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# The ephemerality of prominence: A geospatial analysis of acoustic affordances in a hillfort landscape

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A R T I C L E I N F O

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A B S T R A C T

Prominent places were powerful places. The persistence and stability of prominent places typically depends upon the prioritisation of their physical and visual attributes. Yet if we are interested in the expression of prominence and power, then we should take account of the potential ways that places reached acoustically into the landscape. Acoustics complement visibility since sound like sight helps shape human experiences, memories and emotions. In this paper, we employ a geospatial framework where patterns of sound propagation are modelled and brought into conversation with visibility and mobility-based analyses often applied in geospatial studies of prominence. We apply our approach to a study of the Bryn-y-Castell hillfort in North West Wales. Geospatial studies, employing viewshed and least-cost modelling, examine how topographic and visual exposure might have accentuated the presence of hillforts. We demonstrate the analytical value of combining acoustic, visibility and mobility approaches in mapping zones in which a trade-off in visual and acoustic messages may have been a feature of how landscape prominence was expressed. The contribution of this study lies in challenging us to think, conceptually and methodologically, of prominence as something that varied, was ephemeral, and that lost and gained potency with intensities of inhabitation and landscape dynamics.

## 1. Introduction

Prominent places were powerful places. This assumption underpins archaeological studies that use the relative distinctiveness of locations and the visual exposure of monuments, such as funerary mounds and fortifications, to identify culturally important landmarks and the exercise of power over territories and populations. Whether recognised subjectively as landmarks – perhaps in reference to natural topographic features or existing monuments in the landscape (Tilley, 2010) – or defined quantitatively based on visibility (Llobera, 2001, 2007), prominence is seen as a stable characteristic, ensuring the enduring importance of places for exercising power in the landscape (Driver, 2013). The persistence and stability of prominent places typically depends upon the prioritisation of their physical, and above all visual, attributes (Bernardini et al, 2013). Topography endures, or is slow to change, and so prominence is a feature of places that persisted through the past and into the present.

A widely recognised limitation of this framing is the reduction of places to their visible physical attributes. While the sociality of places can be acknowledged in principle, accommodating it practically is challenging. Geospatial studies have attempted to consider the sociality of places through movement (Llobera et al, 2011; O'Driscoll, 2017a) and/or the fuzziness of visibility (Kvamme, 1992; Llobera, 2001, 2007; Gillings, 2009, 2015; Lock et al, 2014). Yet if we are interested in the expression of prominence and power, then we should also take account of the potential ways that places reached visually *and* acoustically into the landscape (Tilley, 2010). Acoustics complement visual exposure since sound like sight helps shape human experiences, memories and emotions: the 'sonic sensibilities' that help individuals make sense of the places they inhabit (Feld, 1996). This presents us with methodological challenges in applying GIS to experiential landscape analysis (see Gillings, 2009), but it also offers a theoretical and methodological challenge, to think of prominence and presence as something that varied, that was ephemeral, and that lost and gained potency with intensities of inhabitation and landscape dynamics.

Our starting point is to recognise that geospatial approaches offer opportunities for 'what if' *experimentation* (Whitley, 2017) that include asking questions of how and why sound *might* have contributed to the relative prominence of a place. With this in mind, this paper aims to contribute to archaeological debates on landscape prominence by

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modelling patterns of sound propagation and bringing these into conversation with complementary visibility and mobility-based analyses often employed in geospatial studies of prominence. In doing so, we draw on Per Hedfors' (2003: 3) 'model of prominence' to define *acoustic* prominence as *a function of the difference between the amplitude of the sound produced at a source and the ambient background sounds apprehended from the perspective of the listener*. In this model, 'prominent sounds' follow a lifecycle comprising an initial phase of 'attack', a 'body of sound', and a 'region of decay' (Schaeffer, 1966, citied in Hedfors, 2003: 3). These prominent sounds are distinguished against an acoustic background through measures of intensity (amplitude) but they also occur less frequently and last for shorter durations than ambient sounds (Hedfors, 2003: 36).

Conceived in this way, acoustic exposure is an unstable product of human-landscape interactions (Hedfors, 2003; Llobera, 2007; Pijanowski et al, 2011), characterised by spatially and temporally variable zones of sonic activity and isolation (Kolar, 2017). Our starting point here is to conceptualise acoustic exposure through the lens of *affordances* (Gibson, 1979), where affordances represent the "…possibilities for action that are offered to animals by the environment" (Rietveld and Kiverstein, 2014: 325). In the field of ecological psychology, consideration has been given to "…what qualities shared between animals and environments constitute affordances and whether they can be considered to exist in the absence of animals" (Gillings, 2012: 605). One view is that affordances are available for animals to exploit and so do not depend on animals being present in order to exist. An alternative view is that affordances are only brought into being under certain conditions, reflecting how properties in the same environment may only be revealed in the presence of certain animals (Gillings, 2012: 605). In seeking to navigate a path to connect these seemingly contradictory positions, Chemero (2003) contends that affordances are not reducible to properties of animals or environments, but are instead constituted through the *relations* that exist between the abilities of animals to practically engage with features of their surroundings in ways that might evolve and change (Gillings, 2012).

Taking a relational view of affordances opens up the possibility for recognising the rich 'landscape of affordances' on offer to humans in a given context (Rietveld and Kiverstein, 2014). For Rietveld and Kiverstein (2014), an individual affordance is constituted within a complex and multi-layered mosaic of affordances that are embedded in a network of interrelated sociocultural practices and communal norms – what Rietveld and Kiverstein term a 'form of life'. For our purposes, through individual experiences and learning, perceptual awareness of the material properties of surroundings and the possibilities these afford for action give meaning to the engagement individuals have with features of the environment (Ingold, 2000: 36). As an individual's familiarity and knowledge of the 'landscape of affordances' evolves and their ability to engage with particular affordances are honed, so certain features in the landscape will be selectively privileged by individuals while other features will be ignored or marginalised as part of a process of socialisation and empowerment (Tilley, 2010: 39-40).

Set against this conceptual backdrop, we acknowledge that affordances are 'real entities' that can be objectively studied (Chemero, 2003). Yet we are also mindful that *mapping* affordances is extremely challenging owing to the complexity involved in determining the direct relations between specific abilities of individuals and particular features of the environment; an exercise that "…risk[s] not only a reductive objectification but the closing down of relational possibilities" (Gillings, 2012: 605).

With this in mind, we follow Gillings (2012) in employing the concept of affordances as a heuristic when exploring whether sound might have contributed to the relative prominence of a place in the past. In doing so, we recognise that ephemeral zones of acoustic activity and isolation emerge and recede as a product of mutual relations between the sources of sounds, the abilities of the perceiver, and the physical, biophysical and material properties of the environment at a given moment (Pijanowski et al, 2011; Reed et al, 2012 Wrightson, 2000). Such zones might afford individuals, endowed with different levels of abilities (e.g. variable hearing) and familiarity of context (Rietveld and Kiverstein, 2014), opportunities to actively engage with (or ignore) sonic markers (Primeau and Witt, 2018). In an acoustic sense, such factors may potentially reinforce the perceived prominence and power of a place (Wernke et al, 2017), however fleeting, individual and experiential that might be (Pistrick and Isnart, 2013).

Here our own analytical approach is applied to a study of the Bryn-y-Castell hillfort in North West Wales. In the British context, hillforts are a diverse monument type noted for their variable topographical settings, morphological characteristics, and range of (possible) functions (Ralston, 2006). Despite their pre-Roman Iron Age associations (c.700 BCE to AD 43), hillfort sites in Britain have a wide chronology, dating from the late second millennium BC through to the late first millennium AD (Harding, 2012). They are not restricted to hilltops, their sizes and shapes are highly mutable and while many hillforts may have assumed a defensive function (Armit, 2007), the act of constructing and maintaining hillforts also played a part in building community cohesion (Lock, 2011). Geospatial studies, using viewshed and least-cost pathway approaches, examine how topographic and visual exposure might have been used to accentuate the presence of hillforts, sometimes near natural resources or route-ways (Lock et al, 2014; O'Driscoll, 2017a; O'Driscoll, 2017b; Seaman and Thomas, 2020). As we demonstrate, considering acoustic dimensions offers new insights into the potential prominence of hillforts, serving to complement the visual and topographic interpretations that currently dominate research.

## 2. The Bryn-y-Castell Hillfort

Bryn-y-Castell is a small stonewalled hillfort in Gwynedd, North West Wales, dating to c.100 BCE–AD 250 (Fig. 1). Perched on the summit of a small hillock (370 m AOD), the site encloses a pear-shaped area measuring 0.1 ha, overlooking a Mire Valley within a fault-guided basin, a low-lying fold to the north/north-east, and expansive open approaches to the south (Mighall and Chambers, 1995: 300) (Fig. 2).

The height of the stonewalled rampart – which was preserved to a maximum of 1 m along the north east facing side of the hillock (Crew, 1987) – would have been raised by a palisade using timbers set in the stonewall (Crew and Musson, 1996). Between 1979 and 1985 the site was fully excavated, identifying rich evidence of occupation. Two entrances were identified, one in the centre of the northeast rampart and the other, which had been blocked, was located near the northeast corner (Crew, 1987). In addition to a cobbled interior, two stake-walled roundhouses were identified, along with boiling stones, decorated glass beads and evidence for ironworking. A prominent 'snail-shaped' structure found in the interior of the fort was interpreted as a bloom smithy (Crew, 1987), with two other furnaces identified within the fort and another excavated just outside the north entrance (Crew, 1988). Radiocarbon dating and archaeomagnetic analysis suggests that ironworking occurred on site during two phases: 100BC to 70AD and 150AD to 250AD (Crew, 1988). Our focus falls on this earlier phase of occupation.

There is an absence of contemporary monuments in the immediate vicinity of Bryn-y-Castell. The nearest (undated) hillfort, Moel Dinas, is located some 10.2 km to the west. In the locality around Bryn-y-Castell[1], three Iron Age settlements have been identified at Afon Gamallt, Gamallt

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[1] [1] We restricted our search to within 1500m of the site following Rennell's (2012: 517) framework of 'scales of landscape experience' where 1500m is considered to approximate a 'local landscape'.

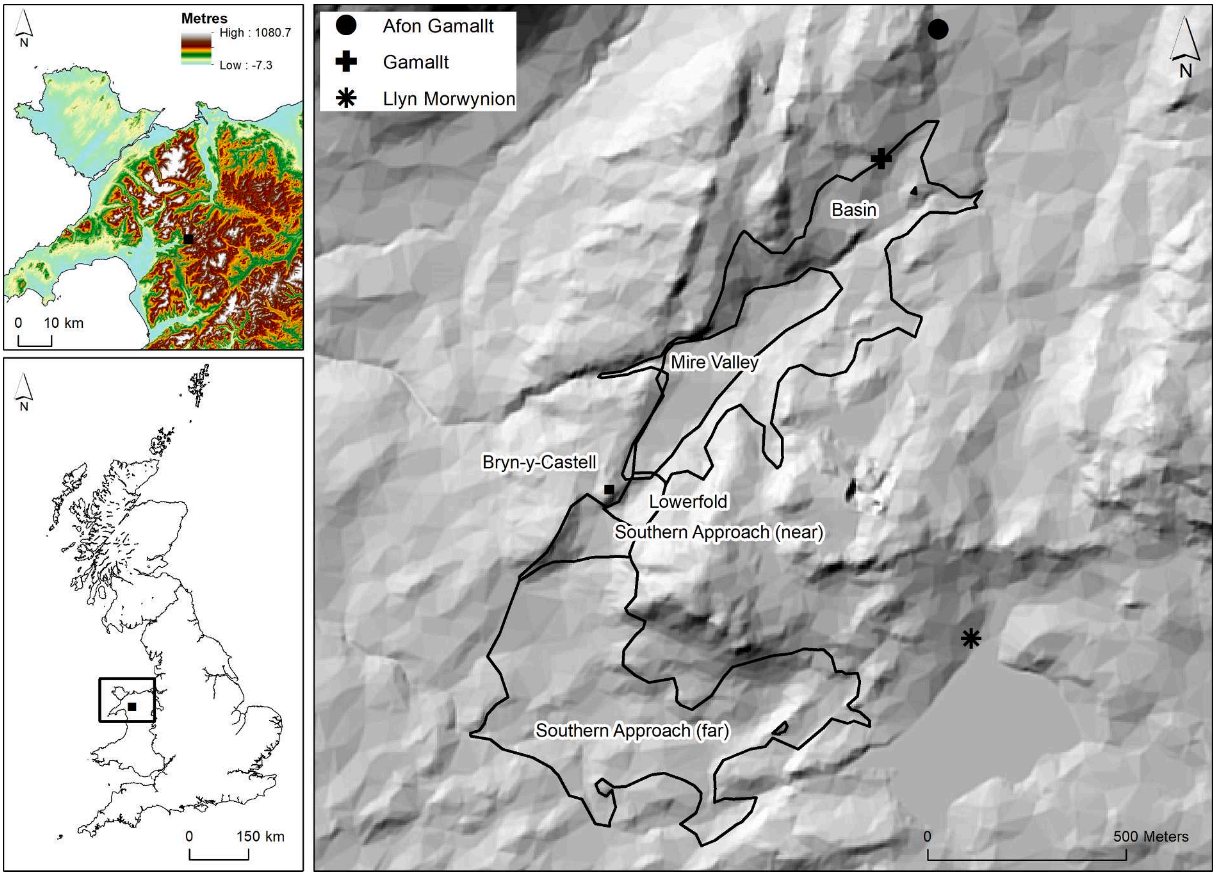

**Fig. 1.** Location of Bryn-y-Castell.

and Llyn Morwynion[2] (Fig. 1) alongside a scattering of hut circles (n = 6) and enclosures (n = 3). Although a lack of direct dating evidence means it is not possible to determine whether these settlements and structures were contemporary with Bryn-y-Castell, they do offer evidence of occupation around the site during the Iron Age and early Roman period. In addition, the Roman road of Sarn Helen is located within 200 m of the site, orientated north–south along the western flank of the hillock, connecting the Bryn-y-Castell landscape to the Roman fort of Tomen y Mur, 4.8 km to the south-west. Tomen y Mur was established sometime after 74AD with Sarn Helen constructed between the two phases of ironworking at Bryn-y-Castell (Mighall and Chambers, 1995) – although this does not preclude the route being used prior to the construction of the Roman road.

Against this context, the established interpretation is that Bryn-y-Castell was located on the hillock as a visual marker in the local landscape, near routeways into the Mire Valley (RCAHMW, 2021) from where bog ore is thought to have been collected to feed the furnaces (Mighall and Chambers, 1987). This paper documents our use of geospatial approaches to explore the potential role of sound in expressing prominence at Bryn-y-Castell, alongside visual and topographic dimensions.

## 3. The geospatial framework

We employ SPreAD-GIS, a plugin to the ArcGIS toolbox (Reed et al, 2012) to predict loss in sound intensity (amplitude) owing to various factors including spherical spreading, atmospheric absorption, land cover, wind, and terrain effects. The model identifies areas of the landscape where prominent sounds exceed those sounds of the ambient background, measured in dB(A) (see Hedfors, 2003).

### 3.1. *Generating acoustic storylines*

Before any modelling work began, the potential population that could be supported at Bryn-y-Castell was estimated using two techniques – Alcock (1961) and Cunliffe (2011) (Table A1) – to help inform the development of *acoustic storylines*. The Alcock-derived estimation was adopted (7–15 individuals) but seasonal occupation may have led to variations in population closer to the range estimated using Cunliffe's approach (2–36 individuals).

Next, 'what if' acoustic storylines were derived using archaeological material, excavation reports and published commentaries on Bryn-y-Castell, as well as sounds recorded by the authors and archived sounds sourced through the open source sound library, *Freesound*[3]. Individual activity tracks were overlaid in *Audacity*[4] to produce an interwoven acoustic storyline. The sound level of each activity was either directly measured or estimated. Direct measurements were taken with a hand-held digital sound level meter (Protmex MS6708) set within 2 m of the source recording in decibels using an 'A' weighted conversion (dB(A)). Sustained sounds (e.g. a crackling fire) were measured continuously for one minute. Readings were taken every 5 s and the average of these readings was adopted. For impulsive sounds (e.g. a sheep bleating), the peak sound pressure was recorded each time the sound was produced

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[2] Afon Gamallt comprises three ruinous stone walled huts. Gamallt comprises nine scattered hut circles and evidence of eight enclosures in the form of cleared terraces and discontinuous walls. Llyn Morwynion comprises two hut circles.

[3] https://www.freesound.org/.

[4] https://www.audacityteam.org/.

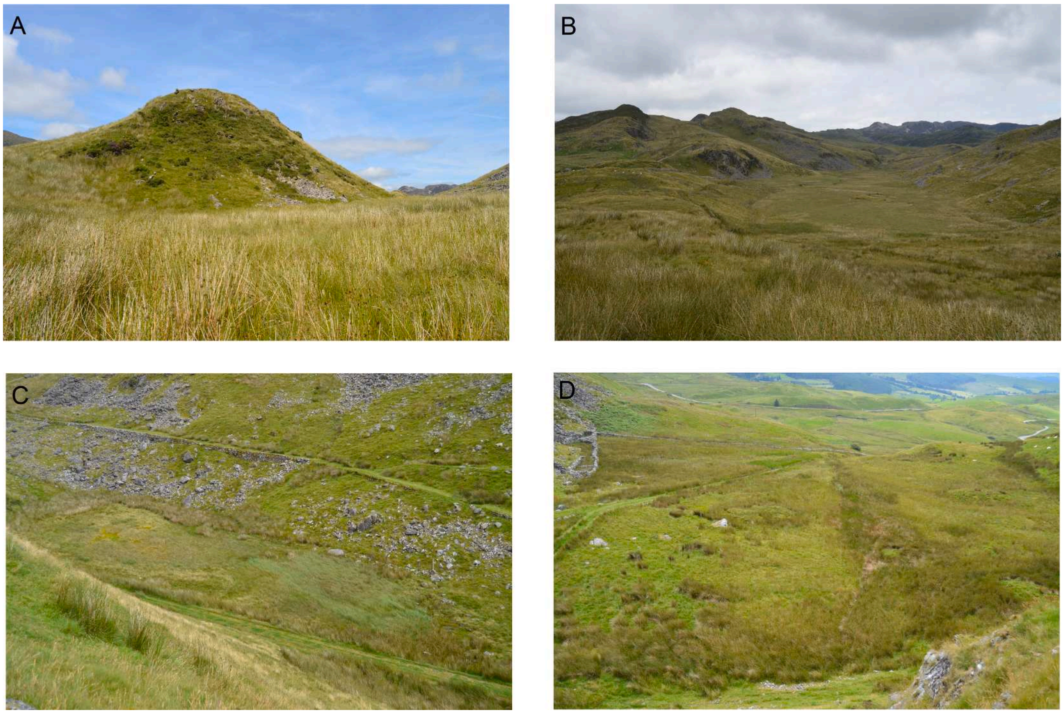

**Fig. 2. The contemporary landscape of Bryn-y-Castell.** *Notes: A) Hilllock on which Bryn-y-Castell is located (viewed from the Southern Approach (near)); B) the Mire Valley and Fault-guided Basin (viewed from the entrance of the fort); C) the Lowerfold (viewed from Bryn-y-Castell); D) the Southern Approach Near and beyond, the Southern Approach Far (viewed from the rear of the site).*

and the highest peak pressure reading was used. In cases where direct measurement was not possible, *Noise Navigator* (Berger et al, 2015), a database of 1,700 sound levels was used to estimate sound levels recorded in 'A' weighted decibels, and to validate the directly measured sounds. The dB(A) levels assigned to individual activities and behaviours were combined in SPreAD-GIS to form a composite dB(A) measure for each storyline.

In developing the storylines, it was recognised that various activities would have been generated within structures (e.g. a roundhouse) that could have contributed to the acoustic profile of the site. However, such activities were not incorporated into the modelled scenarios in recognition that internal acoustic dynamics – including the effects of different surfaces and materials on acoustic reflection, dispersion and absorption – require functionality beyond that embedded in SPreAD-GIS[5]. As such, all storylines were based around extramural activities. Eight storylines were conceived ranging from 71 dB(A) (minimum) to 87 dB(A) (maximum) (Table 1). Here we only report the results of the acoustic storyline that produced the maximum value (i.e. 87 dB(A)).

### *3.2. Setting the model parameters*

#### *3.2.1. Study area and extent*

To model sound propagation from the site, SPreAD-GIS requires a study extent. This was defined using a square polygon measuring 57.2 km$^2$, intentionally over-sized to limit edge effects in the GIS analysis. Within this extent, the geographies of the Basin, Lowerfold and Southern Approaches (near and far) were defined using Valley and Ridge Detection in Q-GIS (v.3.10.14)[6] (Fig. 1). The Mire Valley was defined separately in ArcGIS (v.10.6) using the Flow Direction tool. This involved generating a flow direction raster (D8-type) for a hydrologically corrected 5 m DEM covering the 57.2 km$^2$ study extent alongside a supplementary 'drop-raster'. The drop-raster returns the ratio of the maximum change in elevation from each cell along the direction of flow to the path length between the centres of cells. With the mire being lower lying than the surrounding basin, the drop-raster was used to define the mire extent by extracting the below mean values of steepest descent, representing distinct depressions in the DEM. The subsequent 'mire polygon' was triangulated with aerial photographs and subject to in-field verification. By comparison, Mighall and Chambers (1995) measured the mire at 590 m long by 126 m wide. The mire defined from the drop-raster measured 729 m long and 127 m wide, covering the same but slightly larger spatial extent.

#### *3.2.2. Terrain, land cover and model extent parameters*

The 5 m DEM was also used to capture the effects of terrain on sound attenuation. A wall and palisade were extruded in the DEM to a combined height of 3 m. Although the height of the wall and palisade is difficult to determine from the archaeological evidence, the 3 m extent is analogous to the proposed height of the palisade at the Tre'r Ceiri hillfort on the Llŷn Peninsula in North Wales (Harding, 2012). In addition, two roundhouses were also extruded to a height of 3 m. The heights of these 6 m diameter roundhouses were calculated using a 45° roof slope (Reynolds, 1979)[7].

To take account of the contribution of land cover in shaping ambient conditions and moderating sound attenuation, a rasterised land cover layer is needed as an input into SPreAD-GIS. Palaeobotanical analysis suggests that immediately prior to ironworking commencing at the site the surrounding landscape was largely open, comprising a valley mire, grassland, and/or blanket peats with pockets of deciduous woodland supporting a mix of local tree taxa such as oak and alder (Mighall and

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[5] [5] The open source software I-Simpa or proprietary software such as Odeon Acoustics have embedded functionality that could be used to extend the scope of the storylines developed here to include activities within structures.

[6] [6] Involving systemic experimentation with parameters, triangulation with aerial photographs, and field-testing.

[7] [7] Roundhouse height with a cone roof was calculated using $\tan(\alpha)\frac{a}{b}$ where ($\alpha$) is the angle of roof slope; (b) is the radius of the structure; and (a) is the unknown height.

**Table 1**
Summary of minimum and maximum acoustic storylines.

| Storyline Description | Activity | dB (A) | Context |
|---|---|---|---|
| **One (Minimum):** a 'what if' scenario taking place in an open area of the hillfort. A group of two women and two men can be heard in conversation. A baby can be heard cooing and crying. | **Group of two adult women and two adult men in conversation** | **65** | While evidence of domestic occupation is limited at the site, at least one of the roundhouses was interpreted as fulfilling a potential domestic function (Smith, 2008). Although it is not possible from the available archaeological evidence to determine the composition of the population living and/or visiting the site, women and children might well have assumed a direct or supporting role in iron working activities (Chirikure, 2007; Giles, 2007). Therefore, this storyline reflects the potential presence of men, women and children at the site against a backdrop of social encounters. |
| | Baby cooing and crying | 70 | |
| | Incoherent summing of the signal (sound) level | 71 | |
| **Two (Maximum):** a 'what if' scenario focused on the smithing area where metal is being worked outside of a structure. Bellows can be heard intensifying a fire while a stone hammer can be heard hitting a metal object on a stone anvil. There is also the sound of metal being polished with a stone and throughout there is elevated conversation between two people. | *Bellows intensifying fire (intermittent)* | 70 | As an iron working site, wood is likely to have been used to feed the furnaces (Mighall and Chambers, 1997) and it has been suggested that the furnaces at the site may have been fed by bellows (Crew, 1991). Experiments suggest that a three-person team would be the minimum needed to operate the furnaces without causing undue fatigue (Crew, 1991). Along with the recovery of a stone anvil, tongs, stone hammers and sharpening stones, the experimental work points to iron ore being smithed into billets and objects on site. This storyline reflects part of the communal process of iron working (Crew, 1991; Giles, 2007). |
| | *Stone hammer on iron object sitting on a stone anvil (intermittent)* | 88 | |
| | *Polishing metal with stone* | 50 | |
| | *Loud talking over the sound of bellows and hammer* | 75 | |
| | Incoherent summing of the signal (sound) level | 88 (87) | |

Chambers, 1997: 205).

Although SPreAD-GIS can accommodate seven land cover types (Deciduous Forest; Coniferous Forest; Herbaceous/Grassland; Shrubland; Barren Land; Urban; and Water), determining the specific composition and distribution of open grassland and deciduous woodland was not possible. As a compromise, using the UK Land Cover Map 2015 (LCM2015), areas of Barren Land (i.e. hilltops) were identified. The remaining study extent was reclassified into Herbaceous/Grassland. Under the 1mph wind conditions, an ambient background was set at 15 dB(A) at 800 Hz, which is comparable to a quiet woodland or grassland with no wind (12–15 dB(A)). Under the 18mph wind conditions, the ambient background was set at 23 dB(A) at 800 Hz, which lies between the estimated ambient values associated with a deciduous woodland with a breeze (15-18mph) (24–25 dB(A)) and open grassland with light wind (20–21 dB(A)) (Reed et al, 2012) (see below for further context).

### 3.2.3. *Meteorological parameters and seasonal conditions*

Palaeoenvironmental analysis of peat samples taken from the Migneint Plateau, 8 km from Bryn-y-Castell (Mighall and Chambers, 1995), indicates a shift at the beginning of the first millennium BC to wetter and cooler conditions. Local weather patterns would have varied daily and seasonally owing to the effects of different air masses moving through the region, with potential implications for lived experience at the site (see Pillatt, 2012). To capture possible seasonal variation in meteorological conditions and their impact on sound attenuation, profiles of the most common air masses and their 'extremes' affecting Britain were developed: 1) Tropical Maritime Exposed; 2) Tropical Maritime Sheltered; 3) Arctic Maritime Summer; 4) Arctic Maritime Winter; 5) Tropical Continental Winter; 6) Tropical Continental Summer; 7) Polar Maritime Winter; 8) Polar Maritime Summer; 9) Polar Continental Short Sea Track; 10) Polar Continental Long Sea Track (Table A2).

Air masses and their extremes were profiled to reflect meteorological characteristics (Pedgley, 1962; Met Office, 2012, 2015), with parameters refined to identify specific conditions, representative of each air mass, to be incorporated in the acoustic modelling phase of the analysis (Table 2). The minimum humidity in the model was set at 40% as anything below this tends to be rare in Britain (Pedgley, 1962). Loosely informed by the Beaufort scale using terrestrial specifications[8], two wind speeds were adopted for modelling: 'calm' (0-1mph) and 'moderate or fresh breeze' (18mph). This informed the setting of the ambient background levels to correspond to calm and breezy conditions (see above).

## 3.3. *Mapping prominence*

In SPreAD-GIS, sound propagation patterns are calculated from the source for one-third octave frequency bands (0.125–2 kHz), the audible range of the human ear (Reed et al, 2012). In structuring the models, the land cover and terrain parameters were held constant while the ambient, meteorological and seasonal conditions were adjusted. The frequency was also held constant at 800 Hz and the intensity of the sound source, measured in dB(A), was set using the composite sound levels calculated for the acoustic storylines (i.e. ranging from 71 to 87 dB(A)).

Each model run in SPreAD-GIS generated two raster files. The first was a *baseline* surface of acoustic propagation that accounts for sound attenuation around the site due to spherical spreading loss, atmospheric absorption, foliage and ground cover loss, upwind and downwind loss, and terrain. The second was an *excess* propagation surface that identifies where the predicted baseline sound is likely to be audible *above ambient (background) noise* (Reed et al, 2012). It was this excess propagation surface that was adopted in the analysis of acoustic exposure in this paper.

To determine the spatial extent of acoustic propagation under different seasonal and meteorological conditions, contours were generated at one decibel intervals derived from the excess propagation raster. These contours were subsequently converted to polygons and dissolved for each air mass type at four decibel ranges (May, 2014): 1–10 (audible but poor quality); 11–20 (quiet but clear); 21–30 and 30+ dB(A) (increasingly comfortable hearing). Distance and area metrics were calculated in ArcGIS for each air mass type using the four bands of acoustic intensity.

Next, 632,150 hypothetical 'listening points' were generated on 1 m maximum spacing, excluding the area within the enclosure of the hillfort, limited to the extents of the Basin, Mire Valley, Lowerfold and

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[8] 8 https://www.rmets.org/metmatters/beaufort-scale.

**Table 2**
Modelled parameters of air masses affecting the British Isles.

| Air Mass Type | Air Mass Extremes | | | |
|---|---|---|---|---|
| Tropical Continental | Summer (A) | | Winter (B) | |
| Temperature | 25 °C | | 5 °C | |
| Relative humidity | 55% | | 67% | |
| Prevailing Wind Direction | S/SE | | S/SE | |
| Wind Speed | Calm (0-1mph) | Moderate or fresh breeze (18mph) | Calm (0-1mph) | Moderate or fresh breeze (18mph) |
| Seasonal Conditions | Clear, calm | Clear, windy | Cloudy, calm | Cloudy, windy |
| Polar Continental | Long Sea Track (C) | | Short Sea Track (D) | |
| Temperature | 0°C | | −5°C | |
| Relative humidity | 80% | | 45% | |
| Prevailing Wind Direction | E | | E | |
| Wind Speed | Calm (0-1mph) | Moderate or fresh breeze (18mph) | Calm (0-1mph) | Moderate or fresh breeze (18mph) |
| Seasonal Conditions | Cloudy, calm | Cloudy, windy | Clear, calm | Clear, windy |
| Tropical Maritime | Sheltered (E) | | Exposed (F) | |
| Temperature | 15°C | | 8°C | |
| Relative humidity | 70–75% | | 95% | |
| Prevailing Wind Direction | SW | | SW | |
| Wind Speed | Calm (0-1mph) | Moderate or fresh breeze (18mph) | Calm (0-1mph) | Moderate or fresh breeze (18mph) |
| Seasonal Conditions | Cloudy, calm | Cloudy, windy | Cloudy, calm | Cloudy, windy |
| Polar Maritime | Summer (G) | | Winter (H) | |
| Temperature | 13°C | | 4°C | |
| Relative humidity | 80% | | 80% | |
| Prevailing Wind Direction | NW | | NW | |
| Wind Speed | Calm (0-1mph) | Moderate or fresh breeze (18mph) | Calm (0-1mph) | Moderate or fresh breeze (18mph) |
| Seasonal Conditions | Cloudy, calm | Cloudy, windy | Cloudy, calm | Cloudy, windy |
| Arctic Maritime | Summer (I) | | Winter (J) | |
| Temperature | 18°C | | −2°C | |
| Relative humidity | 70% | | 75% | |
| Prevailing Wind Direction | N | | N | |
| Wind Speed | Calm (0-1mph) | Moderate or fresh breeze (18mph) | Calm (0-1mph) | Moderate or fresh breeze (18mph) |
| Seasonal Conditions | Cloudy, calm | Cloudy, windy | Cloudy, calm | Cloudy, windy |

Notes: all air masses were modelled using an ambient background noise of 15 dB (A) at 800 Hz (1 mph) and 23 dB(A) at 800 Hz (18mph). A 15 dB(A) ambient background is comparable to a quiet woodland or grassland with no wind (12–15 dB(A)) and 23 dB(A) lies between the estimated ambient values associated with, a deciduous woodland with a breeze (15-18mph) (24–25 dB(A)) and open grassland with light wind (20–21 dB(A)) (Reed et al, 2012).

Southern Approaches (near and far) (see O'Driscoll, 2017a for a similar approach using viewshed observer points). The listening points were then intersected using the air mass polygons for 1mph and 18mph winds to determine the proportion of listening points exposed to acoustic propagation under different conditions. Next, each of the air masses and four decibel ranges were intersected with the five delineated areas as a means of exploring differential exposure of the Basin, Mire Valley, Lowerfold and Southern Approaches (near and far) to acoustic propagation.

The analysis was then extended to enable comparison between the patterns of sound propagated under the different air mass types for 1mph and 18mph wind conditions and those parts of the landscape to which the site was visible. This involved a two stage process. First, an initial visibility analysis was carried out in ArcGIS using the 5 m DEM. Here a 5000 m buffer was set around the hillfort (Conçalves et al, 2014) and a point was generated at the centre of each cell in the buffer (7861 in total)[9]. Individual viewsheds were calculated for each point with edge effects minimised using the original study extent (57.2 km$^2$). The refractivity coefficient was set to 0.13 and a surface offset was set to 1.70 m to reflect the height of an observer viewing the hillfort from a standing position. All viewsheds were summed using map algebra to generate a cumulative viewshed capturing the overall visibility of the site from within the buffer extent.

Second, observation points were generated at 10 m intervals along the outer edge of the palisade. These points were segmented into four observation 'zones'[10] and using the same visibility parameters as those outlined above, a viewshed was calculated for each point ($n = 110$). Cumulative viewsheds were generated for each of the four zones to reveal how visibility from Bryn-y-Castell altered as the observation locations changed around the site. Next, the four decibel ranges were merged and dissolved to create a 'composite' polygon for each air mass type. These composite polygons reflected cumulative patterns of acoustic propagation under the different air mass types that were intersected with the four cumulative viewsheds and summarised for the Basin, Mire Valley, Lowerfold, and the Southern Approaches (near and far). This revealed the areas where visibility and acoustic exposure intersected, providing a means of exploring where acoustic and visual influences occurred in isolation or in ways that conjoined, leading theoretically to 'zones' where the visual and acoustic prominence of Bryn-y-Castell might have been variably expressed.

Finally, the air mass polygons for 1mph and 18mph winds were intersected with least-cost pathways (LCPs) converging on the Mire Valley that the hillfort is thought to have been sited to dominate (RCAHMW, 2021). The LCPs were calculated in the following way. To aid computation, a 10 m DEM was derived from the original 5 m DEM and a 7 km$^2$ bounding box defined around the site. A point was digitised at three locations in the Mire Valley to simulate proxy locations of convergence (north, centre and south).

In order to simulate hypothetical origin locations, a slope raster was calculated from the 10 m DEM, rescaled from 0 to 1 (low slope to high slope in degrees) and then inverted 0 and 1 (high slope to low slope in degrees). This inverted slope raster was then used as the probability raster in the 'Create Spatially Balanced Points' tool (ArcGIS) to determine the probability of a location being included in the final sample of origins (0 = low to 1 = high inclusion probability). Using a basic python script, a limitation was imposed so that the creation of spatially balanced

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[9] 9 The viewsheds excluded those cells in which the site was located.

[10] 10 The grouping analysis tool available in ArcGIS was used to segment observer points based on locational traits, with XY coordinates forming two variables. The group limit was set to four with no spatial constraint included. Seed points were chosen randomly and 1000 iterations run using python. The run that maximised the pseudo F-statistic was considered the optimal solution.

points only took account of cells that were located more than 1 km from the site, representing the final approach to the mire locations[11]. Of 16,707 possible locations (cells) that could hypothetically constitute an origin location, a sample of 376 was identified based on a margin of error of +/-5%, and a confidence interval of 95%[12].

The *R* package *movecost* and its associated function 'movecorridor' (Alberti, 2019) was then used to generate the LCPs. Movecost includes the provision to calculate slope-dependent anisotropic cost-surfaces and least-cost paths. The 10 m DEM was used as the terrain input and, applying a subsample of origins from the 376 sample points, energy cost surfaces were generated using the (1) Llobera-Sluckin, (2) Herzog, (3) Van Leusen, and (4) Pandolf *et al* metabolic energy expenditure functions. We ultimately adopted Herzog's function[13] (see Herzog, 2013) because the piloted LCPs approximated well to plausible routes to the mire identified during field visits. In total, 1128 LCPs were generated, with no barriers (e.g. rivers) or land cover parameters imposed, in three runs using the 376 origins as inputs and each of the three digitised points within the Mire Valley as destinations.

Next, 'convergence points' at which LCPs entered the Mire Valley were intersected with the air mass polygons at 1mph and 18mph to determine their exposure to acoustic propagation. The 'Linear Directional Mean' tool was then used to derive the mean directional trend for each LCP based on an average angle of the constituent line segments in each pathway for eight cardinal compass directions. The LCPs were intersected with the air mass polygons to determine whether there was a directional trend to the acoustic exposure of the LCPs.

Finally, the percentage of the total length of each LCP that intersected the different air masses under 1mph and 18mph winds was calculated using the 'Tabulate Intersection' tool in ArcGIS. Descriptive statistics were calculated as a means of summarising the exposure of LCPs to acoustic propagation, taking account of differences in the spatial extent and coverage of each air mass under the two wind speeds. The next section details the results of the study.

## 4. Mapping dimensions of prominence at Bryn-y-Castell

### *4.1. Patterns of acoustic exposure*

The acoustic mapping at Bryn-y-Castell reveals the extent and patterning of sound propagation in excess of the ambient across the decibel ranges under different air masses and wind speeds (Figs. 3 and 4). Sound that is likely to be audible above the ambient but of poor quality (1-–10 dB(A)) exhibited the most extensive propagation patterns under both wind speeds. As the dB(A) level and audibility increases above the ambient, so the spatial propagation of sound under both wind speeds becomes ever more concentrated with closer proximity to the site. The summary statistics in Figs. 3 and 4 illustrate the extent to which acoustic propagation varied under different wind speed conditions with a quieter ambient background and lower wind speed generating audible acoustic propagation above the ambient far in excess of the 18mph wind, both in terms of distance and area covered (Figs. 5 and 6).

As a consequence, different air masses and wind speeds afforded certain listening points more or less exposure to acoustic messages emanating from the site. This ranged from complete coverage for Polar Maritime and Arctic Maritime (Winter and Summer) to just over half (58%) under the Tropical Continental Summer air mass at 1mph for the 1–10 dB(A) range. Under 18mph winds, coverage of listening points ranged from just less than half (47%) under Polar Maritime Winter and Summer conditions to 10% under the Polar Continental Short Sea Track air mass under the same decibel range. At 30+ dB(A), coverage of listening points ranged from 57% under Polar Maritime Winter conditions for 1mph winds to 17% under the Tropical Continental Summer air mass at 1mph. In contrast, there were no listening points exposed to acoustic propagation in excess of the ambient under any air mass for winds at 18mph (Table 3). Although it is not possible to determine whether the three settlements identified in Fig. 1 are contemporary with Bryn-y-Castell, it is still notable that 60% of air masses under 18mph winds intersected at least one of the three-recorded settlements and one of the air masses intersected all three. Under 1mph winds, all air masses intersected at least one of the three-recorded settlements and 80% intersected all three at a minimum of 1–10 dB(A).

Extending the analysis to take account of the propagation of acoustic messages into the Basin, Mire Valley, Lowerfold, and the Southern Approaches (near and far) reveals that these different areas would have been subjected unevenly to the sounds produced at Bryn-y-Castell, conditioned by the rhythms of daily and seasonal life, meteorological conditions, and the physical environment (Figs. 7 and 8). Under a 1mph wind for propagation at 1–10 dB(A), the Mire Valley was subject to complete coverage irrespective of air mass. This was also the same for propagation at 11–20 dB(A). At 21–30 dB(A), more than 90% of the Mire Valley was subject to acoustic propagation, irrespective of air mass. At 30+ dB(A), greater variability was introduced were coverage ranged from just over 60% under Polar Continental Short Sea Track conditions to near complete coverage under Tropical Maritime Exposed and Tropical Maritime Sheltered air masses. This pattern of extensive coverage was also characteristic of the Lowerfold. The Basin and Southern Approach (near) exhibited similar profiles of complete or near complete coverage at 1–10 dB(A), but greater variation was introduced at the 11–20 dB(A) range and above when compared to exposure afforded to the Mire Valley and Lowerfold. The Southern Approach (far) was characterised by much more extensive variation across all decibel ranges where five air masses offered complete coverage of the Southern Approach (near) while the Tropical Continental Summer air mass covered <20%. This profile of extensive variation was also characteristic of the Southern Approach (far) for the 11–20 dB(A) to 30+ dB(A) ranges.

Turning to 18mph winds, it is notable that acoustic exposure across the five areas was constrained to a much greater extent than under the 1mph winds, but was also much more variable between air masses. A case-in-point is the Mire Valley, where 83% of this area was subject to acoustic influences under a Tropical Maritime Sheltered air mass compared to 25% under a Tropical Maritime Winter air mass. At the same time, there was no propagation over 20 dB(A) into the Mire Valley, its surrounding Basin, or the Southern Approach (far) under 18mph winds. The Lowerfold and Southern Approach (near) were characterised by more extensive exposure at the 1–10 dB(A) and 11–20 dB(A) ranges than the Mire Valley or the Basin, albeit to varying extents depending on air mass. Perhaps unsurprisingly given its profile of extensive variation under 1mph winds, the Southern Approach (far) was characterised by consistently lower levels of acoustic exposure under 18mph winds when compared to the Mire Valley, Lowerfold, Basin, and Southern Approach (near).

In acoustics, the Inverse Square Law "…predicts a fall in sound pressure at an approximate rate of 6 dB as the distance from the source doubles" (Primeau and Witt, 2018: 877). However, it does so under the assumption of equal sound propagation in all directions. The physical and environmental moderation of acoustic propagation and intensity are more extreme in rugged upland landscapes than in open lowland areas (Van Renterghem et al, 2007). This results in uneven and fragmented spatial patterns of acoustic propagation, such as those identified within the Bryn-y-Castell landscape.

This unevenness in acoustic patterning raises questions about the quality and clarity of the acoustic messages emanating from the site. In a study of acoustic propagation at Silbury Hill in Southern England, May (2014) found that at the 1–10 dB(A) range, the reception of sounds was

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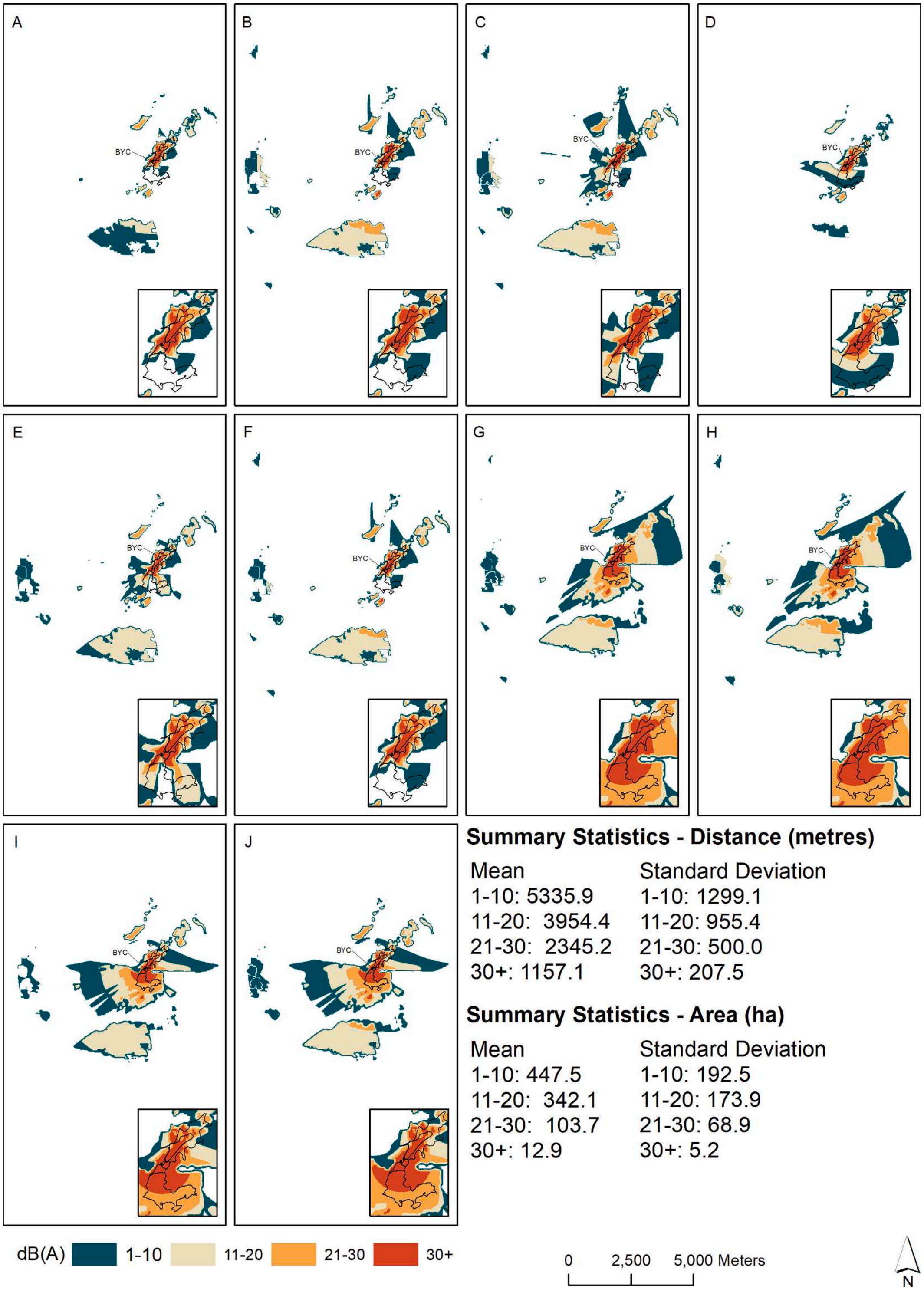
[11] [11] Also recognising that effort would have been invested in arriving at the hypothetical origin.

[12] [12] Sample= (Z-score) $^2$ x Std x (1-std) / (margin of error)$^2$.

[13] [13] Cost(s) = 1337.8 s 6+278.19 s 5–517.39 s 4–78.199 s 3+93.419 s 2+19.825 s+1.64, where (s) is the slope. The function is measured in J/(kg*m) and makes use of the sixth polynomial (see Herzog, 2013).



**Summary Statistics - Distance (metres)**

| Mean | Standard Deviation |
|---|---|
| 1-10: 5335.9 | 1-10: 1299.1 |
| 11-20: 3954.4 | 11-20: 955.4 |
| 21-30: 2345.2 | 21-30: 500.0 |
| 30+: 1157.1 | 30+: 207.5 |

**Summary Statistics - Area (ha)**

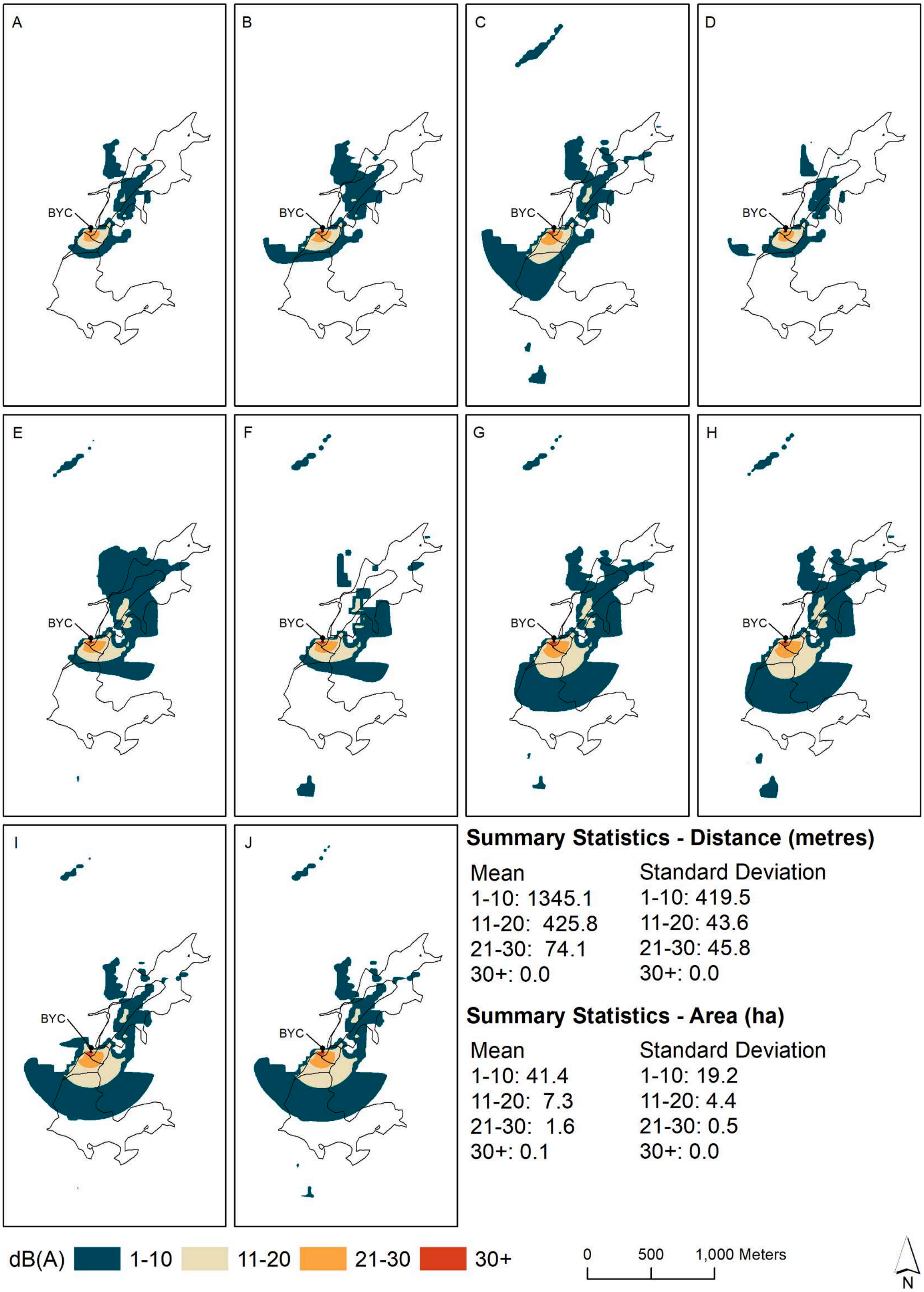
| Mean | Standard Deviation |
|---|---|
| 1-10: 447.5 | 1-10: 192.5 |
| 11-20: 342.1 | 11-20: 173.9 |
| 21-30: 103.7 | 21-30: 68.9 |
| 30+: 12.9 | 30+: 5.2 |

**Fig. 3. Sound propagation at 87 dB(A) at Bryn-y-Castell for each air mass (1mph).** *Notes: For codes A-J, see* Table 2.

of a low quality making sounds difficult to recognise. Nevertheless, these sounds were still audible and served to 'announce' the site, albeit less intensively than in parts of the landscape, where the acoustics were of a higher audible quality. However, the relationship between the 'quality' of reception and intensity became more complex when a listener was familiar with the site or the sounds being produced. Greater familiarity afforded an improved sense of acoustic reception, which heightened awareness and recognition of the site. In this sense, the acoustic prominence of Bryn-y-Castell might well have been conditioned by a listeners' familiarity with the place, the quality of the acoustic reception, and surprise or expectation of 'hearing the site', all of which would have been mediated through meteorological and topographic influences, and the direction and distance of the listener from the source (also see Tilley, 2010).

### 4.2. *Audible, visible or both?*

If acoustic exposure was a variable property of the Bryn-y-Castell landscape, then further consideration is needed of the role of visibility in accentuating prominence and the potential for integrating with this,



**Summary Statistics - Distance (metres)**

| Mean | Standard Deviation |
|---|---|
| 1-10: 1345.1 | 1-10: 419.5 |
| 11-20: 425.8 | 11-20: 43.6 |
| 21-30: 74.1 | 21-30: 45.8 |
| 30+: 0.0 | 30+: 0.0 |

**Summary Statistics - Area (ha)**

| Mean | Standard Deviation |
|---|---|
| 1-10: 41.4 | 1-10: 19.2 |
| 11-20: 7.3 | 11-20: 4.4 |
| 21-30: 1.6 | 21-30: 0.5 |
| 30+: 0.1 | 30+: 0.0 |

**Fig. 4. Sound propagation at 87 dB(A) at Bryn-y-Castell for each air mass (18mph).** *Notes: For codes A-J, see* Table 2.

acoustic dimensions. The first stage of the visibility analysis revealed that the site was in the upper quartile of the most visible places in the 57.2 km$^2$ model extent and the upper quartile of the 5000 m buffer extent (not shown). The viewshed analysis was undertaken using the DEM onto which the stone-wall, palisade, and roundhouse structures had been extruded. This will have contributed to enhancing the visibility of the site beyond the flat summit of the hillock. The indications of the analysis are that the established interpretation that Bryn-y-Castell was located on the crest of the hillock as a visual marker in the landscape, near routeways into the Mire Valley, but that it is generally difficult to see from beyond the immediate area (RCAHMW, 2021) might have underestimated the sites' visual exposure in the wider landscape.

Assuming that visual 'surveillance' was exercised to some extent over the mire landscape from Bryn-y-Castell, it is revealing how different parts of the site afforded different opportunities and constraints in surveilling the surrounding areas. Most of the Mire Valley was in the upper tercile of visibility from observation points A and just over half was visible from observation points B but was difficult to see from points C and D. The Basin exhibited a similar profile to the Mire Valley, although less of the Basin was visible from observation points A and D compared

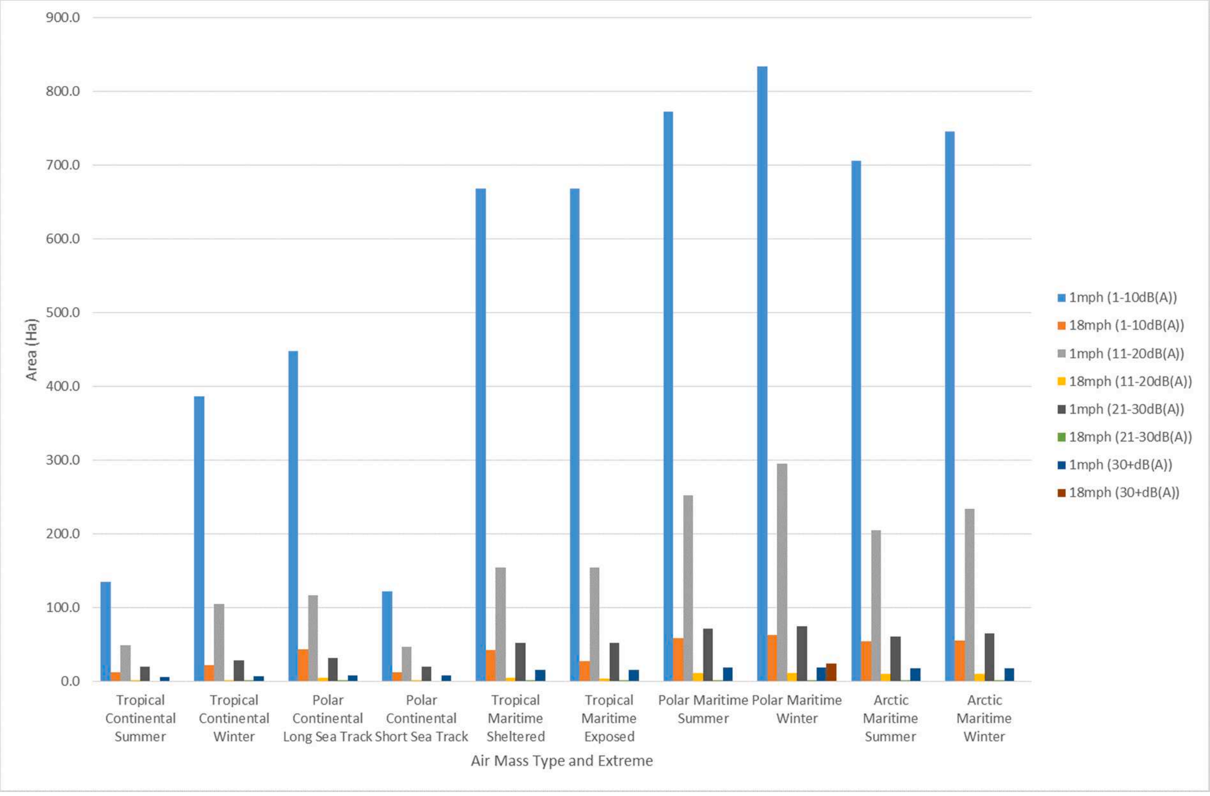


**Fig. 5.** Coverage (ha) of sound propagation at 87 dB(A) for each air mass.

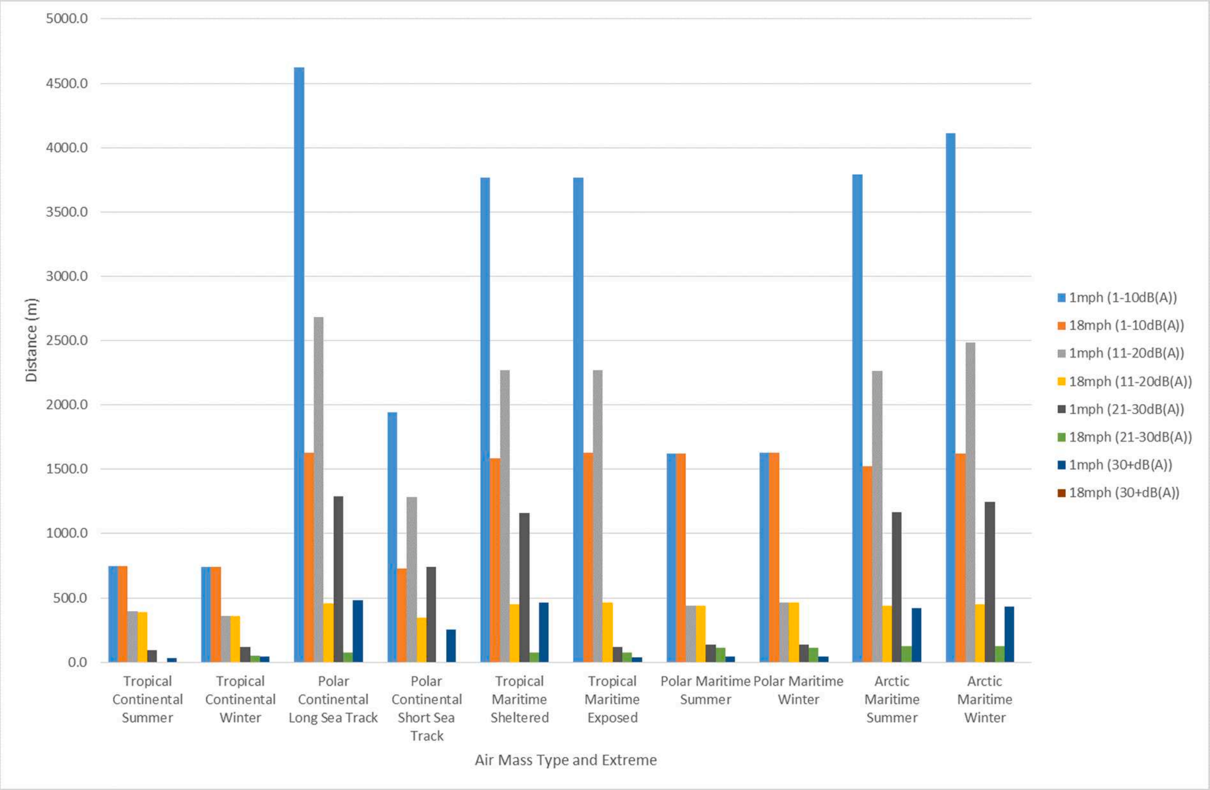


**Fig. 6.** Maximum distance (m) of sound propagation at 87 dB(A) for each air mass.

**Table 3**
Listening points exposed to acoustic propagation under various parameters (%).

| Air Mass | Decibel Range dB(A) | 1–10 | | 11–20 | | 21–30 | | 30+ | |
|---|---|---|---|---|---|---|---|---|---|
| | Wind (mph) | 1 | 18 | 1 | 18 | 1 | 18 | 1 | 18 |
| Tropical Continental | Summer | 58 | 11 | 42 | 0 | 32 | 0 | 17 | 0 |
| | Winter | 66 | 18 | 44 | 1 | 34 | 0 | 23 | 0 |
| Polar Continental | Long Sea Track | 81 | 33 | 58 | 6 | 39 | 0 | 25 | 0 |
| | Short Sea Track | 95 | 10 | 55 | 0 | 36 | 0 | 19 | 0 |
| Tropical Maritime | Sheltered | 84 | 29 | 68 | 5 | 38 | 0 | 19 | 0 |
| | Exposed | 66 | 12 | 43 | 3 | 33 | 0 | 19 | 0 |
| Polar Maritime | Summer | 100 | 45 | 100 | 10 | 97 | 1 | 55 | 0 |
| | Winter | 100 | 47 | 100 | 10 | 97 | 1 | 57 | 0 |
| Arctic Maritime | Summer | 100 | 36 | 95 | 10 | 86 | 1 | 43 | 0 |
| | Winter | 100 | 37 | 95 | 10 | 86 | 1 | 45 | 0 |

**Notes:** Listening point (LP) values are calculated as a proportion of the row total for each wind speed.

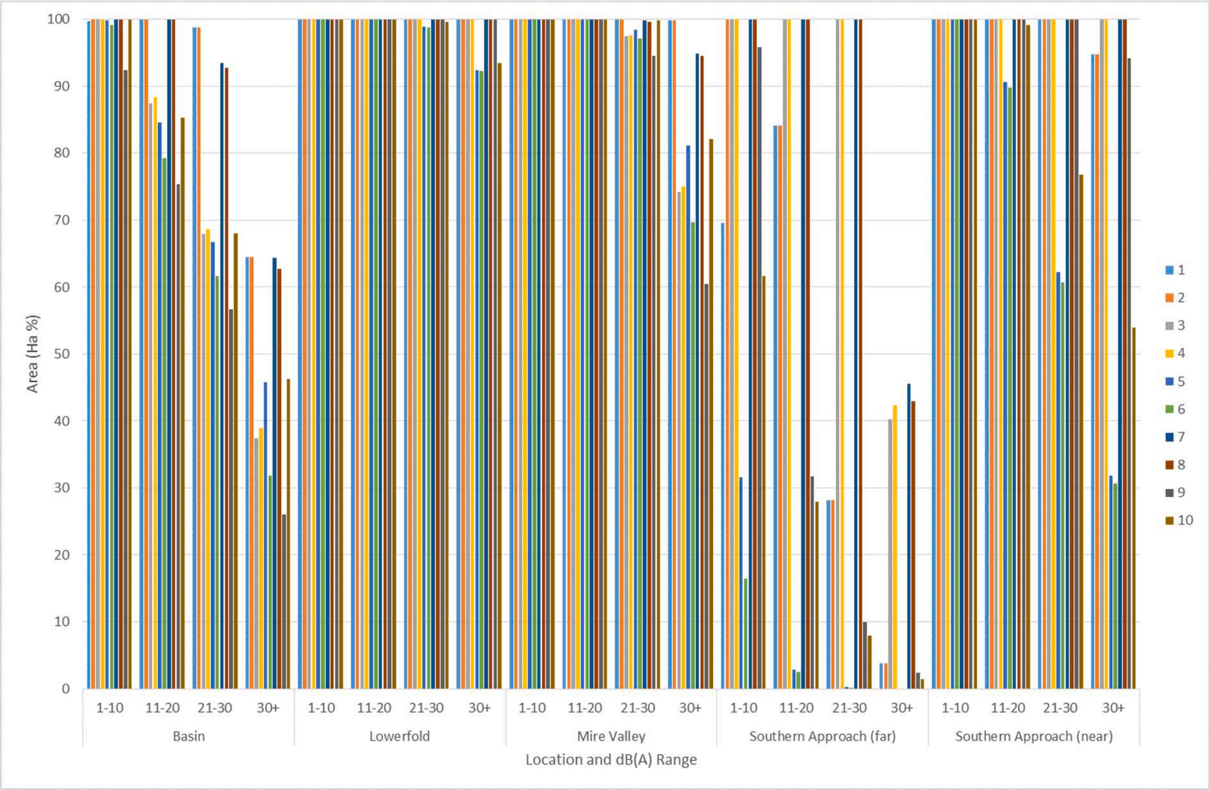


**Fig. 7. Area (Ha) exposed to acoustic propagation under different air mass and decibel ranges – 1mph (%).** *Notes: 1) Tropical Maritime Exposed; 2) Tropical Maritime Sheltered; 3) Arctic Maritime Summer; 4) Arctic Maritime Winter; 5) Tropical Continental Winter; 6) Tropical Continental Summer; 7) Polar Maritime Winter; 8) Polar Maritime Summer; 9) Polar Continental Short Sea Track; 10) Polar Continental Long Sea Track.*

to the Mire Valley. The Lowerfold was highly visible from observation points A and B while observation points C provided most scope for visual surveillance of the Southern Approach (near). The Southern Approach (far) was shown to be the least visible of any of the defined areas with all observation points recording a range of between one-quarter and one-third coverage across all terciles (Figs. 9 and 10).

Extending the analysis to consider the intersection of the areas *from* which the hillfort is visible and *to* which the fort is audible reveals an equally complex set of relationships between visual and acoustic exposure (Fig. 11). Under 1mph winds, over 90% of the Mire Valley was visible from at least some of the observation points around the site as well as being exposed to acoustic propagation under all air masses. A similar profile of visual and acoustic exposure was revealed for the Lowerfold while slightly <90% of the Southern Approach (near) and 70% of the Basin were visible *and* acoustically exposed under 1mph winds. The Southern Approach (far) was characterised by much more uneven visual and acoustic exposure across various air masses, ranging from <5% under the Tropical Continental Summer air mass to just over a quarter for five air masses.

Under 18mph winds, visual and acoustic exposure was reasonably extensive across the Lowerfold and Southern Approach (near), albeit much more variable than under 1mph winds. In terms of the former, coverage ranged from over 90% under six air masses to less than half under the Polar Continental Short Sea Track air mass. In terms of the latter, coverage ranged from over 85% for the Southern Approach (near) under five air masses to just over one-third under the Tropical Continental Summer air mass. Acoustic and visual composition was also much more variable for the Mire Valley, ranging from 25% under the Tropical Maritime Exposed air mass to 75% under the Tropical Maritime Sheltered air mass. The Basin and especially the Southern Approach (far) were characterised by notably lower levels of acoustic and visual exposure under 18mph winds when compared to the Mire Valley,

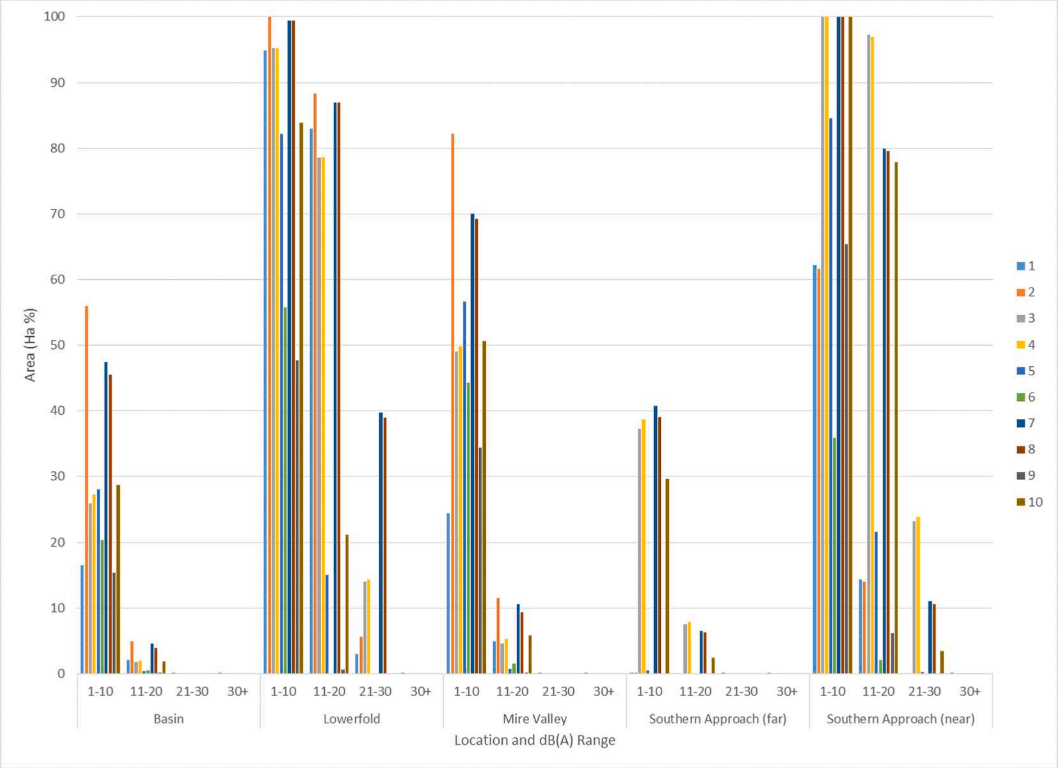


**Fig. 8. Area (Ha) exposed to acoustic propagation under different air mass and decibel ranges – 18mph (%).** *Notes: 1) Tropical Maritime Exposed; 2) Tropical Maritime Sheltered; 3) Arctic Maritime Summer; 4) Arctic Maritime Winter; 5) Tropical Continental Winter; 6) Tropical Continental Summer; 7) Polar Maritime Winter; 8) Polar Maritime Summer; 9) Polar Continental Short Sea Track; 10) Polar Continental Long Sea Track.*

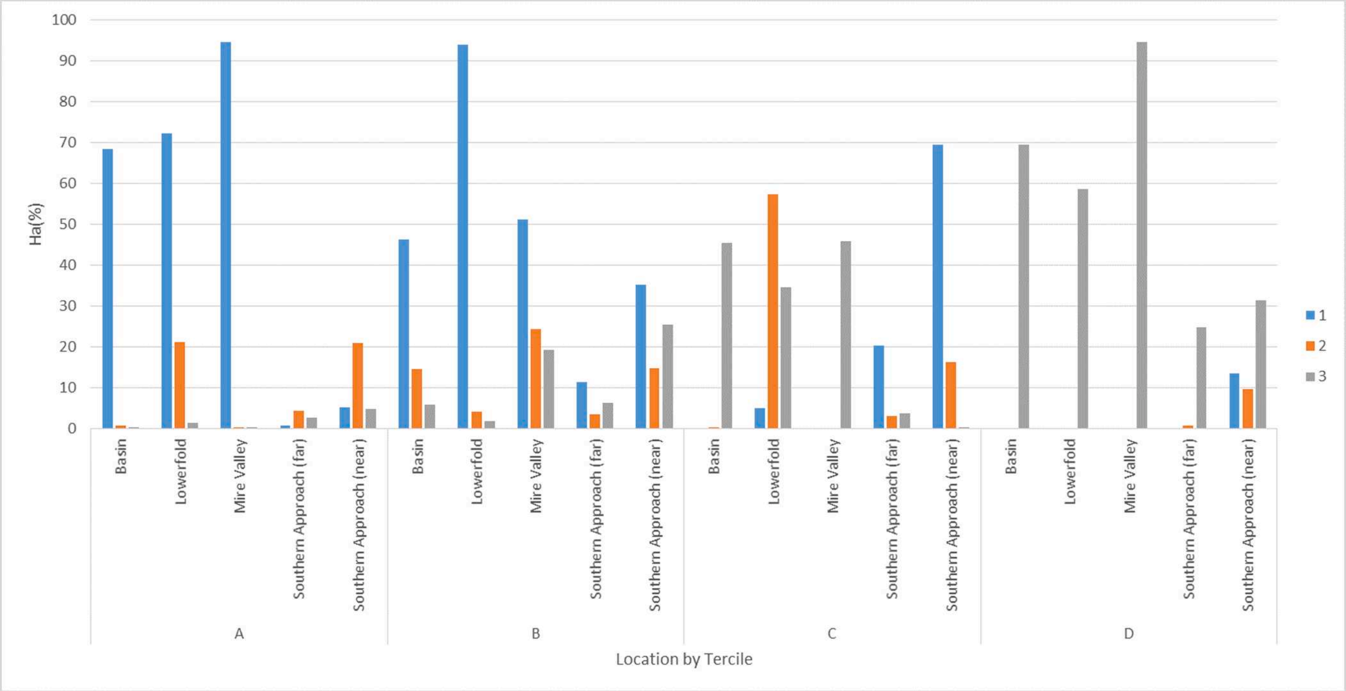


**Fig. 9.** Areas (Ha) visible from observer points A-D from high to low exposure (%).

Lowerfold, and Southern Approach (near). This pattern was only amplified when compared to the levels of exposure modelled under 1mph winds.

Here the analysis suggests that the prominence of Bryn-y-Castell could have been reinforced through the coincidence of visual *and* acoustic exposure but that this would have been dependent on environmental conditions (e.g. air mass and wind speed), acoustic and visual quality, and the location and abilites of those viewing, being viewed, or hearing the site from within the wider landscape. Under 1mph winds, the Mire Valley, Lowerfold and Southern Approach (near) were afforded

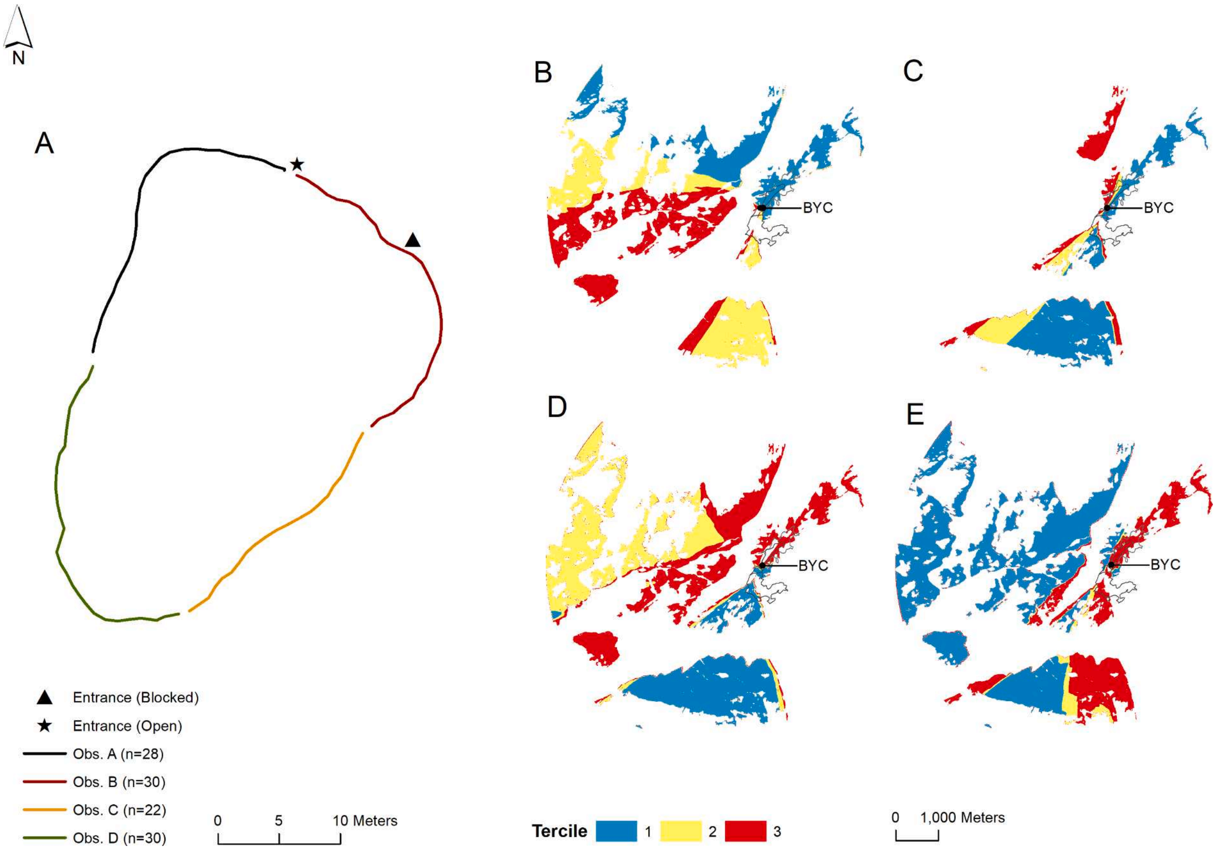


**Fig. 10. Cumulative viewsheds from observation points A-D at Bryn-y-Castell.** *Notes: Observer points A-D; Terciles = 1(high), 2 (medium), 3 (low) visibility.*

almost complete coverage of coincident visual *and* acoustic exposure. It is also notable that all three-recorded settlements around Bryn-y-Castell were subjected to acoustic and visual exposure under 80% of air masses for 1mph winds at a minimum of 1–10 dB(A).

In other parts of the Bryn-y-Castell landscape, acoustic exposure above the ambient would have been diminished compared to visual exposure and vice versa. The almost universal coverage of the Mire Valley, Lowerfold and Southern Approach (near) recorded under 1mph winds would have been replaced under 18mph winds by much more fragmented coverage of visual *and* acoustic exposure, depending on air mass. Of the three recorded settlements, at least one was subjected to acoustic and visual exposure under 60% of air masses at a minimum of 1–10 dB(A) and all three were subjected to acoustic and visual exposure under one air mass. In this sense, the prominence of Bryn-y-Castell, as expressed through a combination of visual and acoustic exposure, would have ebbed and flowed, gaining and losing potency at different times and in different parts of the landscape.

### 4.3. *Exposure of pathways to sound propagation?*

It has been suggested that certain locations were privileged as hillfort sites because of the strategic advantages these afforded a community in accessing and potentially controlling resources and routeways (Hamilton and Manley, 2001; Harding, 2012; O'Driscoll, 2017a; Seaman and Thomas, 2020). At Bryn-y-Castell, the Lowerfold is a natural access point from the south into the Mire Valley. Of the 1128 LCPs modelled, 446 (40%) were found to have traversed the Southern Approaches (near and far) before entering the Lowerfold and converging on the Mire Valley. Here a line density calculation in ArcGIS, with an output cell size of 10 m, illustrates the extent to which LCPs were funnelled through the Southern Approaches into the Lowerfold (Fig. 12). That the Lowerfold and Southern Approach (near) were the two most exposed of the five areas to acoustic and visual exposure supports the interpretation that Bryn-y-Castell was strategically located in relation to the Lowerfold as an access point into the Mire Valley. Equally however, possible alternative access routes from the north, east and west of the mire account for some 60% of the modelled LCPs (Fig. 13). This also includes pathways that broadly track, from north and south, the route of the Sarn Helen Roman road to the west of the hillock. What is notable here is that propagated sound intersected Sarn Helen under all air masses and both wind speeds, although coverage was more extensive, irrespective of air masses, under 1mph winds when compared to exposure under 18mph winds.

Although the plausibility of all of the routes identified in the LCP analysis requires further validation, the distribution nevertheless hints at a potentially uneven relationship between the least-cost routes and areas of acoustic exposure beyond the Lowerfold and Southern Approach (near). As a starting point, 'convergence points' (n = 30) were defined using all LCPs entering the Mire Valley towards the three destination locations (north, south and centre) (Fig. 13). Based on the modelled propagation of sound into the Mire Valley, it was notable that under 1mph winds, all convergence points into the north, south and centre of the valley were intersected by acoustic propagation under all air mass types (Fig. 14).

Under 18mph winds, there was much greater variability in acoustic exposure than under 1mph winds. Under the Tropical Maritime Sheltered air mass, all of the convergence points to the north and centre of the Mire Valley were intersected by acoustic propagation while over 70% of the convergence points to the south were subjected to acoustic exposure. Under Polar Maritime Summer and Polar Maritime Winter air masses, over 60% of convergence points to the mire south were intersected while over 90% of those to the mire north were subjected to acoustic propagation. In contrast, acoustic propagation was limited to between 50% and <10% in the north, south and centre under the

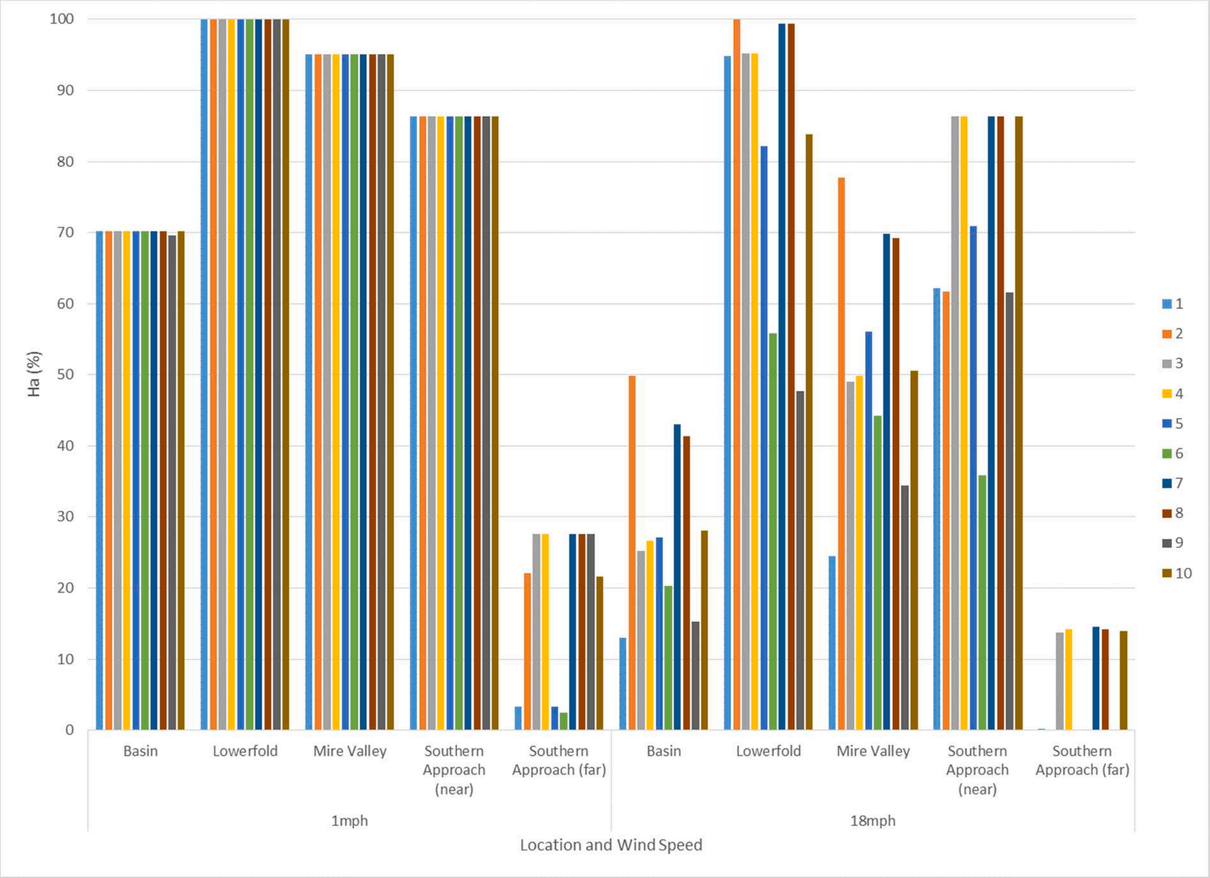


**Fig. 11. Intersection of areas (Ha) from which the hillfort is visible and to which the fort is audible based on air mass and wind speed (%).** *Notes: 1) Tropical Maritime Exposed; 2) Tropical Maritime Sheltered; 3) Arctic Maritime Summer; 4) Arctic Maritime Winter; 5) Tropical Continental Winter; 6) Tropical Continental Summer; 7) Polar Maritime Winter; 8) Polar Maritime Summer; 9) Polar Continental Short Sea Track; 10) Polar Continental Long Sea Track.*

remaining air masses (Fig. 14). The destination point to the north was characterised by the highest variation in acoustic coverage ranging from <10% to 100% of convergence points intersected by acoustic exposure to some extent and intensity under different air masses.

Further analysis also revealed a directional element to the way the LCPs were intersected by acoustic propagation. All pathways into the Mire Valley were intersected to some extent under 1mph winds, irrespective of air mass or direction (Table 4). Under 18mph winds, the intersection of pathways was far more variable than under 1mph winds, dependent on the direction from which the pathway originated. For instance, all pathways converging from the south of the hillfort were intersected to some extent by acoustic propagation, irrespective of air mass. Likewise, between 80 and 100% of LCPs originating from a south-east direction were also intersected to some degree. In contrast, there was comparatively limited intersection of pathways converging from a north, west, or north-west direction compared to those LCPS originating from a south or south-east direction. Here the north, east and north-west represented zones of *comparative* acoustic 'isolation' that largely persisted irrespective of air mass (Table 4).

These results reveal that the exposure of LCPs to acoustic propagation was variable and intermittent, again dependent on air mass, wind speed and orientation. Extending the analysis further, Table 5 summarises the percentage of the total length of LCPs that intersected the different air masses under 1mph and 18mph winds. What is notable is that the proportion of LCPs exposed to acoustic propagation under 1mph winds exceed the same metrics for 18mph winds. This is not surprising given the variation in spatial extent of acoustic patterning recorded under 1mph and 18mph winds, where the propagation of sound into the landscape of the former was much more extensive than the latter (see Figs. 3 and 4). The corollary of this is that as LCPs converge on the Mire Valley over comparatively longer distances without encountering areas of acoustic exposure, a lower proportion of each LCP is exposed to acoustic propagation under 18mph winds when compared to 1mph winds.

Yet the metrics also reveal that at least some LCPs, for a part of their convergence towards the Mire Valley, were beyond zones of acoustic exposure under 1mph *and* 18mph winds. Here some pathways began outside zones of acoustic propagation before converging towards the Mire Valley and remaining exposed to acoustic activity thereafter. Others began inside zones of acoustic propagation and remained exposed as they converged on the Mire Valley. Others moved into, out of, and back into zones of acoustic activity and isolation as the LCPs weaved towards the mire. This complexity means that if sound played a part in accentuating prominence over routeways – whether intentional or otherwise – then zones of acoustic isolation would have afforded different opportunities and challenges to the hillfort community when compared to those zones of acoustic exposure where sonic messages could have reinforced the prominence of the hillfort alongside topographic and visual cues.

## 5. Discussion and conclusion

This paper has sought to contribute to archaeological debates on landscape prominence by modelling patterns of sound propagation and bringing these into conversation with complementary visibility and mobility-based analyses often employed in geospatial studies of prominence. The underlying premise was that acoustics could serve to complement visual exposure since sound like sight helps shape human

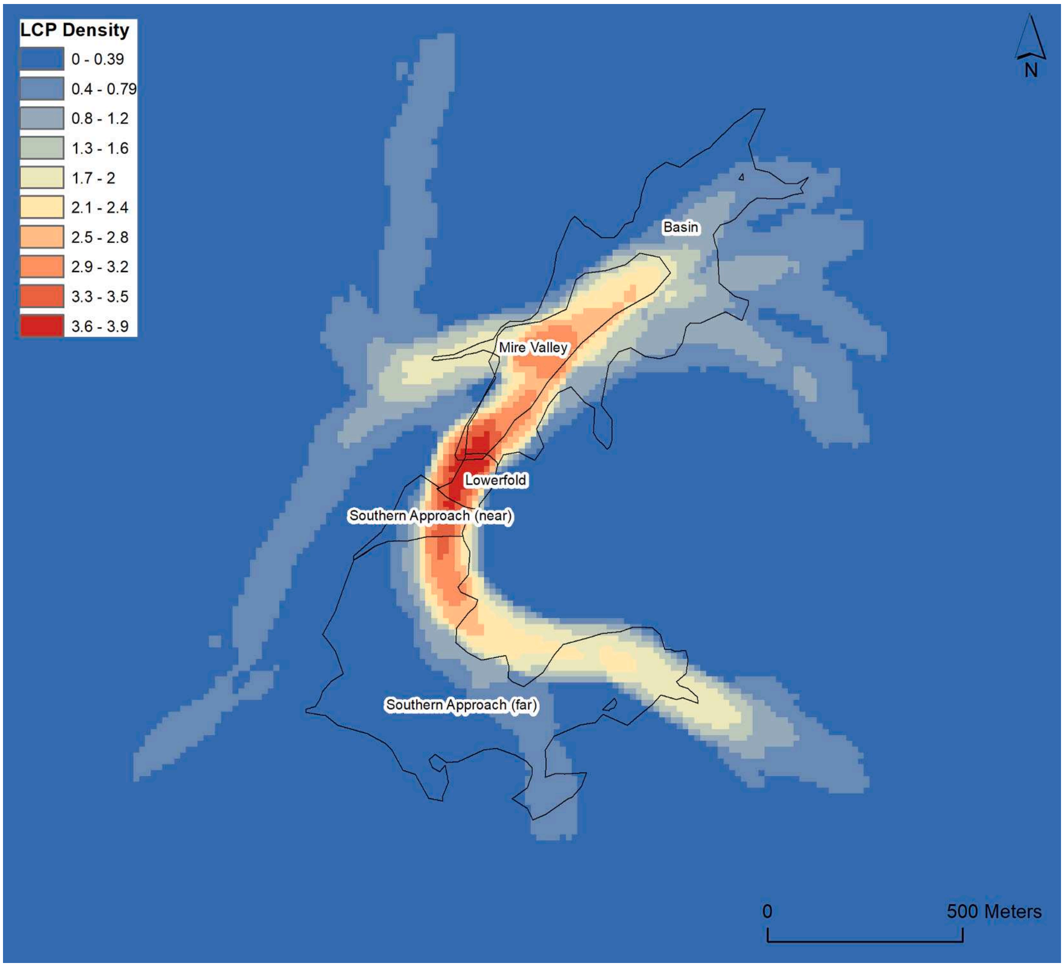


**Fig. 12.** Least-cost path line density.

experiences, memories and emotions (Feld, 1996; Tilley, 2010). In putting this contention to work, our focus fell on the small-stonewalled hillfort of Bryn-y-Castell in Gwynedd, North West Wales. A recognised interpretation of the site is that it was situated as a visual marker in the landscape, near routeways into a Mire Valley (RCAHMW, 2021), from where bog ore is thought to have been collected to feed the furnaces employed in ironworking (Mighall and Chambers, 1987). Following Whitley (2017), we made the case that geospatial approaches can be used *experimentally* to test 'what if' scenarios, asking questions of how and why sound might have contributed to the expression of prominence (at Bryn-y-Castell), alongside visual and topographic dimensions.

We conceptualised acoustic exposure through the lens of affordances (Gibson, 1979), taking a relational perspective that reflected the idea that affordances are constituted through the relations that exist between the abilities of animals to practically engage with features of their surroundings (Chemero, 2003; Gillings, 2012). This opened up the possibility for recognising the rich 'landscape of affordances' that are on offer to humans and which are embedded in a complex network of interrelated sociocultural practices and communal norms (Rietveld and Kiverstein, 2014), including those underpinning ironworking that would have been entangled with the rest of Iron Age life (Garstki, 2019: 456). Yet we also appreciated that *mapping* affordances is extremely difficult owing to the complexity involved in determining the direct relations between specific abilities of individuals and particular features of the environment. As such, we followed Gillings (2012) in employing the concept of affordances as a heuristic when exploring whether sound might have contributed to the relative prominence of Bryn-y-Castell.

Having established this conceptual backdrop, the first stage of the analysis focused on identifying patterns of acoustic propagation at Bryn-y-Castell, modelled using parameters associated with ten air mass types, two wind speeds and underpinned by 'acoustic storylines' that enabled us to establish robust sound level parameters for the acoustic models. The analysis demonstrated that sound produced at Bryn-y-Castell could have been propagated into each of the Basin, Lowerfold, Mire Valley, and Southern Approaches (near and far). A quieter ambient and lower wind speed generated audible acoustic propagation above the ambient under all air masses, far in excess of the 18mph wind, both in terms of distance and area covered.

Under 1mph winds, the Mire Valley, Lowerfold and Southern Approach (near) were afforded almost complete coverage of acoustic exposure irrespective of air mass when compared to the Basin and Southern Approach (near) but the coverage of acoustic exposure became far more uneven under 18mph winds. Under both wind speeds, irrespective of air masses, the analysis revealed that sound that is likely to be audible above the ambient but of poor quality (1–10 dB(A)) exhibited the most extensive propagation patterns. As the decibel level increased above the ambient, so the spatial propagation of sound under both wind speeds was found to be ever more concentrated with closer proximity to the site (also see Primeau and Witt, 2018). Although it was not possible to determine whether the recorded Iron Age settlements in the Bryn-y-Castell landscape were contemporary with the site, it is still notable that this variability in acoustic exposure also extended to these occupation sites. Likewise, propagated sound was found to have intersected the route (and LCPs tracking the route) of the Sarn Helen Roman road under all air masses and both wind speeds, albeit variably with greater coverage under 1mph winds and higher fragmentation of coverage

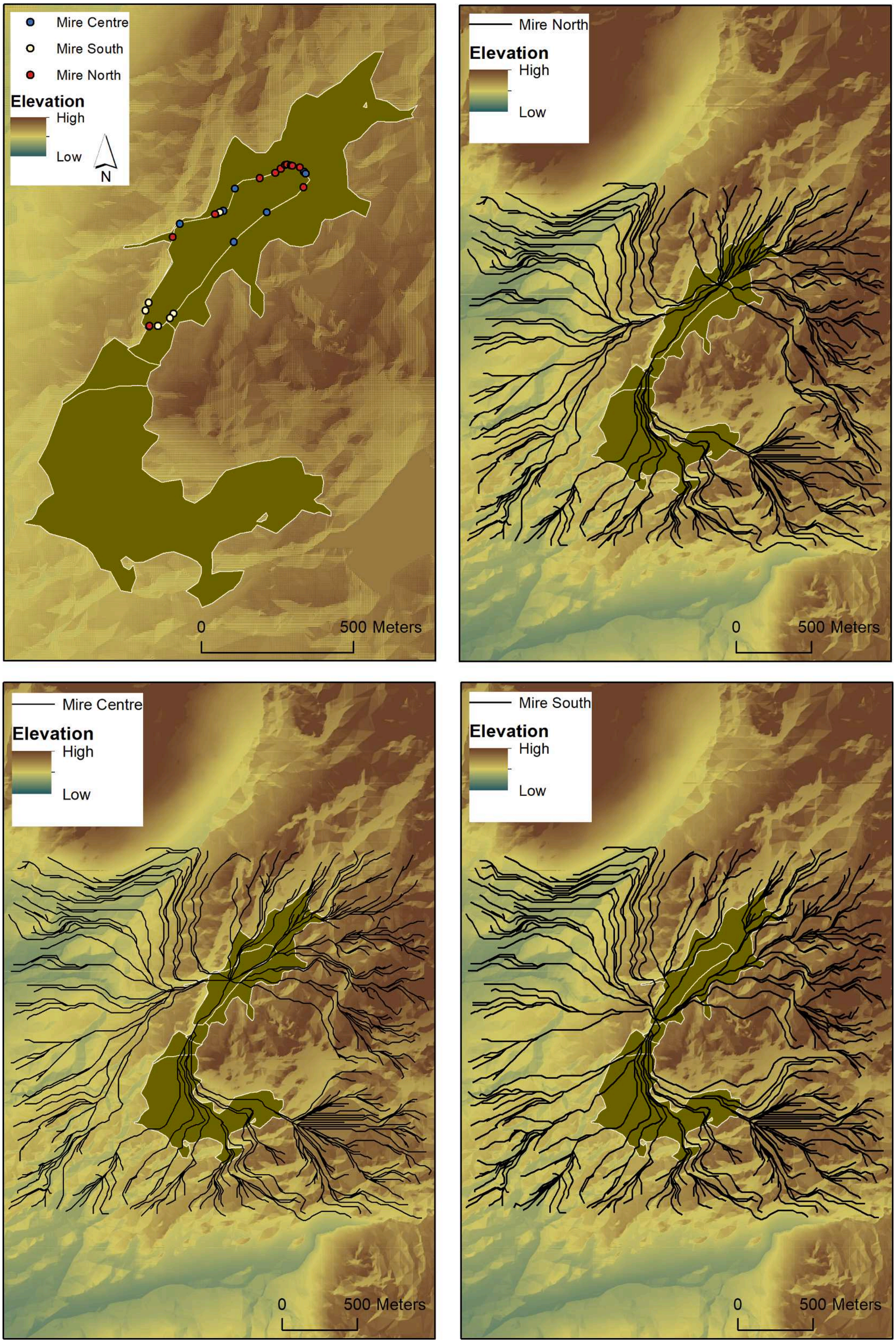


**Fig. 13.** Least-cost pathways into the Mire Valley (Mire North, Centre and South).

under 18mph winds.

When considered in the context of a ‘rich landscape of affordances’ (Rietveld and Kiverstein, 2014), combining, acoustic, visibility and mobility approaches within a geospatial framework offered an opportunity to consider where visual and acoustic messages may have been a feature of how prominence was expressed and reinforced at Bryn-y-Castell. The combination of acoustic and visual analysis revealed ‘zones’ and pathways in which a trade-off between visual and acoustic messages afforded the site, to differing extents, *either* visual or acoustic exposure, acoustic *and* visual exposure, visual exposure *and* acoustic isolation or visual isolation *and* acoustic exposure. This would have been conditioned by acoustic and visual quality, meteorological conditions,

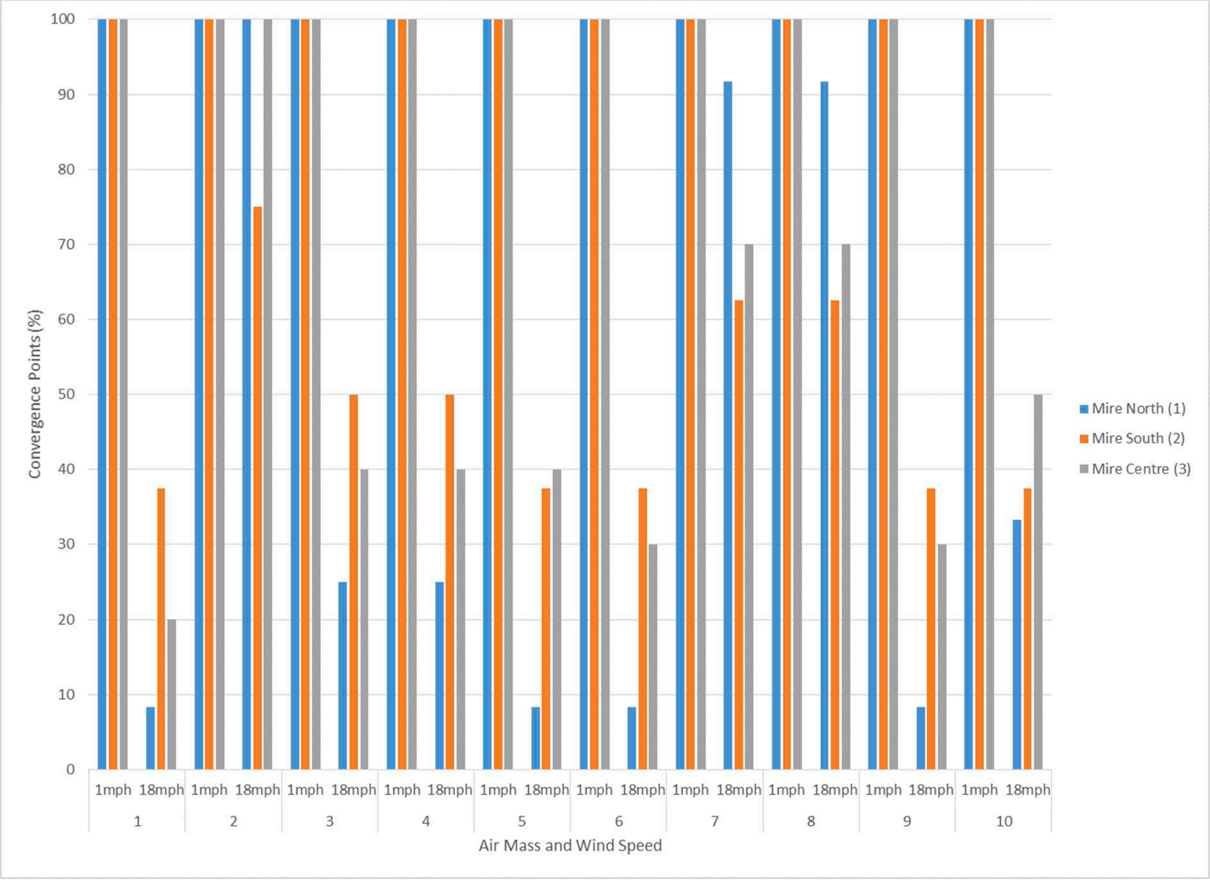


**Fig. 14. Intersection of 'convergence points' into the Mire North, South and Centre by air mass and wind speed (%).** *Notes: 1) Tropical Maritime Exposed; 2) Tropical Maritime Sheltered; 3) Arctic Maritime Summer; 4) Arctic Maritime Winter; 5) Tropical Continental Winter; 6) Tropical Continental Summer; 7) Polar Maritime Winter; 8) Polar Maritime Summer; 9) Polar Continental Short Sea Track; 10) Polar Continental Long Sea Track.*

**Table 4**
LCPs intersected with areas of acoustic exposure under different air masses (%).

| Air Mass | Wind | N | NE | E | SE | S | SW | W | NW |
|---|---|---|---|---|---|---|---|---|---|
| Tropical Continental Summer | 1mph | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18mph | 33.3 | 45.9 | 57.8 | 81.1 | 100.0 | 52.6 | 1.1 | 7.1 |
| Tropical Continental Winter | 1mph | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18mph | 44.4 | 45.9 | 57.8 | 81.1 | 100.0 | 90.3 | 1.1 | 7.1 |
| Polar Continental Long Sea Track | 1mph | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18mph | 33.3 | 98.7 | 64.5 | 81.1 | 100.0 | 100.0 | 15.2 | 7.1 |
| Polar Continental Short Sea Track | 1mph | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18mph | 33.3 | 44.0 | 57.8 | 81.1 | 100.0 | 90.3 | 1.1 | 7.1 |
| Tropical Maritime Sheltered | 1mph | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18mph | 77.8 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 80.4 | 53.6 |
| Tropical Maritime Exposed | 1mph | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18mph | 33.3 | 46.5 | 48.8 | 81.1 | 100.0 | 52.6 | 1.1 | 7.1 |
| Polar Maritime Summer | 1mph | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18mph | 57.8 | 100.0 | 100.0 | 100.0 | 100.0 | 52.6 | 1.1 | 7.1 |
| Polar Maritime Winter | 1mph | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18mph | 57.8 | 100.0 | 100.0 | 100.0 | 100.0 | 52.6 | 1.1 | 7.1 |
| Arctic Maritime Summer | 1mph | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18mph | 33.3 | 97.5 | 64.5 | 81.1 | 100.0 | 90.3 | 16.3 | 7.1 |
| Arctic Maritime Winter | 1mph | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | 18mph | 33.3 | 97.5 | 64.5 | 81.1 | 100.0 | 92.6 | 1.1 | 7.1 |

Notes:
1. The LCPs were originally generated from the 376 origin points towards the three destination locations. This meant that the 'Linear Directional Mean' tool outputted a default measure of direction 'towards' the Mire. Using the 'Flip Line' tool in ArcGIS, the direction of each of the LCPs was flipped to allow a measure of direction 'from' the Mire to also be determined. It was this latter measure that was used to consider directional trends in the LCPs by focusing on the direction from where the LCPs originated.
2.The bins for each of the eight cardinal compass directions were defined as follows: < 22.5: North; >= 22.5 and < 67.5 Northeast; >= 67.5 and < 112.5: East; >= 112.5 and < 157.5: Southeast; >= 157.5 and < 202.5: South; >= 202.5 and < 247.5: Southwest; >= 247.5 and < 292.5: West; >= 292.5 and < 337.5: Northwest; >= 337.5: North (https://support.esri.com/en/technical-article/000014483).
3. The cardinal compass directions were calculated to capture direction from the origin towards the Mire Valley.

**Table 5**
Length of LCPs that intersected the different air masses under 1mph and 18mph winds (%).

| Air Mass | Wind | No. LCPs (*n = 1128*) | Min. | Max. | Mean | STD. |
|---|---|---|---|---|---|---|
| Tropical Continental Summer | 1mph | 1128 | 11.0 | 100 | 45.6 | 21.4 |
| | 18mph | 912 | 2.6 | 32.9 | 14.6 | 7.3 |
| Tropical Continental Winter | 1mph | 1128 | 11.3 | 100 | 53.6 | 25.4 |
| | 18mph | 914 | 4.1 | 37.5 | 18.8 | 8.1 |
| Polar Continental Long Sea Track | 1mph | 1128 | 15.5 | 100 | 66.9 | 24.1 |
| | 18mph | 971 | 2.7 | 58.4 | 24.4 | 11.7 |
| Polar Continental Short Sea Track | 1mph | 1128 | 14.5 | 100 | 60.1 | 21.8 |
| | 18mph | 911 | 0.3 | 28.7 | 13.0 | 6.3 |
| Tropical Maritime Sheltered | 1mph | 1128 | 10.2 | 100 | 66.8 | 23.3 |
| | 18mph | 1061 | 4.6 | 68.8 | 24.0 | 12.3 |
| Tropical Maritime Exposed | 1mph | 1128 | 11.3 | 100 | 53.6 | 25.4 |
| | 18mph | 912 | 1.9 | 37.1 | 13.0 | 6.7 |
| Polar Maritime Summer | 1mph | 1128 | 16.6 | 100 | 84.3 | 24.2 |
| | 18mph | 1059 | 3.0 | 67.3 | 31.8 | 17.3 |
| Polar Maritime Winter | 1mph | 1128 | 16.9 | 100 | 84.4 | 24.1 |
| | 18mph | 1059 | 3.0 | 80.2 | 32.7 | 17.9 |
| Arctic Maritime Summer | 1mph | 1128 | 16.4 | 100 | 83.9 | 24.1 |
| | 18mph | 975 | 2.8 | 61.5 | 29.1 | 16.2 |
| Arctic Maritime Winter | 1mph | 1128 | 16.7 | 100 | 84.6 | 24.0 |
| | 18mph | 961 | 2.9 | 62.7 | 30.3 | 16.1 |

terrain, the abilities of the perceiver, and the familiarity of individuals with the site itself (May, 2014).

It has been noted elsewhere that considerable forethought would have been taken in the siting of hillforts, drawing on knowledge of topographic and visual prominence within local landscapes (O'Driscoll, 2017a). It is equally plausible that individuals and communities would also have developed a familiarity and knowledge of the acoustic properties of local landscapes as part of a process of socialisation (Tilley, 2010). Here uneven acoustic and visual exposure could well have afforded opportunities to the hillfort community as well as variable challenges. In areas where the site was visible but acoustically isolated, it may well have acted as a visual marker in the landscape (Hamilton and Manley, 2001). Notably, Bryn-y-Castell was visible from all three of the recorded Iron Age settlements in the region – drawing on the same parameters used in the visual analyses above – reinforcing the interpretation of the site as a visual marker in the local landscape (RCAHMW, 2021). In other areas of the Bryn-y-Castell landscape, or at certain times of visual concealment but acoustic exposure, sound may have acted as an acoustic marker , serving to 'announce' the presence of the hillfort (May, 2014), heightened with increasing proximity to the hillock. Where visual and acoustic exposure coincided, the effect could have been to accentuate the hillfort as a landscape marker more so than either visual or acoustic messages in isolation (Kolar, 2017; Rennell, 2012).

The analysis undertaken here reveals the extent to which acoustic exposure constitutes an unstable product of human-landscape interactions (Hedfors, 2003; Llobera, 2007; Pijanowski et al, 2011), characterised by spatially and temporally variable zones of sonic activity and isolation (Kolar, 2017). In modelling and mapping acoustic propagation and bringing the empirical insights into conversation with visibility and mobility-based analyses at Bryn-y-Castell, this study challenges us to think, conceptually and methodologically, of prominence as something that potentially varied, was ephemeral, and that lost and gained potency with intensities of inhabitation and landscape dynamics.

The approach outlined here is experimental rather than definitive and so there are aspects of the approach and analysis that would benefit from further development. Our construction of 'acoustic storylines' enabled us to establish robust sound level parameters for use in the acoustic models. However, these parameters are not assumed to be definitive; they were shaped by our interpretations of the archaeological evidence. Alternative interpretations of the archaeologcial evidence might well lead to different parameters being employed to those used here (Brouwer-Burg, 2017). Nevertheless, this scope for divergence is not a limitation if the intention is to explore the range of ways that acoustic prominence might have been expressed (Whitley, 2017).

Likewise, a focus on a single frequency band, use of limited ambient values, and the adoption of relatively broad land cover categories were necessary compromises here but adjusting these values and running multiple iterations would serve to deepen the analysis undertaken above. In a similar vein, the parameters used in the visibility and LCP analyses could have taken many other forms that could have led to different interpretations of the prominence of the site (Gillings, 2009; Llobera, 2001, 2007; Llobera et al, 2011). We also recognise that the SPreAD-GIS plugin introduced biases through its coding and the parameters it required to calculate sound propagation. An extension to the modelling of acoustic exposure undertaken here could include the use of acoustic software designed to accommodate the effects of different surfaces and materials on acoustic reflection, dispersion and absorption in 3D complex domains. In the context of hillforts, this could offer a more granulised understanding of how the enclosing elements (e.g. structures, walls, palisades or banks), the morphology, and internal settlement structure conditions acoustic propagation beyond the site. Finally, GIS-based acoustic modelling has been shown to underestimate the distance sound travels in reality (May, 2014). Further field study would serve to complement geospatial modelling as a means of testing existing plugins, developing alternatives, and further advancing our understanding of acoustic expressions of prominence in variable landscape contexts.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaa.2022.101423.

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