Livestock Science 146 (2012) 59–66

Contents lists available at SciVerse ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Temperature-driven river utilisation and preferential defecation by cattle in an English chalk stream

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ARTICLE INFO

Article history:
Received 30 November 2011
Received in revised form 17 February 2012
Accepted 20 February 2012

Keywords:
Behaviour
Fluvial
Geomorphology
Groundwater
Water meadows
Cattle

ABSTRACT

Cattle have the potential to be important geomorphic and ecological agents in the low-energy, high biodiversity chalk rivers of southern England. To improve our understanding of cattle–river interactions, a unique high temporal resolution study of cattle behaviour and distribution was conducted across 500 h on a chalk river in Hampshire, England (UK) between April and October 2010. It was observed that cattle spent approximately 2% of their time in the aquatic environment and approximately 7% of their time in the riparian zone. Cattle activity and distribution varied according to the time of day and the time of year. A statistically significant correlation was recorded between the amount of time spent in-stream by cattle and air temperature. Cattle also defecated five times more frequently in-stream than the average defecation frequency, contributing greater than expected direct organic matter and nutrient inputs. The study suggests that the impacts of cattle in chalk river environments may have been underestimated, particularly at a time of global warming.

1. Introduction

Groundwater-fed chalk rivers and their associated floodplain wetlands are at the forefront of the conflict between biodiversity conservation and optimal land management (Environment Agency, 2004; Raven et al., 1998). Characterised by stable planforms, low stream densities and clear, alkaline waters, chalk rivers are internationally recognised for their ecological value, with nearly four thousand kilometres of chalk river reach in England; the largest number of chalk rivers of any European country (Jackson and McLeod, 2000; Lawton et al., 2010; Mainstone, 1999; Sear et al., 2003; Smith et al., 2003).

The conservation of chalk rivers is a key concern for land managers, with ten chalk river Sites of Special Scientific Interest and four candidate Special Areas of Conservation across the UK (Environment Agency, 2004; Mainstone, 1999; Raven et al., 1998). However, pressures on these ecosystems, including water abstraction, urbanisation, agriculture, water pollution, fine sediment inputs and invasive species establishment, can act against sustainability objectives (Clothier, 2009; Environment Agency, 2004; Mainstone, 1999; UKBAP, 1995). One pressure whose effects within the chalk river environment are poorly understood is cattle grazing.

Although much has been written about the ecological and geomorphological consequences of cattle grazing in certain ecosystems (Kauffman and Krueger, 1984; Trimble, 1994; Trimble and Mendel, 1995), there are few studies analogous to chalk rivers. Nonetheless, the supposedly generic effects of cattle grazing, such as river bank destabilisation and plant mortality, have been cited in land management plans as a basis for cattle exclusion in English chalk rivers (Lawton et al., 2010; Raven et al., 1998), despite several studies from other environments that suggest cattle can enhance habitat heterogeneity and species richness (Curry et al. 2008; Hiernaux et al., 1999; Pykälä, 2005).

To date there have been few studies into the way in which cattle behave in chalk river environments, with the limited existing body of literature focusing solely on the consequences of allowing cattle access to chalk rivers (Harrison and Harris,

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doi:10.1016/j.livsci.2012.02.022

2002; Summers et al., 2005, Summers et al., 2008). This dearth of studies is not specific to chalk rivers, and highlights a broader research gap; how and why do cattle interact with watercourses?

2. Materials and methods

2.1. Site descriptions

The study was conducted across two adjacent chalk river sites in Hampshire, England: the northern and southern Midlington sites on the River Meon at Droxford. The northern Midlington site covers 29 ha and is bisected by the River Meon which runs for 1200 m through the site. Access to the River Meon at the north Midlington site is partially restricted by barbed-wire fencing that runs for 600 m along its length, leaving 600 m of accessible river. The southern Midlington site is 19 ha in size, with 770 m of accessible river and no river-side fencing. Both sites share a landscape and cultural history that is characteristic of southern-England chalklands. Evidence of water meadow management is clear, with numerous artificial drainage ditches across both sites, superimposed upon relict floodplain channels (Everard, 2005). Neither site contained water troughs, although both drainage ditches and floodplain channels were observed to retain surface water following large precipitation events.

Hydrologically, the River Meon is typical of a classic English chalk river, with a groundwater dominated flow regime, stable temperatures, and a non-flashy flood hydrograph (Sear et al., 1999; Smith et al., 2003). The river is 34 km in length with an average discharge of 0.98 ms^{-3} and recorded flow velocities in excess of 1 ms^{-1} within the study reach. Water quality is naturally high; clear, alkaline and mineral-rich (Smith et al., 2003).

Geomorphologically, the floodplain soil is characterised by a shallow, humus-rich surface layer containing silt alluvium and deep peat subsoils with small fragments of chalk (Melville and Freshney, 1982). In-stream sediments are predominately flint gravel-based, although fine sediment accumulates in areas of slow flow (Smith et al., 2003). Pool-riffle sequences are present, as well as cattle-made bank landforms, or cattle ramps; destabilised, shallow banks created by cattle repeatedly entering and leaving the aquatic environment (Trimble, 1994; Trimble and Mendel, 1995). River depth does not exceed 2 m at either site, with the majority of the river at a suitable depth for cattle access and river crossing (<1 m depth).

Ecologically, the sites provide an array of different habitats and support a large number of common chalk river organisms, including riparian plants (e.g. *Carex riparia*), emergent aquatic macrophytes (e.g. *Mentha aquatica* and *Nasturtium officinale*), fish (e.g. *Thymallus thymallus*, *Salmo trutta* and *Lampetra planeri*), invertebrates (e.g. *Ephemeroptera* spp.) mammals (e.g. *Arvicola terrestris*), birds (e.g. *Motacilla cinerea* and *Ardea alba*) and amphibians (e.g. *Rana temporaria*: Mainstone, 1999; Raven et al., 1998; UKBAP, 1995).

The climate of the area is temperate; typical of southern lowland England. In the study year (2010) total precipitation was 100 mm below average and air temperature in the summer months was approximately 0.5 °C above average (compared to values from 1971 to 2001; Fig. 1: UK Met Office, 2010).

2.2. Study animals

From April until late-October 2010, the northern Midlington site was occupied by 35 Holstein bullocks aged between 10 and 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 and 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.

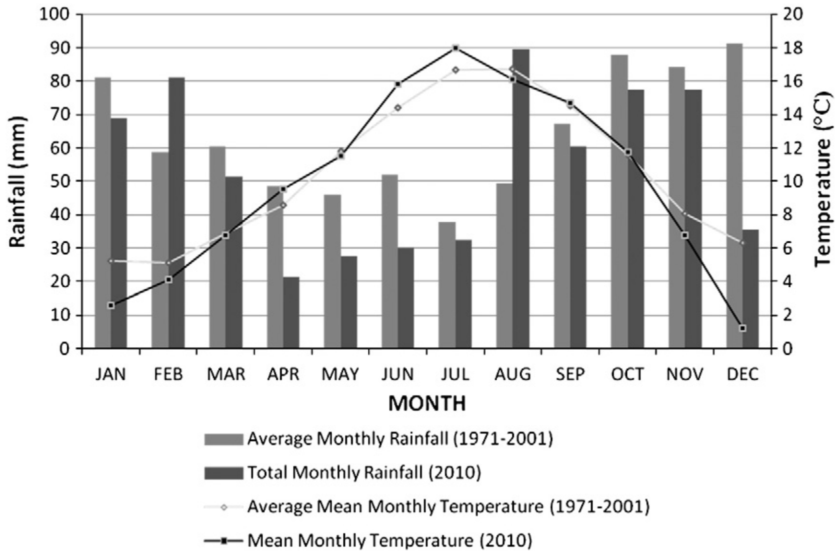

Fig. 1. Climate data for southern England (Southampton Weather Station: UK Met Office, 2010).

2.3. Field methodology

Cattle were observed for 59 days between April and October 2010: 30 days at the northern Midlington site and 29 days at the southern Midlington site. Cattle were monitored continuously for 450 min between 0830 and 1600 h each 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 min prior to the first observation each day, and left 10 min after the final observation of each day. The observer remained within approximately 50 m of the animal at all times and within 200 m 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 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 (Tables 1 and 2); 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.

In addition, on observation days after 11th May 2010, herd activity data were also collected (22 days at the southern Midlington site and 20 days at the northern Midlington site). At 1 min intervals, the number of cattle in the herd was counted and their behaviour 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. This data, accounting for air temperature, precipitation events, overhead conditions (e.g. cloudy, clear skies, mist), air pressure and humidity every 30 min, was extrapolated (averaged) across the observation data sets, providing minute by minute values for each variable.

Table 1
Categories of cattle behaviour for the observational study.

Behaviour class	Description
Defecating	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 activity supercedes any other behaviour.
Drinking	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.
Grazing	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.
Moving	Behaviour in which animals move through the landscape continuously. No head-down position or grazing. May include bucking and running as well as walking.
Other	Behaviour including grooming, scratching, fighting, playing, browsing and any other activity that is not covered by the previously listed behaviours.
Resting	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 supercedes the Other classification.
Standing	Behaviour in which animals are standing but static and not grazing or involved in another activity such as grooming. May include ruminating.
Urinating	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 supercedes any other behaviour.

Table 2
Classification of location types.

Location class	Description
Aquatic	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.
Floodplain	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 supercedes the Wooded classification in Floodplain environments containing trees
Wooded	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 (*Trifolium* spp.) and the common nettle (*Urtica dioica*)
Valley	Landscape elements in the valley. These areas are identified both visually within the field and from LiDAR data as regions of high elevation (>10 m above the height of the rivers' surface)
Riparian	Any area within 5 m of the main river channel that is not within the channel itself. The Riparian classification supercedes the Wooded classification in riparian environments containing trees
Terrestrial	Landscape elements within the floodplain that are neither floodplain channels nor within 5 m of the main river channel nor under trees

2.4. Data analysis

The area of each location type was derived from analysis of LiDAR data of site topography 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 co-efficient 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 pair-wise 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.

3. Results

3.1. Cattle activity and site

Neither the amount of time cattle spent involved in different behaviours (Table 1: $N=8$, $T=0$, $P=1$, $df=13$) nor the amount of time cattle spent in different locations (Table 2: $N=6$, $T=0$, $P=1$, $df=9$) varied significantly between sites. However, cattle behaviour did vary from location to location; cattle spent approximately 3.2% of their time in the aquatic environment defecating, compared to 0.6% of their time defecating overall (Fig. 2). Moreover, Hunter's (1962) index of preference shows a discrepancy between cattle landscape utilization and landscape availability; cattle preferred certain areas within the landscape (Table 3).

3.2. 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 min during which at least one herd

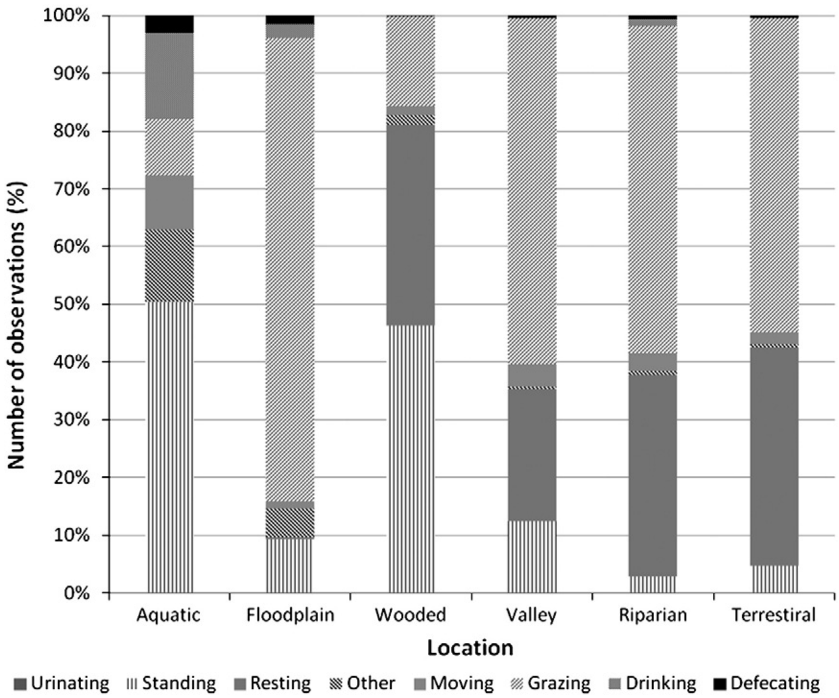

Fig. 2. Cattle behaviour by location. The percentage of observations cattle were involved in different activities as a proportion of the total number of observations in each environment.

Table 3
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.

	Aquatic	Floodplain channels	Wooded	Valley	Riparian	Terrestrial
Northern site						
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_i	*0.73*	*0.62*	**1.71**	*0.25*	**2.60**	**1.83**
Southern site						
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*	**1.91**	*0.14*	**1.15**	**2.05**

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.

3.3. Cattle activity and time of day

The location of cattle varied according to the time of day (Fig. 3). For 1.36% of observations made between 08:30 and 14:29 cattle were in-stream, compared to 4.38% between 14:30 and 15:59. Between 10:00 and 14:29 the utilisation of the riparian and valley environments fell below the average (riparian mean: 7.95%; valley mean: 8.55), whilst wooded environment utilisation was greatest between 10:45 and 12:59. Floodplain channels exhibited the least variability by time, whilst the terrestrial environment was used extensively (mean = 66.2%) but variably (maximum = 74.58%, minimum = 56.84%).

Differences in behaviour by time of day were characterised by consistency in defecating, urinating, drinking, other behaviours and moving, and variability in grazing, resting and standing behaviour. Cattle spent the most time standing and resting between 10:45 and 12:59 (15.89% standing and 42.67% resting). Over the same period (10:45 until 12:59) cattle spent 38.24% of their time grazing, compared to a mean value of 49.37% overall and a maximum value of 72.21% (recorded between 08:30 and 09:14); when cattle were not grazing, they were often observed resting.

3.4. Cattle activity and time of year

The behaviour and location of cattle varied by the month and across the grazing season. The terrestrial location was consistently the most frequently utilised throughout every month (mean = 65.85%), with the time spent in the terrestrial environment ranging from 55.22% in July to 81.77% in August. Aquatic environment utilisation peaked in July (4.33%), whilst riparian environment utilisation differed between April, May, and July (mean = 12.8%), and August, September and October (mean = 1.43%; $N = 3$, $T = 17.46$, $P = 0.003$, $df = 2$). For 36% of observations made in October, cattle were recorded in the valley environment; a value four times greater than the mean (8.09%) for this environment. Unlike location, there were no statistically significant differences in cattle behaviour between months.

3.5. 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

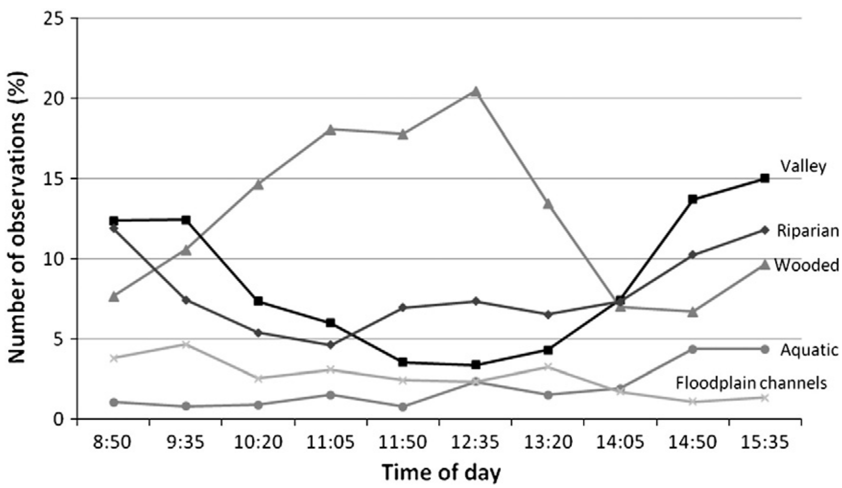

Fig. 3. Changes in landscape utilisation by cattle over time.

relationship was observed between humidity and the time cattle spent in-stream ($r = -0.084$, $N = 80$, $P = 0.448$).

With respect to cattle location, the valley environment was relatively popular 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: Fig. 4).

4. Discussion

4.1. Location

Haan et al. (2010) observed that cattle spent 10.5% of their time in the streamside zone in their three year study of Angus cow activity in North America, compared to our study, which observed that cattle spent, on average, 7.7% of their time in the riparian zone.

In terms of cattle utilization of the aquatic environment, Ballard and Krueger (2005) observed that cattle spent less than 1% 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 (2.17%); although this is likely due to the restriction of our study to daylight hours, amongst other methodological, climatological and environmental differences between studies.

The index of selection (Hunter, 1962) was generally consistent across sites except with respect to utilization of the riparian environment. Cattle spent twice as much time in the riparian environment at the northern Midlington site than at the southern Midlington site. This was despite each site having approximately the same length of accessible river bank (600 m at the northern Midlington site and 770 m at the southern Midlington site). The only major difference between the two sites was that the northern Midlington site was partially fenced, whilst the southern Midlington site was entirely unfenced. Hence, and although it is counter-intuitive, cattle spent more time in the riparian environment that contained fencing. Precisely why is unclear, although there are several possibilities. The cattle were curious and would investigate any alien structures (including fences) within their environment. Cattle also used the fences for rubbing against, defecating against and urinating against. Additionally, cattle would walk adjacent to fencing en-route to river access points; when there was no fencing cattle would enter the river at the most suitable, proximate location.

4.2. Behaviour

The behavioural observations appear consistent with the existing literature, both with respect to the absolute amount of time spent engaged in different activities and the daily cycle of activity (Albright and Arave, 1997; Broom and Fraser, 2007; Houpt, 2010; Jensen, 2009; Mitlohner et al., 2001, Phillips, 2002). Cattle were most restful, and grazed the least, during the middle of the day, which is coherent with existing observations (Albright and Arave, 1997; Houpt, 2010). The utilisation of wooded environments during the middle part of the day supports the notion that cattle seek shade to avoid heat stress (Armstrong, 1994; Schütz et al., 2009), whilst increasing aquatic environment utilisation towards the mid-afternoon may reflect behavioural thermoregulation (Schütz et al., 2011).

The observation that cattle preferentially defecated in the aquatic environment is not instantly explainable (Aland et al., 2002; Oudshoorn et al., 2008; Phillips, 2002). This observation in particular requires verification to establish whether the relationship emerges in different situations. Preferential defecation in the aquatic environment represents the main direct biochemical consequence of allowing cattle access to chalk rivers. It is likely to have implications for in-stream biota (particularly fish and amphibians), water quality, nutrient loading, rates of deoxygenation due to organic matter decomposition, sediment movement and pathogen virulence (Mainstone, 1999; Raven et al., 1998). In chalk rivers, where winterbournes and headwaters can experience a reduction or cessation in flow during the summer months, high frequency in-stream defecation could have

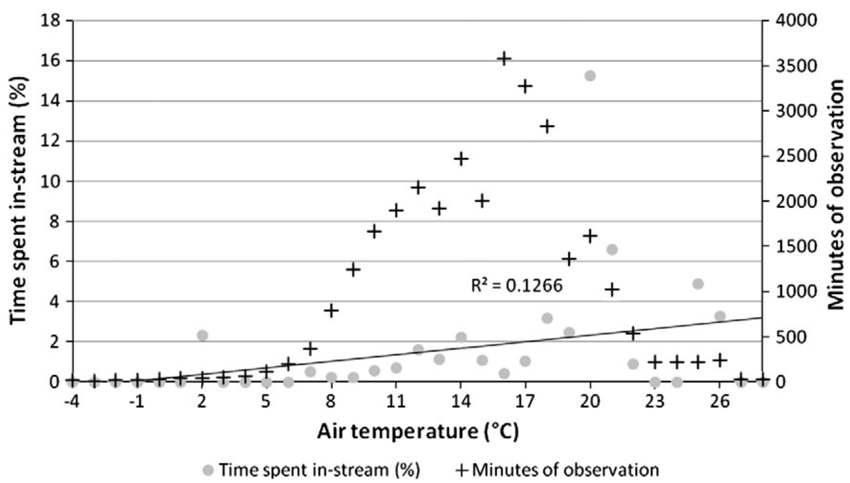

Fig. 4. Time spent in-stream (%) refers to the number of in-stream observations as displayed as a percentage of the total number of observations made at each air temperature The total number of observations at each air temperature, a correlation trendline for the time spent in-stream (%) and R^2 value are also provided.

profound effects (Everard, 2005, Mainstone, 1999). Although some existing works have considered the chemical composition of cattle faeces in the context of river pollution (e.g. Hubbard et al., 2004), current calculations of nutrient loading have not considered the defecation frequency observed in this study. The next step is to quantitatively establish these effects with respect to chalk river environments specifically.

Finally, it is important to note the potential role that social facilitation played in the distribution and behaviour of subject animals. Cattle are social animals and generally have hierarchies in which there is the potential for learning through the observation of others, and through following others (Albright and Arave, 1997; Bailey et al., 2000; Kiley-Worthington, 1977). Although the effects of such social interactions are likely minimised in our study due to the use of herd data, the selection of unique individuals for each observation period and the herd size (>30), the role of social facilitation in determining cattle behaviour and distribution should always be considered.

4.3. In-stream activity and air temperature

The observation that cattle utilise the aquatic environment more frequently and for longer periods of time when it is warmer is supported by previous investigations into the relationship between cattle behaviour, water availability and air temperature (Armstrong, 1994; Kendall et al., 2007; Legrand et al., 2011; Schütz et al., 2011). Our study has established a statistically significant positive correlation between air temperature and the amount of time that cattle spent within a river.

5. Conclusions

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%.

Conflict of interest statement

None of the authors of the submitted manuscript has declared any conflict of interest which may arise from being named as an author on the manuscript.

Acknowledgements

We are grateful to the land owner and grazier at Midlington Farm, Dan Bower, for the use of his land and for allowing his cattle to be observed during this study. We would also like to thank the Environment Agency for funding and supporting this work.

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