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Qualitative Landscape Theories and Archaeological Predictive Modelling—A Journey Through No Man's Land?

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Abstract An approach to test and interpret geographic information system-based, quantitative archaeological predictive models using techniques from qualitative (experiential) landscape theory is described and demonstrated *via* a case study. The result is the transformation of statistical output from quantitative predictive models into more archaeologically meaningful interpretations of spatial data.

Keywords GIS · Predictive modelling · Phenomenology · Archaeology

Introduction

Over the past four decades, predictive modelling in archaeological research and cultural resource management have become popular, particularly in North America (Hudak *et al.* 2002; Judge and Sebastian 1988; Kvamme 1989, 1990, 1995, 2006) and The Netherlands (van Leusen *et al.* 2005; van Leusen and Kamermans 2005; Verhagen 2007), but less often elsewhere (Allen *et al.* 1990; Lock and Stančič 1995). During this time, important breakthroughs in model construction were achieved, especially when the use of geographic information systems (GIS) became widespread in archaeological research (Aldenderfer and Maschner 1996; Conolly and Lake 2006; Gillings *et al.* 1999; Judge and Sebastian 1988; Lock and Stančič 1995; Mehrer and Wescott 2006; Parker 1985; Wescott and Brandon 2000). With the growing availability of digitised environmental and archaeological records and the help of modern GIS packages, environmental characteristics at the locations of archaeological activity can now be almost instantaneously collected and quickly analysed for statistically significant patterns (Hudak *et al.* 2002; Kvamme 1990; Verhagen 2007; Verhagen and Whitley 2012; Wescott and Brandon 2000).

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The work presented here builds on two such models (Graves 2009, 2011). These were designed to predict the locations of Neolithic settlements or occupation activities of mainland Scotland. Environmental patterns of data from locations of megalithic tombs known as chambered cairns, timber halls and sites with dated episodes of pit-digging were used as input for the first model. The second model used only the locations of the chambered cairns. The output from the models enabled important new evidence to emerge about where Neolithic settlement activity may be found on the Scottish mainland (see Graves 2011, pp. 639–640). The challenge remained to find a way to use the available evidence to test the models' predictive power cheaply and robustly *via* fieldwork. It was theorised that the locations of early Neolithic cursus and later Neolithic timber circles might act as a valid blind test of the predictive power of the models. It was also suspected that much more could be learned about the models' outputs by surveying areas of medium and high site potential around a case study area. In other words, is it possible to perceive on the ground what the models have identified as likely areas for Neolithic activity? Could any new information gleaned from fieldwork be fed back into the models to improve predictive power?

After considering these questions, a case study was designed to test and reinterpret the predictive power of the models. The summary that concludes the discussion focuses on how qualitative fieldwork and quantitative analysis can be made to complement each other within a research agenda that includes the use of archaeological predictive modelling.

In Search of a Middle Ground, or 'Does Predictive Modelling Really Need a Qualitative Approach?'

Archaeological predictive models have been built to predict where people in the past chose to settle, to hunt, to bury the dead, to create or discard objects in particular locations to the exclusion of others and so on. It has been theorized that the archaeological activities associated with significant environmental patterns can therefore be made predictable because human behaviour is in part affected by environmental conditions (Ebert 2000; Kvamme 1990; Parker 1985; Woodman and Woodward 2002). However, two major objections have been raised: that model data are incomplete, biased and unable to quantify or predict human behaviour (Wheatley 2004) and that archaeological predictive models are environmentally deterministic (as discussed by Gaffney and van Leusen 1995). These criticisms can be seen as part of a much larger debate that has grown over the past 20 years between two strands of archaeological theory: between those who use GIS in a processual, empirical or quantitative approach, on the one hand, and advocates of phenomenological or experiential exploration on the other.

It is beyond the scope of the present work to delve into the history of this debate (see Brück 2005; Fleming 2006; Gillings in the present volume; Johnson 2006; Llobera in the present volume), but a very condensed summary might be offered as follows. Proponents of post-processual, qualitative, experientialist or phenomenological landscape theory in archaeology have argued that quantitative or empirical techniques, which include GIS-based mapping methods and predictive techniques, effectively dehumanise and distort the past through the distinctively Cartesian gaze of Western society (Bender 1999; Cosgrove 1984; Thomas 1993a,b, 1999, 2004, pp. 198–201, 2008; Tilley 1994, 2004). In response, strong criticisms have been raised about the validity of evidence presented in the qualitative, experiential or phenomenological frameworks, especially research methods that are characterised as highly subjective attempts to empathise with the lives of long-dead human beings (Fleming 1999, 2005, 2006; Johnson 2011; Shennan 2002, 2011, 325). Efforts to combine quantitative and qualitative methodologies are rare (Hamilton *et al.* 2006; Jerpåsen 2009; Sims 2009; Sturt 2006), though researchers engaged in visualisation studies have built some bridges (Gillings 2009; Lake and Woodman 2003; Llobera 1996, 2000, 2011; Llobera *et al.* 2004).

Predictive modelling in archaeology has long been embroiled in this debate (Ebert 2000; Gaffney and van Leusen 1995; Kamermans 2007; Kvamme 2006; Verhagen 2007; Verhagen *et al.* 2007; Verhagen and Whitley 2012; Wheatley 2004; Wheatley and Gillings 2002). Attempts have been made to create models based on social, cultural or emotional variables that might have influenced past human behaviour (Sebastian and Judge 1988), and new ground has been broken recently (Kamermans 2007; Verhagen *et al.* 2007; Verhagen and Whitley 2012). This work remains vital if predictive models are to aid archaeological research. For although predictive models can help archaeologists better understand the environmental patterns of site distributions, or predict the locations of sites yet to be discovered, it is more important to transform the statistical output of a model into a better understanding of the behaviour of past peoples. Discussions of model output have rarely focused on this (Verhagen *et al.* 2007; Verhagen and Whitley 2012). Instead, model output is usually presented as statistical statements about site distributions and estimates of predictive power (Gibson 2005; Graves 2009, 2011; Hudak *et al.* 2002; Kvamme 1988, 1990; Verhagen 2007; Wescott and Brandon 2000). The statistical foundation is the first step; the next should be to use model output data to better understand behaviour in the archaeological past. The combination of GIS, quantitative techniques and quantitative, experiential, landscape theory to interpret model output could be one way forward.

Finally, utilizing qualitative theory could provide a new way to validate and improve models beyond the traditional quantitative techniques. It has been established that models be recalibrated when new input sites are discovered, or upon completion of fieldwork that tests the validity of predictions (Judge and Sebastian 1988; Rua 2009). However, both are slow processes that have been rarely undertaken (Verhagen 2007; Verhagen and Whitley 2012), although the early years of modelling did feature such work (Thoms 1988). Although it is important to update the model input datasets with the latest information, including newly discovered sites, if there are too few new sites to be statistically significant, the model's predictive power logically will not significantly improve (Graves 2011, p. 644). Instead, efforts to modify models might be better served by focusing on what to change based on archaeologically meaningful interpretations made from model output. This would allow models to become part of archaeological theory and debate in a more meaningful way, as models can be modified to address ideas that occur through the debate process. The case study below will demonstrate one way this can be accomplished.

Lochbrow, Near Lockerbie, Dumfries and Galloway, Scotland

The purpose of the case study was to use non-invasive survey to test two related Scottish Neolithic predictive models (see Graves 2011). It is known that pit-defined sites, which comprise part of the input dataset for the models, sometimes appear in landscapes that once contained older monuments (Barclay and Russell-White 1993, pp. 167–168; Graves 2011, p. 634, Appendix 1). It would be very useful if the models could be tested using older monuments because newly discovered Neolithic activity on the Scottish mainland is very rare; waiting for new input sites to test the models' predictions could take years. Therefore, a number of known early Neolithic timber monument sites that were not included in the input dataset were treated as blind tests for the models (Table 2). Successful predictions are defined by the minimum prediction values, or thresholds, as reported by Graves (2011, Table A2.1 and Table 1). The models successfully predicted the locations of a number of Neolithic timber monuments (Tables 2 and 3). When fairly strong predictions were returned at the coordinates of at least three crop-mark features at Lochbrow (Table 2), it was selected for further field-based investigation.

The site of Lochbrow (Figs. 1 and 2) is in an unexcavated field near Lockerbie, in Dumfries and Galloway. The Neolithic activity at this field is evidenced by crop-marks of an early to late Neolithic timber cursus monument and two timber circles (Millican 2007, 2009, 2012; RCAHMS 1988, 1989, 1992, 1997). This places the activity at Lochbrow within the Scottish Neolithic from as early as 4,000 cal BC to 2,500 cal BC (Ashmore 2002; Barclay 2003; Bonsall *et al.* 2002; Cowie and Shepherd 2003; Kinnes 1985; Malone 2001; Richards 2004; Warren 2004; Whittle 1996). The fieldwork was designed to explore qualitatively and quantitatively what aspects of the Scottish Neolithic the models are able to target. To do this, quantitative environmental characteristics driving the model were extracted from the locations of the monuments at Lochbrow (Table 4). These are briefly discussed in the following section. Then Lochbrow is explored qualitatively to fuel a discussion about what the models are identifying as areas of high and medium probable site presence.

Quantitative Background and Analysis

The locations of the NE timber circle, the cursus monument, and the SW timber circle are shown in Figs. 3, 4, 5 and 6. Areas of low, medium and high probability are coloured white, orange and green, respectively. Following proposals by Gibson (2005), each model is weighted for accuracy and precision, respectively. This results in two versions of each model. The accuracy-weighted models identify at least 85 % of the known site record in its input database within minimum thresholds (see also Graves 2011, pp. 641–644). The precision-weighted models attempt to capture the highest number of sites within the smallest areas of high or medium probability. This results in the removal of 83.6 and 77.3 % of the landscape for models 1 and 2, respectively.

Statistically, when model 1 is weighted for accuracy (hereafter M1A), it is the most successful (Tables 2 and 3); it predicts up to 92 % of the 58 Neolithic monuments used for testing and produces high or medium prediction values at the locations of the three monuments at Lochbrow (Table 2). However, when M1A is mapped, it can be

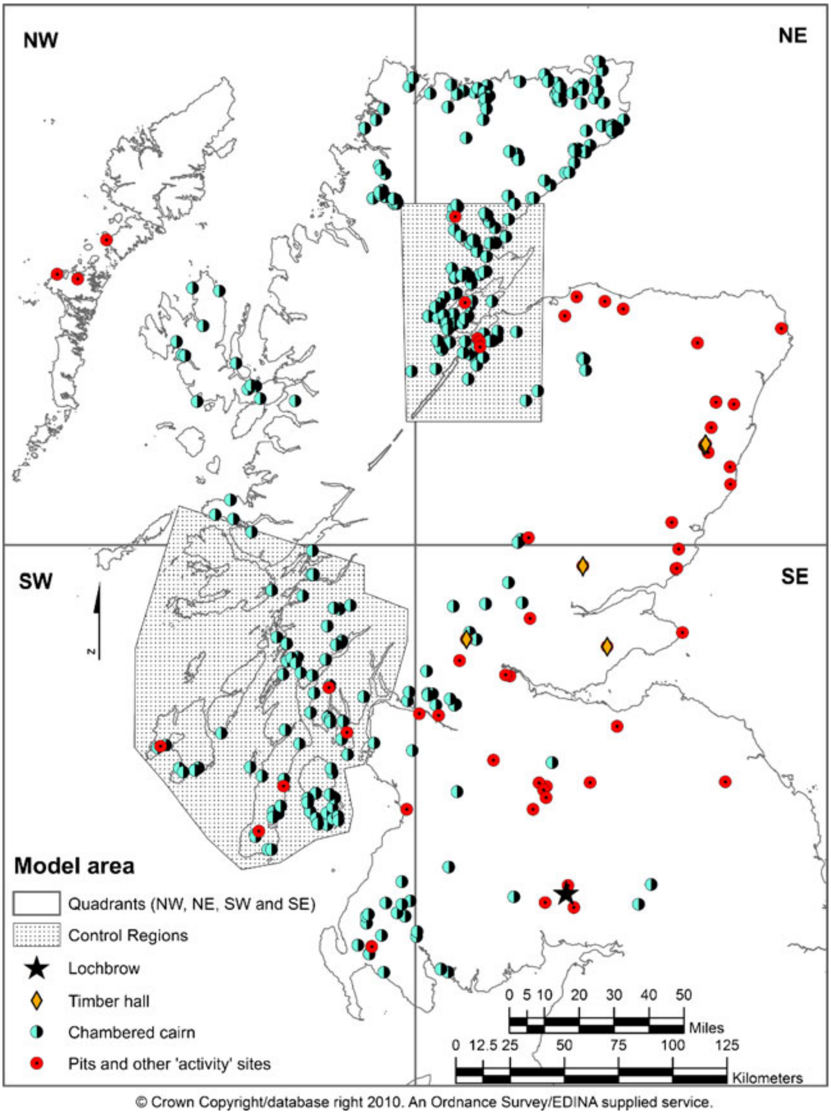

Fig. 1 Lochbrow and the models' study area

seen that the model has identified the whole area around the monuments at Lochbrow as highly likely for site presence without making clear distinction as to what constitutes low, medium or high probability (Fig. 3). Although the numbers reported in Tables 2 and 3 are attractive, the M1A's output can at best be described as 'noise' because the values around the three sites at Lochbrow are virtually the same. This would imply that all areas of this landscape were very attractive to Neolithic people to create a monument; this does not help to explain why the areas that do contain archaeological remains were chosen. M1A neither narrows down an area for prospection nor provides any suitable way forward to suggest why it has captured all three monuments at Lochbrow.

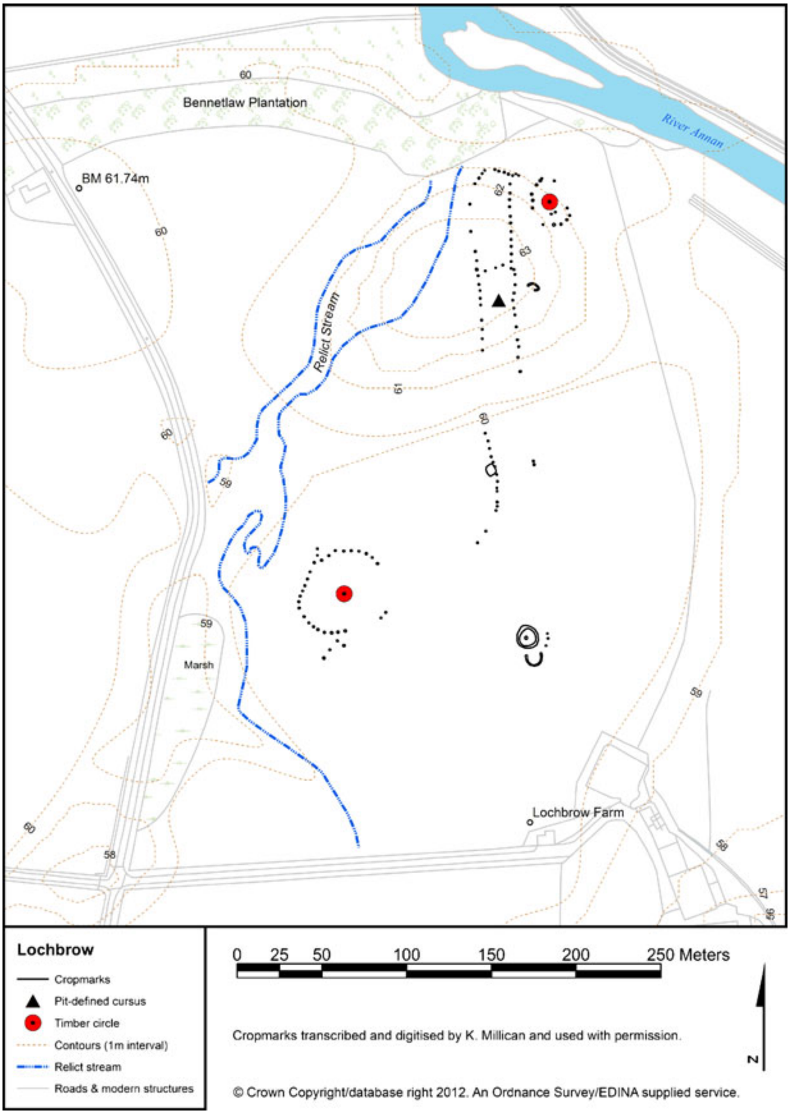

Fig. 2 Lochbrow

It is possible to satisfy the former problem very easily by weighting model 1 for precision (hereafter M1P), but in doing so, M1P does not meet the thresholds to capture any of the sites at Lochbrow (Tables 1 and 2). When M1P is nevertheless mapped, the NE timber circle and the cursus are both within 10 m of areas of high probability (Fig. 4). Areas to the west and east are still noisy, and the SW timber circle is undetected. Despite its low scores, predictive distinction appears in the landscape, though medium potential, represented as orange, has largely disappeared. This strongly suggests that the grouping criteria for low, medium and high probability are likely too harsh. Although it is the least successful of the weighted models, when compared to M1A, M1P is better for archaeological prospection and interpretation

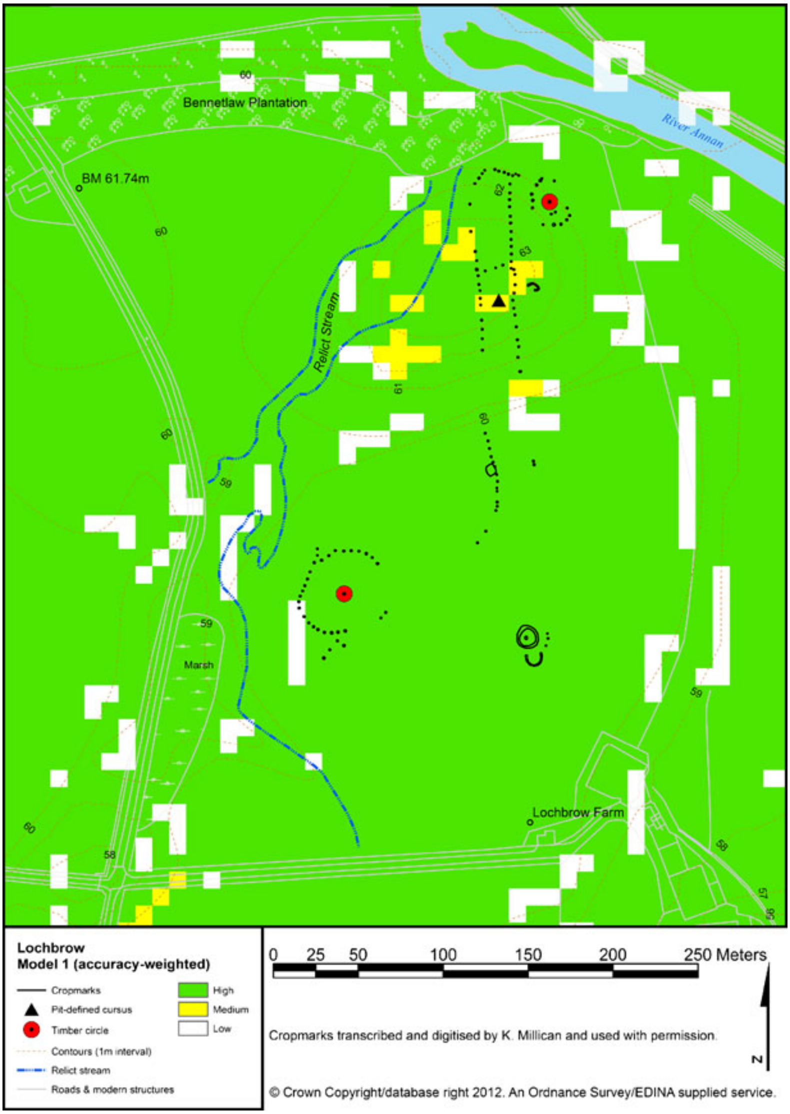

Fig. 3 Model 1 (accuracy-weighted)—M1A

because it offers less noise. Using this model, it is possible to suggest that the area of greatest interest for prospecting and archaeological interpretation is within or very close to the cluster of high probability cells that are surround the NE timber circle and cursus.

When model 2 is weighted for accuracy (hereafter M2A), it is the second most successful at predicting the early Neolithic timber monuments (Tables 2 and 3). However, it is the best result when mapped (Fig. 5). This shows the area around the NE timber circle and the northern terminus of the cursus monument neatly represented in a patch of green (high) potential, surrounded on the northern and north-western edge by medium potential. The SW timber circle is close to the orange

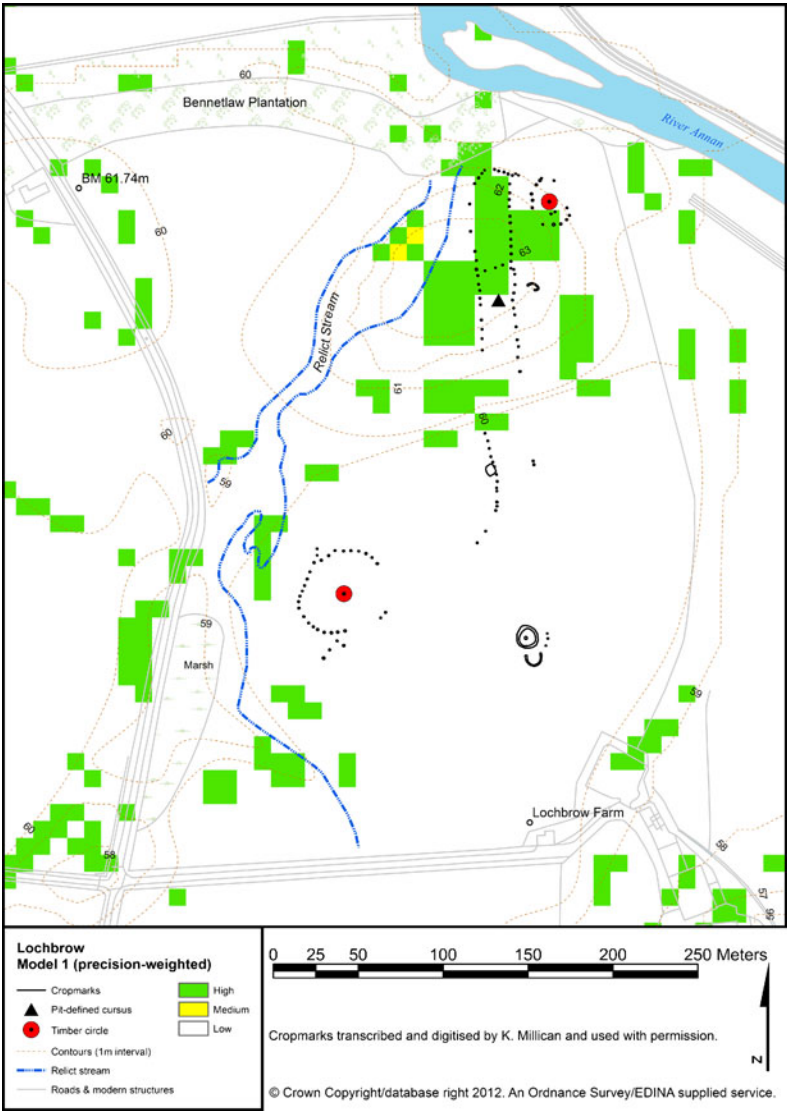

Fig. 4 Model 1 (precision-weighted)—M1P

areas of medium site probability, though it still remains undetected. Using this model, it would be very easy to suggest where to prospect for some of the archaeological remains at Lochbrow; it would also provide a useful starting point for considering important landscape characteristics during a survey. When model 2 is weighted for precision, hereafter M2P, it successfully predicts the NE timber circle and the cursus, but not the SW timber circle (Fig. 6). Medium potential areas have disappeared.

It can now be asserted that the prediction ranges for these models, though adhering to the high standards proposed by Gibson (2005), need revision. This is obvious because the medium and low potential values are not well represented. This is a simple mathematical problem that can be easily resolved by tweaking the prediction

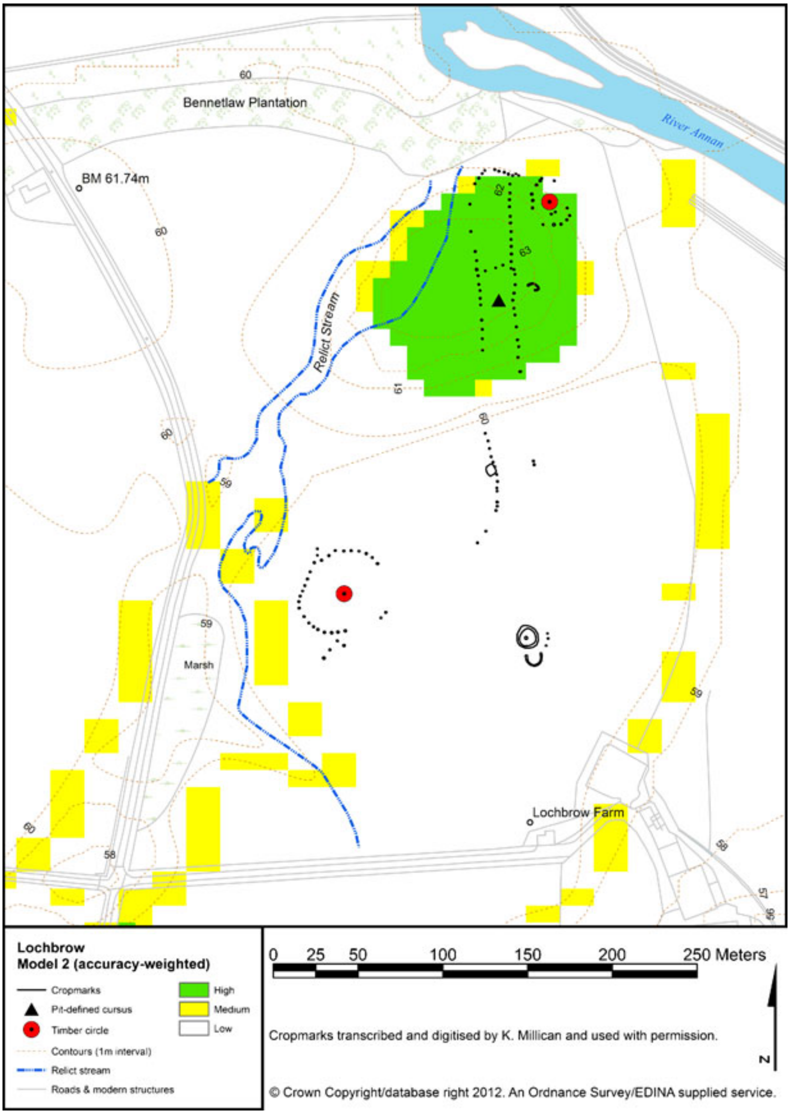

Fig. 5 Model 2 (accuracy-weighted)—M2A

ranges. Knowing this, it is now possible to improve the quantitative aspect of the model cheaply and efficiently after its initial construction.

Moving onto model output interpretation, it is clear that there is something important that each model identifies about the location immediately at and around the NE timber circle and cursus. High probability values are clustering where there is low exposure and aspect, lower elevations and less steep slopes. The medium probability values are likely reflecting a very precise boundary between too low and too high values. This is likely why a lowland site like Lochbrow is so sensitively picked up by models using highland chambered cairns for training data. Archaeological sites that sit in the medium probability are almost certainly going to be strongly correlated with transitions in the

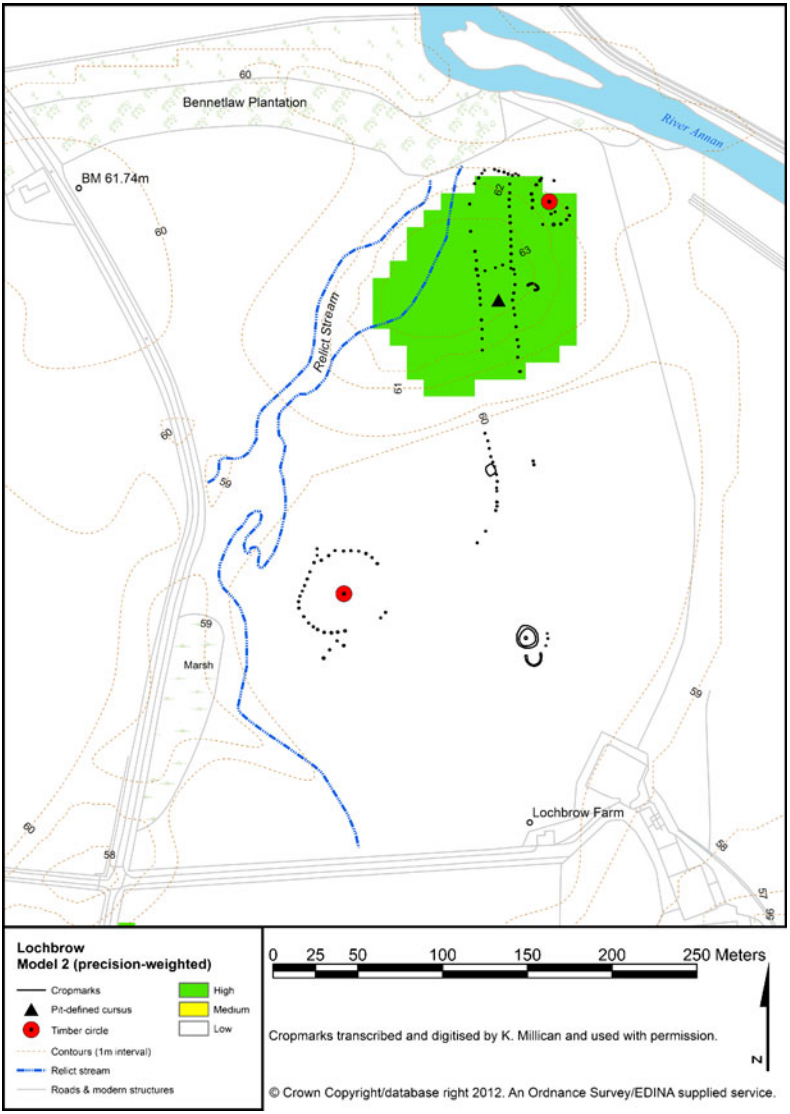

Fig. 6 Model 2 (precision-weighted)—M2P

Table 1 Threshold prediction values for medium or high probability

Area	Model	'Accuracy' model		'Precision' model	
		Medium	High	Medium	High
Southeast	Model 1: chambered cairns, pits and timber halls	0.652669	0.8974185	1.142170	1.2237526
	Model 2: chambered cairns only	0.70962	0.922214	0.922214	0.993078

Table 2 Prediction values of early Neolithic timber monuments

No.	Site name (type)	Area	Prediction values[a]			
			Model 1 (M1A/M1P)		Model 2 (M2A/M2P)	
1.	Eweford (timber circle)	East Lothian	1.029001	High/NP	0.761931	Medium/NP
2.	Eweford (timber circle, poss.)	East Lothian	0.563393	NP/NP	0.759548	Medium/NP
3.	Eweford East (timber circle)	East Lothian	1.433304	High/high	0.754782	Medium/NP
4.	Eweford East (cursus, poss.)	East Lothian	1.015095	High/ medium	0.750020	Medium/NP
5.	Eweford West (mortuary palisade structure)	East Lothian	1.017885	High/ medium	0.752401	Medium/NP
6.	Eweford West (mortuary split post structure)	East Lothian	1.017885	High/ medium	0.752401	Medium/NP
7.	Pencraig Hill 1 (mortuary palisade structure)	East Lothian	1.484939	High/high	1.145336	High/High
8.	Pencraig Hill 2 (mortuary palisade structure)	East Lothian	1.484939	High/high	1.145336	High/High
9.	Skateraw (timber circle)	East Lothian	1.003894	High/NP	0.740505	Medium/NP
10.	Kirklands (avenue)	Borders	0.721005	Medium/NP	0.684236	NP/NP
11.	Dalswinton Roads (avenue)	Nith Valley	1.015093	High/NP	0.750020	Medium/NP
12.	Fourmerkland (cursus)	Nith Valley	1.021466	High/NP	0.735754	Medium/NP
13.	Holm (cursus)	Nith Valley	1.374746	High/high	1.160290	High/high
14.	Holm (timber circle)	Nith Valley	1.421609	High/high	1.160290	High/high
15.	Holywood North (cursus)	Nith Valley	1.015095	High/NP	0.750020	Medium/NP
16.	Kirkland Station (cursus)	Nith Valley	0.846097	Medium/NP	0.786193	Medium/NP
17.	Lochbrow (timber circle)	Nith Valley	0.915253	High/NP	0.667510	Medium/NP
18.	Lochbrow (cursus)	Nith Valley	0.882419	Medium/NP	1.037145	High/high
19.	Lochbrow (timber circle)	Nith Valley	0.972777	High/NP	1.041477	High/high
20.	Lochhill (mortuary split post structure)	Nith Valley	1.455893	High/High	1.216585	High/high
21.	Slewcairn (mortuary split post structure)	Nith Valley	0.366626	NP/NP	0.929427	High/medium
22.	Tibbers (curvilinear site, poss.)	Nith Valley	1.328434	High/high	0.869579	Medium/NP
23.	Tibbers (cursus, poss.)	Nith Valley	0.965035	High/NP	0.883762	Medium/NP
24.	Trailflat (timber circle)	Nith Valley	0.936326	High/NP	0.860096	Medium/NP
25.	Trailflat (cursus)	Nith Valley	0.930553	High/NP	0.855348	Medium/NP
26.	Bennybeg (cursus)	Strathearn	1.393572	High/high	1.083875	High/high
27.	Bennybeg (timber circle)	Strathearn	1.344528	High/high	1.085949	High/high
28.	Bennybeg (timber setting)	Strathearn	1.344528	High/high	1.085949	High/high
29.	Broich (timber circle)	Strathearn	0.961360	High/NP	0.704989	NP/NP
30.	Broich Road Farm (cursus, poss.)	Strathearn	0.964219	High/NP	0.707347	NP/NP
31.	Craggish (pit-defined cursus)	Strathearn	0.468689	NP/NP	0.6698378	NP/NP
32.	Crieff High School, Broich Road (timber circle)	Strathearn	0.949895	High/NP	0.6955748	NP/NP
33.	Dargill 1 (timber setting)	Strathearn	1.417103	High/high	0.7286352	Medium/NP

Table 2 (continued)

No.	Site name (type)	Area	Prediction values[a]			
			Model 1 (M1A/M1P)		Model 2 (M2A/M2P)	
34.	Dargill 2 (timber circle)	Strathearn	0.529918	NP/NP	0.7286352	Medium/NP
35.	Dargill 3 (timber circle)	Strathearn	0.989804	High/NP	0.7286352	Medium/NP
36.	Forteviot (palisaded enclosure)	Strathearn	1.360806	High/high	1.1044111	High/high
37.	Forteviot (timber circle)	Strathearn	1.364338	High/High	0.7405057	Medium/NP
38.	Forteviot (timber circle)	Strathearn	1.362576	High/high	1.1064391	High/high
39.	Forteviot (timber setting)	Strathearn	1.362576	High/high	1.1064391	High/high
40.	Forteviot (timber setting)	Strathearn	1.360806	High/high	1.1044111	High/high
41.	Forteviot (timber circle)	Strathearn	1.364338	High/high	1.1084624	High/high
42.	Kincladie (poss. rectilinear enclosure)	Strathearn	0.951945	High/NP	1.0880191	High/high
43.	Kincladie 1 (timber circle)	Strathearn	0.975623	High/NP	0.7167949	Medium/NP
44.	Kincladie 2 (timber circle)	Strathearn	0.975623	High/NP	0.7167949	Medium/NP
45.	Kincladie 3 (timber circle)	Strathearn	1.444540	High/high	1.0838751	High/high
46.	Leadketty (palisaded enclosure)	Strathearn	1.400012	High/high	1.1333457	High/high
47.	Leadketty (timber circle)	Strathearn	1.396807	High/high	0.7167949	Medium/NP
48.	Leadketty (timber hall, poss.)	Strathearn	0.989804	High/NP	0.7286352	Medium/NP
49.	Millhaugh (rectilinear enclosure)	Strathearn	0.939209	High/NP	0.8624691	Medium/NP
50.	Millhaugh (timber circle)	Strathearn	1.326519	High/high	0.8672104	Medium/NP
51.	Millhills 1 (timber setting)	Strathearn	0.986975	High/NP	0.7262646	Medium/NP
52.	Millhills 2 (timber setting)	Strathearn	0.986975	High/NP	0.7262646	Medium/NP
53.	Millhills 3 (timber circle)	Strathearn	0.986975	High/NP	0.7262646	Medium/NP
54.	North Mains A (timber circle)	Strathearn	1.353650	High/high	0.7262646	Medium/NP
55.	North Mains B (timber circle)	Strathearn	1.353650	High/high	0.7262646	Medium/NP
56.	Tullichettle (cursus)	Strathearn	0.894910	High/NP	0.6512855	NP/NP
57.	Westerton I (timber circle, poss.)	Strathearn	0.766415	Medium/NP	0.4916093	NP/NP
58.	Westerton II (timber hall)	Strathearn	0.504910	NP/NP	0.7049899	NP/NP

[a] NP means not predicted, meaning the value falls below the minimum thresholds shown in Table 1

landscape, and by isolating what those transitions are, better predictions might be produced. However, this is only half of the problem faced with improving the models. Further improvement can be made when qualitative analysis is applied.

Qualitative Descriptions and Analysis

It is important to address the issue of the modern land cover before creating any qualitative descriptions of Lochbrow. This is because the modern land cover does not

Table 3 Summary of prediction values

	Model 1: cairns, pits and timber halls prediction values (%)			Model 2: chambered cairns only prediction values		
	M1A	M1P	% Total high predictions only	M2A	M2P	% total high predictions only
East Lothian (10 locations)						
Total medium or high predictions	90	60	30	90	20	20
Nith Valley (15 locations, including Lochbrow)						
Total medium or high predictions	93.33	26.67	26.67	100	40	20
Strathearn (33 locations)						
Total medium or high predictions	90.91	48.48	48.48	78.79	33.33	30.30

relate to the prehistoric period; Lochbrow lies within in a field currently used for silage, while the surrounding fields are used for growing wheat crops or pasture. Although there are no known pollen samples from Lochbrow, the Scottish palynological record suggests that during the Mesolithic and early Neolithic this area was likely covered in mixed forest of *Alnus*, *Corylus*, *Quercus* and *Ulmus* (Bradley 2007; Millican 2012; Noble 2006; Tipping 1994, 1995; Tipping and Milburn 2000). The forest at Lochbrow would likely have been cleared for the timber necessary to construct the monuments if only around their immediate areas. As the precise prehistoric land cover and its history are unknown, the descriptions of the landscape taken from the surveys are considered from the modern (unforested) view and the possible ancient (forested) view.

The cursus and NE timber circle are located at the north end of a long, elevated terrace that narrows in the north into a distinctive v-shape (Fig. 1). Today, the journey to the monuments is a short walk easily accomplished in <10 min from the gated entrance at the southeast end of the field, near the modern Lochbrow Farm buildings. For readability, the monuments will be referred to below as the cursus, the NE timber circle, and the SW timber circle.

The NE timber circle lies about 10 m to the northeast of the northern terminal of the cursus, while the SW timber circle is approximately 150 m to the southwest of the cursus. All of the monuments are east of a palaeochannel (Fig. 2). The SW timber circle lies near the western edge of the terrace and overlooks part of the palaeochannel. On bright, clear days, which were common during the 2010–2011 field seasons, long unbroken views of the horizon were afforded to the northeast and east from almost anywhere in the field, including when standing at the cursus and the NE timber circle. The northeast and eastern views include the modern road (B 7076) and the hills beyond. Trees obscure the view to the north beyond the modern fence line, but the River Annan can be seen through the trees if standing closely enough. The River Annan flows from the north and bends to the east before returning to the south, effectively cutting off the north and northeast sides of the field. The modern fences on the east and north sides of the field reinforce the parcelling of the landscape. These modern fence boundaries follow the curve of the terrace.

Millican argues that the form of the Lochbrow cursus is intended to mimic the shape of the terrace on which it is located and the path of the relict stream bed that it lies near (Millican 2009, 2012). When standing at the top of the terrace, it is easy to see that the areas in the western half of the compass have noticeably lower elevations. Reversing the view, one could suggest that the area chosen for the cursus and NE timber circle may deliberately be in a visible and prominent position on the terrace. However, during the 2010–2011 field seasons, it was noticed that the cursus and NE timber circle are in a slight dip on the terrace that effectively hides people standing in their locations from the views of those approaching from almost any direction except the east, along the River Annan. This 'dip' neatly characterises the local relief variable shown in Table 4, but it is not perceptible in the 1-m contours generated from the digital terrain model (DTM). This is because the DTM has a cell resolution (10 m) that is insufficient to capture the dip. It was not unusual to lose sight of colleagues working in the 'dip' when working elsewhere in the field; however, it was easy to find those same colleagues in the 'dip' if they were walking with an upright GPS-mounted pole used for the topographic survey. This suggests that the tops of timber posts that were used to construct the monuments may have been visible in the landscape, provided that they were at least 1.5 m high and the forest did not obscure the view. Conversely, it is not possible to see the south or southwest areas of the field from the cursus or NE timber circle. This adds up to an impression of hiding or being hidden in the dip when standing where the cropmarks for the terminus of the cursus and NE timber circle are located.

It is unlikely then that the suspected cursus and northeast timber circle would have been visible when approaching from a direction other than the south and only after coming close enough for the terrace or the timber posts to become visible. Approaches from the south may have been easiest as the height of the terrace on which the monuments sit restricts access (Millican 2009, 2012). The forest might also have meant that approaching from anywhere other than the river was more difficult, though not impossible. Approaches from the river are favoured, as water transport in prehistory was especially important (Davison *et al.* 2006; Noble 2006, 2007; Sherratt 1996). Whether or not the 'dip' was obscured by forest, foreknowledge of the location of the monuments might have been necessary because the river is lower than the terrace on which northern monuments are situated.

Discussion: Re-translating the Model Output

What do the high and medium probability bands contain at Lochbrow? Is it possible for an archaeologist to identify the transition area from high or medium potential

Table 4 Environmental data at Lochbrow

Site	NMRS number	Elevation	Slope	Local relief	Aspect	Exposure	Order of water	Cost–distance to nearest source of water
Lochbrow (SW timber circle)	NY08NE 36	61	0	32	0	–1	1 (palaeochannel)	75
Lochbrow (cursus)	NY08NE 34	64	3.2	32	0	162	1 (palaeochannel)	273
Lochbrow (NE timber circle)	NY08NE 34	62	3.2	32	0	27	1 (palaeochannel)	162

See Graves 2011, Table 1 for details of the construction of each variable areas on the ground? Can the insights gained from qualitative survey be exploited to improve the models, and if so, how?

After considering the above analyses, it is argued that the best model for reconsidering the output of the models is M2A (Fig. 5). This model has the best balance of high and medium probability areas that correspond closely with the experiences of surveying Lochbrow. For example, Fig. 5 shows that the high and medium probability areas follow some of the 1m contour lines and most of the palaeochannel. The rises in this field are very slight, no more than an approximately 3m increase in elevation around the NE timber circle and cursus. The palaeochannel cuts through the field and is easily visible on the ground. Using the palaeochannel as a natural pathway, keeping the River Annan visible to the north and east, and walking until the rise in the terrace became visible, it was simple to find to the locations of the northern terminal of the cursus monument and the NE timber circle.

Just as three out of four models did not successfully predict the SW timber circle, it was not so straightforward to locate that monument on the ground. This area of the relict streambed is less obvious in the field than its northern portion. Although the streambed meanders along the western edge of the terrace, the location of the SW timber circle over the terrace edge makes it difficult to locate in relation to the palaeochannel. There are no other obvious changes in the landscape to help find the SW timber circle, which was located *via* the GPS and maps. After considering this experience and each model's performance, it is concluded that the SW timber circle is not well predicted by the models because it is not close enough to the palaechannel and the western edge of the terrace where cells of medium probability follow the natural curve of the latter.

By locating the monuments during fieldwork, it is possible to see how the environmental data is driving the models' predictions; it is the interaction of elevation, slope and cost–distance to the nearest source of water that is a key to understanding the model output here. The cost–distance variable is strongly suggested by the path of the palaeochannel, but until environmental data suggesting when it was flowing can be gathered from the latter, it remains unknown whether its path directly influenced the placement of the monuments at Lochbrow. Theories about the importance of the river are not directly referenced by the data the model uses concerning the order of the nearest source of water or the cost–distance to the nearest source of water. However it is noticeable that these variables fall within ranges consistent with increased site presence for this area of Scotland (see Graves 2009, pp. 145–157). Site presence is more likely in places where cost–distance to the nearest source of water stays relatively low (Graves 2011, p. 640). One reason for this might be the fact that bodies of water play very important roles in the location of Neolithic monuments (Brophy 2000; Fowler and Cummings 2003; Perry and Davidson 1987; Richards 1996; Tilley 1994). The river and the palaeochannel, if filled during the Neolithic, might together have been seen as a natural 'boundary' marking out the edges of the area around the cursus and both timber circles. If this is one of the driving reasons for the placement of the monuments at Lochbrow, the cost–distance variable may be the key reason why the M2A identifies no areas of high site potential, and very little medium site potential areas, up to 0.8 km (0.5 mi) east of the River Annan at Lochbrow (Fig. 7). The location of the SW timber circle seems to emphasize the importance of the palaeochannel, which lies nearby, but not close enough for the model to find without manually expanding the middle and high bands of probability.

Looking for similar ‘bullseye’ areas that appear to obey the qualitative narrative established above, there is an intriguing spot of high site potential approximately 2 km (1.2 mi) to the southeast of Lochbrow, nestled around the bends of the River Annan and slight rises in the landscape (Fig. 8). Given that all of the necessary predictive variables are present to suggest high probability, and taking into account the qualitative narrative above, it is possible to select this area out of all of the high potential areas suggested by the model. Querying the known archaeological record curated by RCAHMS showed that the area identified as having a high likelihood of site presence contains no known Neolithic archaeological features. Further research would have to be taken to ascertain whether the model is correct in its prediction. It is

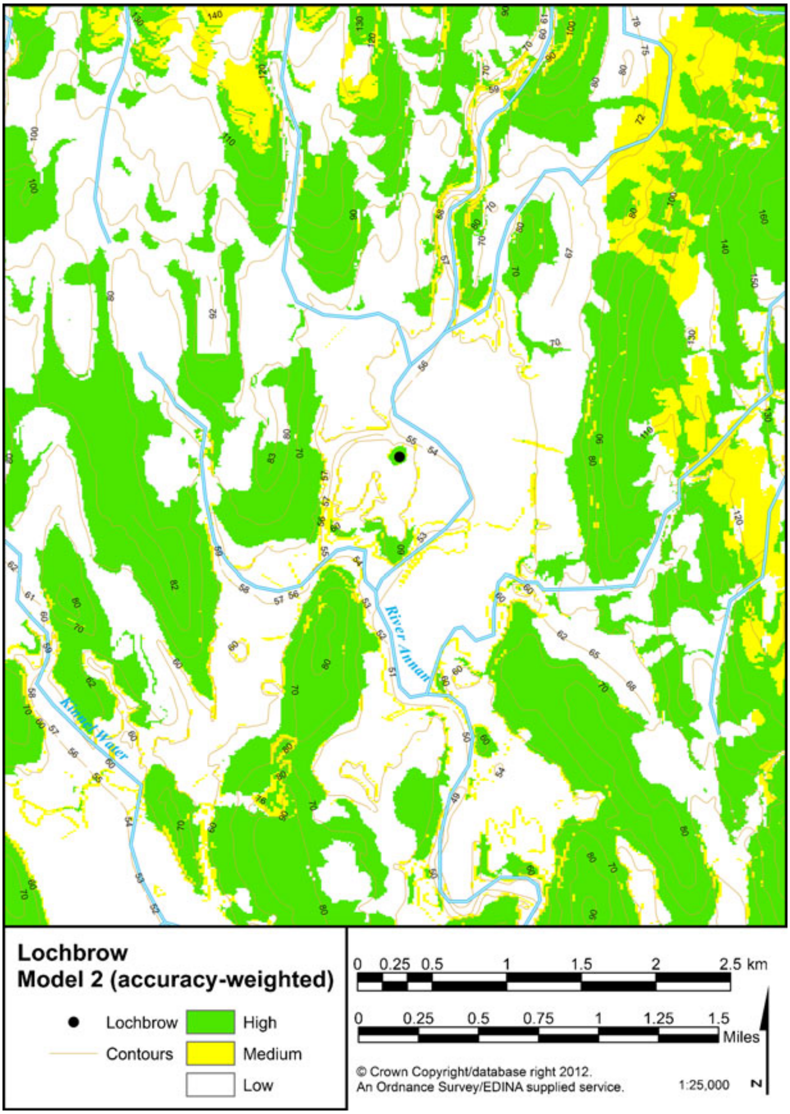

Fig. 7 Lochbrow and M2A in its surroundings

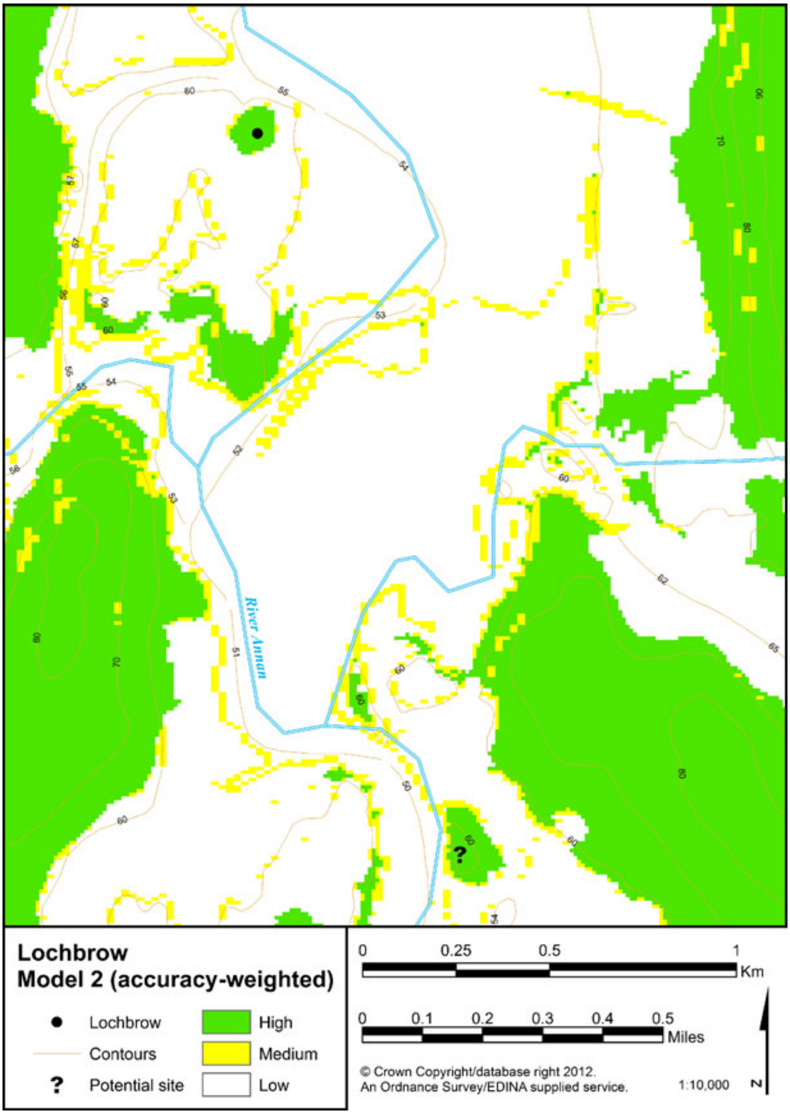

Fig. 8 Potential site

also important to stress that this prospecting technique is likely to be less valid as distances increase or topography changes radically.

By considering the qualitative analysis, it is possible to improve the models on the grounds of archaeological theory, rather than statistical analysis alone. To do this for the Nith Valley case study area, the following steps are proposed. A DTM with better resolution than 10 m must first be obtained. A GPS survey is already underway at Lochbrow, which should provide resolutions at 10 cm. For larger areas, LiDAR data at 2 m or better spatial resolution is the most logical, though costly choice. Using the new DTM, visualisation studies should be taken at various locations on the landscape, but most especially along waterways, which have been digitized for use in a

GIS. It has been established that viewsheds from the locations of the sites comprising the input database are significantly important in the modelling process (Graves 2011, p. 639). Qualitative views at the locations of the monuments at Lochbrow have been established above, but inter-visibility from all points at Lochbrow and its surroundings should to be calculated by the GIS and checked in a formalised qualitative survey. The views can be quantified in the GIS, checked during fieldwork and fed back into the modelling process. The creation of inter-visibility grids is a key to quantifying views, ascertaining statistical significance, if any, and feeding significant data back into the model building process. Should the views prove to be statistically insignificant, consideration should be made to include the variable based on the qualitative analysis. Virtual 3D modelling of landcover, acoustics and fuzzy visibilities due to weather systems should be addressed in the quantitative and qualitative analysis as much as possible, acknowledging of course that the inclusion of landcover cannot be readily simulated on the ground for qualitative fieldwork.

Conclusions

The use of qualitative analysis greatly improves the translation, modification and utilization of the output of archaeological predictive models. By considering the qualitative analysis gained by studying the microtopography of Lochbrow, it is possible to use the quantitative bands of high, medium and low potential to identify similar features in areas close by, e.g. within a 2-km distance. The qualitative analysis provides a powerful lens through which the archaeologist can view the model output in the GIS. This is something that only an archaeological gaze can provide, as this knowledge is not inherently contained in the model training dataset or output.

The purpose of archaeological predictive modelling in academic research is not just to create highly accurate or precise models, but to achieve a better understanding of the behaviour of and material culture produced by people of societies long past. The future of predictive modelling in academic research depends on reaching this goal, which cannot be achieved by statistical analyses alone, limited as they are to explicating what may already be known about an already flawed input dataset. Instead, by combining on-the-ground experiences, interpretations grounded in archaeological theory can be used to better understand, utilize and modify the predictive output of models. This approach offers a means to assess model performance using affordable, non-invasive survey techniques. The analyses provide fresh insight into the model output, which allows for archaeological input into improving the models to be made.

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