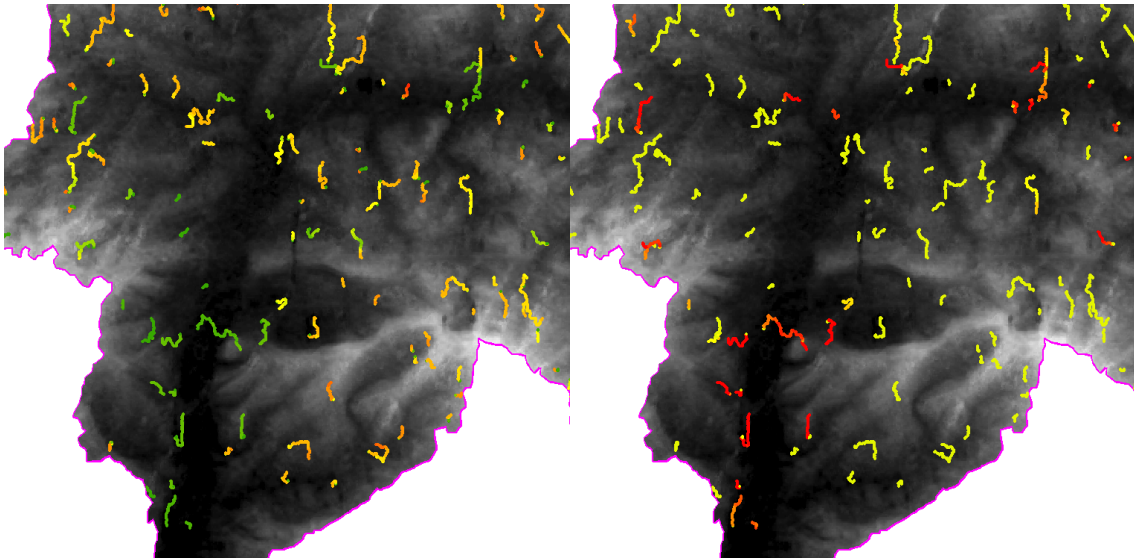


**Figure 8.16. Differences in fine sediment risk outputs (cattle) between the final map (left) and the map produced in run two (right). Areas of low fine sediment risk (green) in the final map appear areas of high fine sediment risk (red) in the run two output map. These snapshots are from the Itchen catchment.**

The reason for the inversion of results and disproportionately increased fine sediment risk when poaching effects are more heavily-weighted is unclear. Run 1 and Run 2 outputs for the Test catchment did not demonstrate this pattern, and produced identical output maps to the final output maps (Figure 8.17).



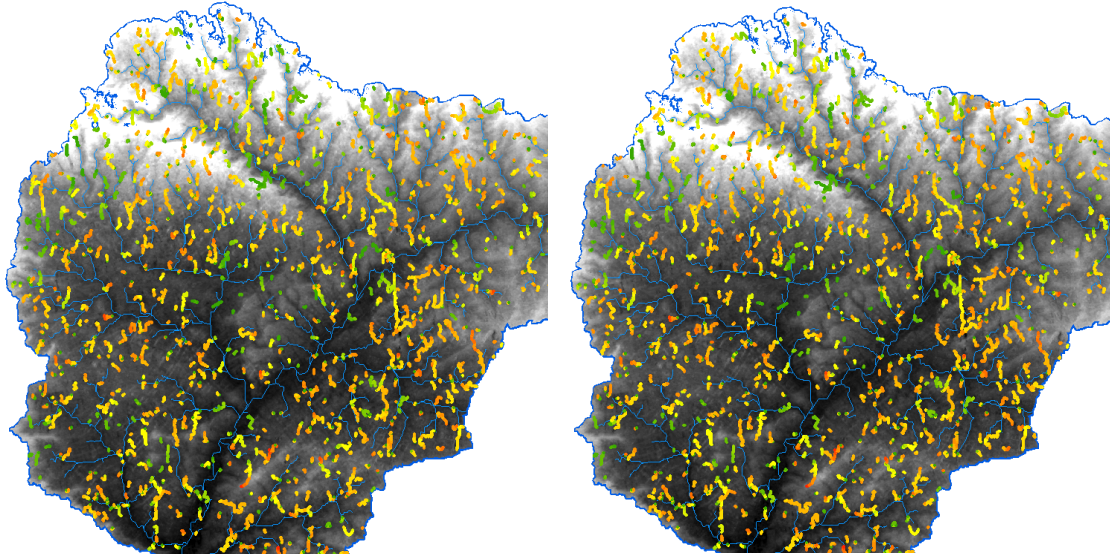


**Figure 8.17.** Outputs of fine sediment risk were identical between Run 2 (left) and the final run (right) in the Test catchment.

The Test catchment is over twice the size by area of any other catchment in this study, and it appears that catchment size affects the sensitivity of SCIMAP's erodibility input variables. Input erodibility values for the final SCIMAP outputs produced maps displaying areas of both high and low fine sediment risk across all catchments suggests these input values were suitable for this application. Hence, although greater weightings could have been given to cattle effects, using such values would have prevented comparisons of fine sediment risk between catchments.

The second reason for the relatively small difference in fine sediment risk between land cover and cattle output maps is the scarcity of locations with evidence of poaching. Of the 18510 River Habitat Survey data points across England and Wales, only 5510 had any evidence of poaching. Of these only 85 (Itchen: 19; Lee: 50; Meon: 4; Test: 12) of these poaching locations occurred within the catchments within this study. Resultantly, the input variables for the cattle and land cover maps were not substantially different; only 1km<sup>2</sup> of the 108km<sup>2</sup> area of the Meon catchment was modified between model inputs.

The third factor, and the reason for reduced fine sediment risk in the Meon catchment, is the misclassification or generalisation of land cover in the CEH input map. With a cell size of 1km<sup>2</sup> the CEH data fail to project small-scale land cover differences. Specifically, small areas of pasture adjacent to arable land may be misclassified as arable land. These misclassified areas are input into the SCIMAP model with an erodibility of 1 when they should have an erodibility of 0.2. Consequently, overlaying cattle effects in these areas causes the local erodibility to fall from the misclassified value of 1 to a poaching value between 0.05 and 0.2. It therefore appears that there is a reduction in the fine sediment risk between the basic land cover map and the cattle effects map, when in actuality the effects of poaching were always present but were not detected in the coarse resolution CEH land cover data. Where poaching values (Table 8.1) replace higher land-cover values the map output gives the impression that cattle presence is leading to a decrease in erodibility, when it is likely the opposite is true; this is a failing of the classification values.

All of these factors aside, it remains that based upon poaching data and given the weightings attributed, SCIMAP outputs evaluated the effects of cattle upon fine sediment risk to be relatively minor across a number of English chalk stream catchments. Although this appears to contradict field-scale findings regarding river bank destabilisation (section 7.1) and cattle trail erodibility (section 7.4), the SCIMAP outputs contain information relevant to their scale. Specifically, SCIMAP outputs highlight the disconnected nature of chalk stream environments; cattle may increase soil erodibility locally but this has no effect upon overall fine sediment risk if the area of risk is not connected to the main river channel. Moreover whilst cattle trail soil erodibility may be higher than non-cattle trail soil erodibility, areas of river bank poaching occupy such a small fraction of chalk stream catchments, relative to other easily eroded land cover types (i.e. arable farmland), that the effects of cattle grazing are comparatively unimportant.

Finer-resolution, higher-quality data on the distribution of cattle and the landforms they produce would improve the accuracy of SCIMAP outputs. Low-level aerial photography maps of cattle trails and cow ramps, such as that discussed in section 7.7, could be used

for this purpose. Using such data the cumulative effect of cattle grazing upon fine sediment risk at the catchment scale could be better assessed. In addition the classification system for erodibility values could be improved upon significantly, with the current recommended values for intensive pasture (erodibility value 0.2) and extensive pasture (erodibility value 0.1: Reaney *et al.* 2011) appearing to be underestimated, particularly when compared to other land-use types such as arable farming (erodibility value 1). The appropriate classification of erodibility values is essential for future work attempting to understand the effects of cattle grazing upon fine sediment risk in chalk stream catchments.

#### **8.4.2. Field-scale**

Results from both the Tichborne and Midlington sites suggest that cattle trails and cow ramps, although likely sources of fine sediment, are not the landforms through which fine sediment risk is transmitted across the landscape. Elevation and changes in topography appear to be the key control upon the accumulation of fine sediment risk across chalk streams at the field-scale.

This finding is counterintuitive insofar that cattle-made landforms often appear, visually, to connect different parts of the landscape. However and as previously discussed in section 4.2.2.3, the location of cattle trails may be determined by surface roughness, soil organic matter content, the availability of shade, the presence of fencing and the distribution and quality of forage (Hoare, 1992; McKillop and Silby, 1998; Mader *et al.*, 1999; Phillips, 2002; Phillips and Morris, 2003). As such it should not be expected that cattle trails develop along the same pathways as water channels.

Although cattle trails and cow ramps may not act as direct pathways for fine sediment, it remains likely that they are sources of fine sediment. At both the Tichborne site and the Midlington site, fine sediment risk was greater within the boundary of the field where cattle were kept than outside of it. This can be explained by combining data from the GPS study (section 6.2) with the SCIMAP output for the Tichborne site (Figure 8.18)

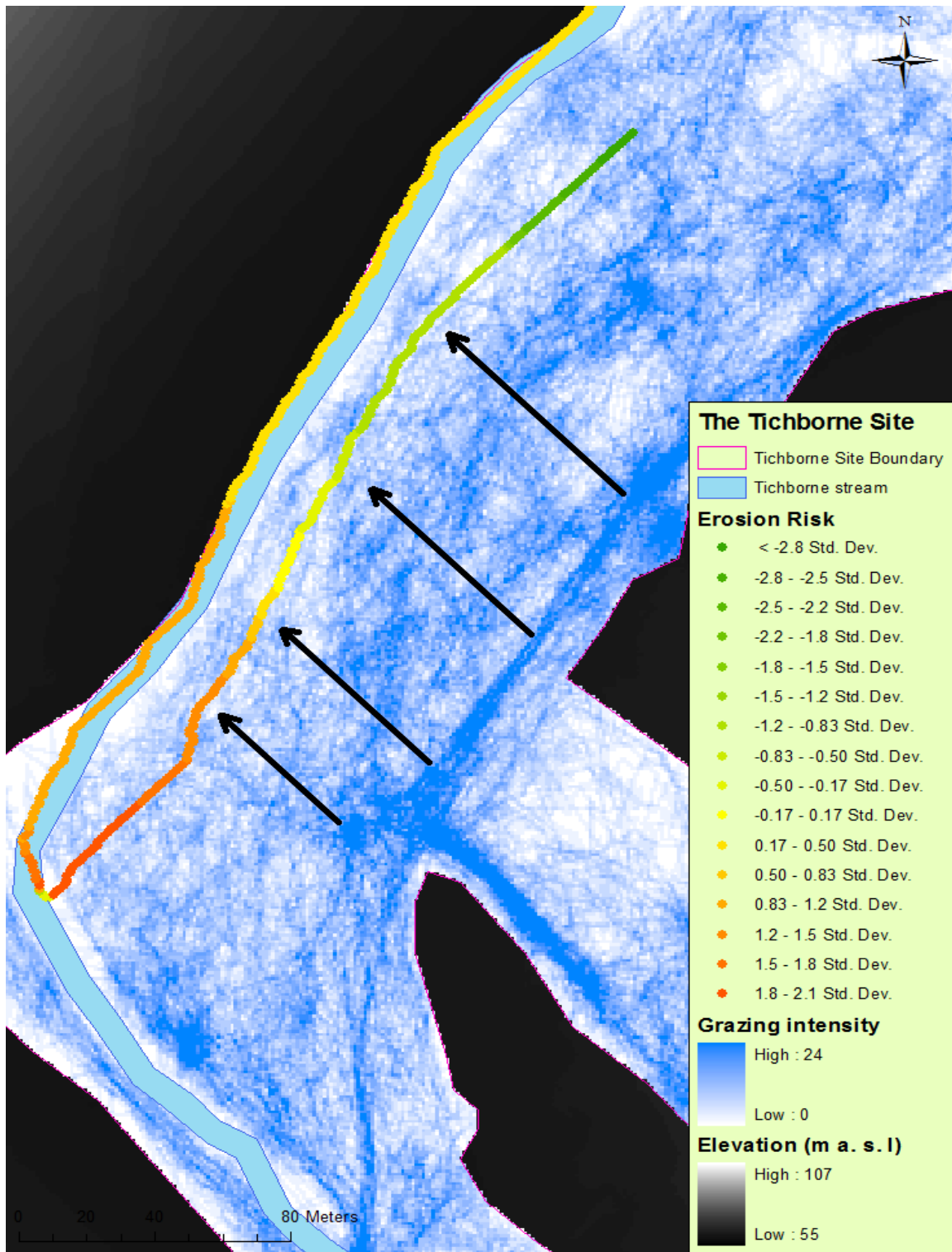


Figure 8.18. A map combining GPS cattle collar data with SCIMAP output from the Tichborne site. Blue areas represent the areas of most frequent usage by cattle and likely areas for the occurrence of cattle trails. Black lines represent the movement of fine sediment downslope from cattle trails to fine sediment risk pathways.

Fine sediment will be transported downslope from the relatively high elevation cattle trails into relatively low-lying fine sediment risk pathways via hillslope and hydrological processes. Although there is a clear physical link between areas of high grazing intensity and the main river channel, there is no fine sediment movement within these features; cattle trails run parallel to the contour of the valley and there is no change in elevation to induce fine sediment movement. This finding underlines the importance of topography in determining connectivity within a landscape, and shows that if there is no linkage between critical source areas and the drainage network then the risk posed by such sources is minimal (Lane *et al.*, 2009; Reaney *et al.*, 2011).

### **8.5. Testable hypotheses**

The testable hypothesis for this section ( $H_5$ ), that the areas of greatest risk from diffuse pollution and fine sediment sources created by cattle are those with the greatest connectivity to the landscape and which cattle most frequently occupy, was not fully proven. Specifically, the areas of greatest risk from fine sediment are those that are well-connected to sediment sources generated by cattle activity. Connectivity, which is a function of local topography, land cover and precipitation, is the greatest control on fine sediment risk; the presence of cattle alone does not determine risk.

### **8.6. Conclusion**

This study has demonstrated that using only a small number of input variables (i.e. topographic, rainfall and land-use data) a diffuse pollution risk model (SCIMAP) can be used to identify those parts of the river network that are at greatest risk from fine sediment inputs within chalk stream catchments. Furthermore, it has been shown that by modifying the land-use input variable to incorporate river habitat survey data of river bank poaching activity, it is possible to modify the model output to take into consideration the effects of cattle grazing. The study also successfully adapted the SCIMAP model to work at the reach-scale rather than the conventional catchment-scale

by reducing the cell size of the model inputs and output; this has not been done previously.

SCIMAP outputs suggest that the effects of cattle grazing upon fine sediment risk in chalk stream environments are minimal at the catchment-scale. At the field-scale, cattle trails and cow ramps were shown not to act as direct pathways for the movement of material from the terrestrial to the aquatic environment, although it is likely they are important sources of fine sediment. There is a discrepancy between the effects of cattle grazing upon fine sediment risk at the catchment-scale compared to the field-scale; this is explained by methodological differences (e.g. the resolution and type of data used) and scale differences (e.g. the signal of localised cattle effects is lost at the catchment scale).

Further research is necessary to establish how the effects of field-scale cattle landforms impinge upon fine sediment risk at the catchment-scale. Outputs for this study are partly a function of misrepresented land cover inputs and insufficiently resolved datasets. Specifically, relatively erodible cattle trails and cow ramps are not detected in conventional remotely sensed land cover data. Future work would involve the use of low-elevation aerial images, or an equivalent high-resolution dataset, to map the distribution of cattle-made landforms at the catchment-scale. Using such maps as inputs to the SCIMAP model, areas of fine sediment risk in chalk stream catchments could be better predicted.

## **9. The effects of cattle grazing in English chalk streams**

### **9.1. Study summary**

Groundwater-fed English chalk streams are characterised by stable planforms, clear alkali waters and gravel bed substrate (Sear *et al.*, 1999; Smith *et al.*, 2003). With over four thousand kilometres of river reach spanning from the River Hull in Lincolnshire to the River Frome in Dorset, English chalk streams are of great ecological, cultural and economic importance both regionally and internationally (Mainstone, 1999; Environment Agency, 2004; Lawton *et al.*, 2010). Achieving good ecological and chemical status for English chalk streams is an important objective of the Water Framework Directive (WFD, 2000); cattle activity has the potential to work against this objective.

With approximately 10 million cattle in England and the greatest combined length and number of chalk streams in Europe, the potential for interactions between cattle and chalk streams is high (Environment Agency, 2004; Clothier, 2009; DEFRA, 2010a).

An extensive literature review revealed that although many studies have been conducted into the effects of cattle grazing (e.g. Trimble and Mendel, 1995; Belsky *et al.*, 1999), very few have considered how these effects may manifest in chalk stream environments. Moreover, existing studies focus almost exclusively upon the impacts of cattle but seldom investigate the drivers of cattle-river interaction. This highlighted a broader research gap: how and why do cattle interact with watercourses and what are the effects of these interactions upon aquatic systems?

Analysis of the literature allowed for the development of a conceptual framework which identified three overarching effects resulting from cattle activity: herbivory (cattle eating plants); animal transit (cattle locomotion); and excretion (faecal and urinary deposits).

Theoretical models and hypotheses were postulated that attempted to explain the physiological and psychological mechanisms behind cattle landscape utilisation.

Thereafter, the likely ecological and geomorphic effects of cattle grazing in chalk streams were considered. A number of testable hypotheses regarding cattle behaviour (e.g. cattle will spend more time in rivers when it is warmer) and cattle impact (e.g. soils in areas

subject to greatest usage by cattle will have a lower horizontal shear stress than areas infrequently used by cattle) were put forward.

Having highlighted the need for further research and posed a number of relevant questions, the next step was to establish the techniques and methods most suitable to ensure the realisation of the project's aims and objectives. A broad assessment of potential methodologies to monitor and record both cattle behaviour (e.g. Boitani and Fuller, 2001) and impact (e.g. Belsky *et al.*, 1999) was undertaken. Disparate strands of vaguely related studies from the disciplines of ecology, biology, ethology, geomorphology, hydrology, soil science and animal management were coalesced. Several methods constituting the empirical research element of the project emerged from this review.

With respect to cattle behaviour, an intense high-temporal resolution observational study of cattle activity within chalk stream environments would be undertaken. The spatial component of cattle landscape interaction would be recorded using GPS cattle collars. In this way, the amount of time cattle spent utilising different zones could be quantified and their behaviour recorded.

Having monitored and analysed cattle behaviour, several studies were employed to assess the impact of this activity. A terrestrial laser scanner (TLS) was used to record changes in river bank morphology over time at a cattle crossing point. In-stream water quality probes were co-ordinated with GPS cattle collars to identify turbidity events resulting from cattle ingress to the river. Chemical analysis of cattle faeces was undertaken to quantify the amount of key nutrients (nitrogen, phosphorous and potassium) being loaded into chalk streams via excretion. A cohesive strength meter was used to compare the erodibility of floodplain areas subject to frequent use by cattle and those seldom used by cattle. Low-altitude aerial photography from a helikite was amalgamated in a vision-based computer program to generate maps of the distribution of cattle-made landforms. Results from these studies then provided the input data for several calculations, as well as the SCIMAP landscape connectivity model.



## **9.2. Key findings**

During the observational study cattle spent approximately 2% of their time in-stream and approximately 7% of their time in the riparian zone. A statistically significant positive correlation between air temperature and the amount of time cattle spent in-stream was identified. It was also observed that cattle preferentially defecated in-stream.

In the GPS study, cattle spent 0.88% of their time in-stream and 2.43% of their time in the riparian zone. Discrepancies in aquatic and riparian zone utilisation between studies are attributable to differences in the duration and timing of observation (eight hours from 0800 to 1600 in the observational study compared to 24 hours in the GPS study).

Laboratory analysis of cattle faeces to establish excrement nutrient content indicated that levels of nitrogen (0.79% of faeces weight), phosphorous (0.43% of faeces weight) and potassium (0.43% of faeces weight) within cow pats broadly agreed with values published in previous studies. The chemical oxygen demand of cattle faeces was also recorded (25mg<sup>l</sup><sup>-1</sup> of oxygen removed per 1g of faeces). Moreover, it was found that water constituted 89% of the total weight of cattle faeces; cattle faeces are highly soluble and mobile relative to other livestock excrement such as that from sheep or horses.

The cohesive strength meter revealed a statistically significant difference in erodibility between unvegetated soils in cattle trails and adjacent vegetated soils outside of cattle trails ( $T = -73.46$ ,  $P = 0$ ,  $DF = 5$ ). Cattle trail soils had an average critical horizontal shear stress of 1.58Nm<sup>-2</sup>, whilst non-cattle trails soils had an average critical horizontal shear stress of 8.01Nm<sup>-2</sup>. It was shown that cattle exert sufficient force during locomotion to cause soil deformation and displacement of both vegetated and unvegetated soils; cattle trails can form in any soil within chalk stream environments given repeated disturbance.

Analysis of changes in river bank topography, as derived from digital elevation models developed using TLS, showed that cattle can cause a net reduction in river bank volume; approximately 0.18m<sup>3</sup> of bank material was removed over a six week period at one cattle

crossing point. However, cattle were also responsible for the movement of allochthonous material from the floodplain to the river bank. Resultantly, the principle finding of the TLS study was that cattle induced heterogeneity in bank elevation, with areas of erosion at the base of cow ramps and areas of deposition at the top.

Only one increased turbidity event was confidently attributed to an instance of cattle access to the river. Methodological limitations and non-cattle turbidity events hindered the establishment of a significant correlation between cattle access and turbidity. Nonetheless, it was shown that in-stream cattle activity can cause substantial short-term increases in turbidity due to the mobilisation of fine sediment. However, these events account for a relatively small amount of the total turbidity recorded; effluent discharge from an upstream sewerage treatment works and surface runoff caused the greatest turbidity.

Low-elevation aerial images from a helikite-mounted camera mapped the location of cattle-made landforms. When combined with GPS collar data, landform maps revealed that the distribution of cattle trails and cow ramps related directly to the areas of most frequent occupancy by cattle.

The final stage of the project, the application of the SCIMAP connectivity model, mapped diffuse pollution and fine sediment risk at the reach and catchment scale. A number of chalk stream catchments, including the River Itchen and the River Lee, were included in the analysis alongside reach scale mapping of the Tichborne study site. It was shown that elevation, rather than the location of cattle trails and cow ramps, was the most important control upon the distribution of fine sediment risk hotspots. Although cattle trails and cow ramps act as fine sediment sources, these sources only contribute fine sediment to river channels if they are connected topographically.

### **9.3. Implications for management**

The findings of this thesis have a number of potential implications for river management, cattle management, and for the management of cattle grazing in English chalk streams.

These implications relate to cattle psychology and physiology, as well as the geomorphic, hydrological and ecological consequences of cattle behaviour.

The utilisation of the aquatic environment by cattle throughout the study has highlighted the role lotic systems can play in the day-to-day activities of bovine livestock. Cattle used watercourses for thermoregulation, grazing and drinking. From a cattle welfare perspective it seems beneficial to enable cattle access to rivers, where they can freely acquire fresh water from the channel and high-quality forage from the riparian margin. Moreover, access to a stream provides a constant source of drinking water for cattle, negating the need for drinking troughs.

From a river management perspective there is less of an incentive to allow cattle access to English chalk streams. This study has shown the potential for cattle faeces to have a significant effect upon water quality in terms of increasing orthophosphate concentrations and lowering dissolved oxygen levels. Cattle have also been shown to increase in-stream turbidity through the disruption of fine sediment and can cause potentially irreversible morphological changes to channel planform by creating cow ramps. Whilst there are ecological benefits to be accrued from the disturbance caused by cattle, there is a fine line between desirable levels of disturbance in an otherwise homogeneous environment and overgrazing. Therefore cattle may require careful management, particularly around sensitive areas such as SSSI's, SAC's or salmon spawning grounds. Stocking densities should not exceed 2 livestock units per hectare and cattle should only be kept at pasture during the traditional grazing season, from May until October. In sensitive areas it may be advisable to employ a rotational grazing regime, moving cattle from one field to another within the same grazing season in order to allow the vegetation community to recover.

However, even if these suggestions are implemented it may not be possible to prevent cattle from having an effect upon in-stream morphology. Our study has shown that an individual cow can exert sufficient shear stress to cause bank erosion, and it is feasible that cattle may create cow ramps and cattle trails even when stocked at low densities.

Moreover because such geomorphic agency is unlikely to be remedied by natural fluvial processes, care should be taken to ensure these features are only allowed to develop where they may be ecological or geomorphologically beneficial. For example if cow ramps created by cattle improve lateral connectivity where there is otherwise limited floodplain functionality then cattle activity is having a positive ecological effect. Conversely if cattle trails are acting as a fine sediment transport pathway by connecting the river channel to nearby fields that are used for arable farming, it may be advisable to remove the grazing pressure and allow the vegetation community to recover.

Where cattle are kept within fields adjacent to chalk streams there are a number of mitigation measures that could be used to minimise their negative environmental impact and optimise their positive environmental benefits. Allowing cattle access to only areas of the riparian margin containing mature trees will reduce river bank erosion, with tree roots providing protection for soils that may otherwise be eroded by cattle activity. Moreover during the summer trees may provide shading that will allow cattle to thermoregulate their body temperature without entering streams. Erecting fencing in especially vulnerable locations (e.g. at access points adjacent to riffles used by salmonids as spawning habitat) is advisable. In the absence of specific features, periodic riverside fencing may achieve the highest levels of biodiversity, with fenced-off areas creating a habitat for grazing-intolerant plant species.

Although the economic imperatives of population growth and an ever-increasing demand for cattle derivatives may often supercede the ecological value of maintaining these relic landscapes, care should be taken not to overlook the ecosystem services provided by chalk streams. The most appropriate management will likely involve a risk-based approach. For example, cattle may not be allowed access to regionally, nationally or internationally important chalk stream sites (e.g. the River Itchen SSSI), but may instead be allowed to graze in homogeneous, degraded or neglected locations, where their presence may benefit the local ecosystem.

## **9.4. Conclusion**

Overall the effects of cattle grazing upon English chalk streams appear relatively unimportant compared to other pressures such as weed cutting, fertiliser use and water abstraction. The most significant effects relate to faecal inputs and nutrient loading, which at current stocking densities contribute substantial quantities of phosphate to chalk streams.

Geomorphologically, cattle can modify chalk streams in ways they would not be modified in the absence of cattle; creating cow ramps and cattle trails. However, the net effect of this appears to be minimal. Cattle do cause short-term increases in suspended sediment concentrations when they enter and exit the aquatic environment but such events do not mobilise as much sediment as elevated discharge events. Equally, cattle do create cow ramps and cattle trails but the total amount of bank material removed due to cattle movement is small.

The principle question may be whether land and river managers are willing to tolerate the long-term changes in planform that are likely to result from cattle activity within chalk streams. As naturally low-energy systems, chalk streams do not generally experience changes in planform due to overbank flows and flood events. Consequently, any cattle-made modifications to channel shape are unlikely to be modified by natural geomorphic agency, even after the cessation of grazing pressure.

At the correct stocking densities, the presence of cattle-made landforms can introduce habitat heterogeneity into otherwise homogeneous chalk stream environments. The minimal effects of river bank destabilisation, fine sediment mobilisation and increased soil erodibility appear to be offset by the ecological benefits of variable sward heights, the presence of cattle faeces and the modification of in-stream flow.

However, whether species with narrow habitat optima, such as salmon, benefit from the presence of cattle, remains unclear. Even the small quantities of sediment mobilised from

the river bed and removed from river banks by cattle could have a deleterious effect upon organisms particularly susceptible to elevated concentrations of suspended fine sediment. Further research is required into these biotic-abiotic relationships that concern key species whose conservation may be prioritised ahead of overall increases in biodiversity.

## 1.1. Summary

As discussed, although visual monitoring has been the traditional means of recording cattle behaviour, there is an increasing body of literature using GPS and remote sensing to good effect. In either instance, there are a range of different methodologies that can be employed that vary in terms of their duration, frequency and scale. The suitability of a particular approach is dictated by the aims and objectives of the study. With respect to measuring cattle grazing impact, there are a number of useful indicators that can be measured. These indicators measure abiotic or biotic variables, with the suitability of a particular indicator again determined by the desired outcomes of the study. The future of cattle grazing studies looks towards behavioural and impact modelling studies, with a small number of existing models providing a platform on which to build.

From this review of existing methodologies it has been possible to identify those that will be of greatest use in this study. A high-temporal resolution observational study of cattle will be undertaken to improve our understanding of cattle-chalk stream interactions. A study of cattle spatial distribution within chalk stream environments will also be undertaken using GPS cattle collars to quantify the amount of time cattle spend in

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