The application of GIS, predictive modelling, and morphological analysis to further understand cave use in Neolithic Ireland

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Declaration

This thesis is submitted to the Institute of Technology Sligo in fulfilment of the requirements for a PhD. This is my own work except where otherwise stated and acknowledged by references.

Thorsten Kahlert

Abstract

This thesis presents the results of two archaeological predictive models applied to two geographic regions in Ireland - North Connaught and Munster. The main aim of the project was to identify caves that were most likely to have been chosen as places of Neolithic funerary activity. This was achieved using a non-invasive assessment strategy, consisting of data collection through field visits and desk-based research. In a juxtaposed setting, internal morphological characteristics of caves were used in a cognitive-deductive predictive model, whereas external environmental factors were used in a second, correlative-inductive predictive model.

Several archaeological predictive modelling and survey methods were critically evaluated and adapted for this project, including cognitive modelling approaches and cave survey techniques. The resulting model for North Connaught forms a new approach to cognitive-deductive archaeological predictive modelling. Fieldwork was a major component of this thesis and encompassed detailed recording and surveying of numerous caves, mainly in the northwest of Ireland but also in the south where almost all caves of Neolithic significance are located. The catalogue presented here is the first extensive record of relict caves in the northwest of Ireland.

Cave archaeology in Ireland is a relatively new sub-discipline. The majority of sites identified thus far as places of Neolithic activity were discovered during antiquarian excavation campaigns. This thesis seeks to employ a more pro-active approach in identifying caves that are likely to contain Neolithic deposits. This is the first major attempt to target likely caves rather than react to chance finds. In fact, the discovery of human remains of Neolithic date in a cave on Knocknarea Mountains, Co. Sligo, one of the most iconic Neolithic ritual landscapes in Ireland, has led to new interpretations of the relationship between natural places and monuments.

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(centre) free from vegetation (Scharff et al. 1906). Right: recent photo looking out from Bats' Cave into the dense vegetation that covers the entire outcrop.

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"That, of course, is the dangerous part about caves: you don't know how far they go back, sometimes... or what is waiting for you inside."

- J. R. R. Tolkien: "The Hobbit" (1937)

Chapter 1: Approaching caves and archaeological predictive modelling

Caves provide a unique topic for researchers from a multitude of disciplines ranging from the study of ancient and contemporary biology to the deepest geological history of our planet. Plant and faunal remains that are locked in the sediments of hydrologically inactive fossil caves allow scientists to reconstruct past environments and the evolutionary history of many species, including humans. The hosting material, Carboniferous limestone, is itself a geological and biological record of marine life dating back 359 to 299 million years (Mitchell and Ryan 2001, 11-2).

Venturing into caves for scientific exploration in Europe became widespread during the 19th century to search for extinct fauna. It was during this time that remains of *Homo neanderthalensis* were discovered in Feldhofer Cave, Neander Valley, Germany (fig. 1.1); Schmerling Cave, Belgium; and Forbes' Quarry Cave, Gibraltar. These and subsequent discoveries of other hominid species placed humans, along with other primates, firmly into Darwin's evolutionary tree (Darwin 1859). Since these discoveries, an ever-increasing number of new hominid species have been discovered in caves. Sterkfontein

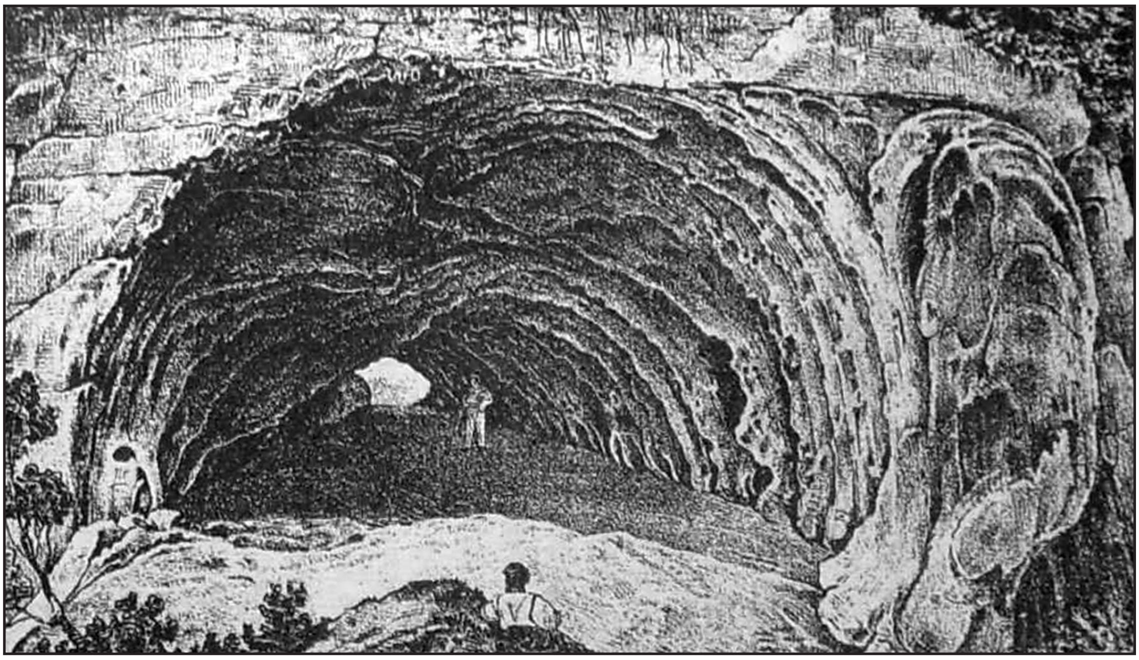


Figure 1.1: Feldhofer Cave, Neander Valley, Germany. The cave was destroyed during 19th century limestone mining operations (Bongard 1835).

in the ‘Cradle of Humankind’, South Africa, where the remains of thousands of early hominids have been systematically excavated since 1966, provided insights into human evolution spanning over three million years (Clarke and Partridge 2010). Tools, charcoal, and animal remains, all washed in from the surface of these deep vertical caverns, allow a glimpse into the life and death of our earliest ancestors. As human evolution proceeded, increasing cognitive abilities of later species were also recorded in cave deposits. The earliest evidence for higher cognitive abilities in the form of tool making, art and religion all come from cave contexts such as Wonderwerk Cave, South Africa (Chazan *et al.* 2012), Blombos Cave, South Africa (Henshilwood *et al.* 2009; Vanhaeren *et al.* 2013), Skhul Cave, Qafzeh, Israel (Bar-Yosef Mayer *et al.* 2009), and the most recent and controversial discovery of *Homo naledi* in the Rising Star Cave, South Africa (Bower 2015; Randolph-Quinney 2015). Arguably the most prominent and enigmatic are late Pleistocene cave art sites like Altamira, Spain; Chauvet, France; and the recently announced oldest known cave art from Sulawesi, Indonesia (Aubert *et al.* 2014; Clottes 2012; Clottes and Geneste 2012; Lasheras Corruchaga 2003).

The exciting archaeological finds made during early cave investigations in other countries triggered a series of cave investigations in Ireland during the late 19th and early 20th centuries. Initial efforts focussed on the search for faunal remains from the Pleistocene, but finds of archaeological remains were relatively common (Adams *et al.* 1881; Adams 1879; Boulger 1875; Evans 1910; Foot 1878; Forsayeth 1909; Hardman 1874, 1892; Jackson 1929; Plunkett 1876, 1879a, 1879b; Plunkett *et al.* 1875; Scharff 1895, 1902; Scharff *et al.* 1903a; 1903b; 1905; 1906; Stelfox 1930; Tratman 1929; Ussher 1880, 1881, 1882, 1902; Ussher *et al.* 1879; Wakeman 1866; Westropp 1903). A focus on the search for archaeological remains occurred with the discovery of a potentially Palaeolithic skeleton in Kilgreany Cave, Co. Waterford (fig. 1.2) (Dowd 2015, 38-9; Tratman 1929). However, the archaeological finds from the Continental mainland were not replicated in Ireland - neither in quantity nor in antiquity - and no convincing evidence for human occupation prior to the Mesolithic has been found in Ireland for almost another century (Woodman 1986a; 1986b; 2002). Contemporaneous cut marks on a bear patella that was

Figure 1.2: Early antiquarian excavation at Kilgreany Cave in 1934 (after Movius 1935 et al.).

dated to the mid-thirteenth millenium cal. BP from Alice and Gwendoline Cave, Co. Clare provides the first tangible evidence of human presence in Ireland during the late Upper Palaeolithic (Dowd and Carden 2016). This absence of a Palaeolithic may have put Irish cave archaeological research into a disadvantage for most of the 20th century; a circumstance that has changed only in the last 15 years, primarily due to the work of Marion Dowd. Interest in Irish cave archaeology ground to a halt in the mid 20th century and only gained momentum around the turn of the current century as a series of new cave archaeological discoveries and research sparked a renewed appreciation for Irish caves as potential archaeological sites. A recent analysis of antiquarian and archaeological research on Irish caves demonstrates their significance in all periods of prehistory and history (Dowd 1997, 2004, 2015). Notwithstanding, only a minority of cave archaeological discoveries have been made by archaeologists; the majority were historically made by antiquarians, quarry workers, cavers, and casual visitors.

Even in light of the emerging significance of caves as archaeological sites, there still seems to be a reluctance to enter and study these dark and mysterious places in pursuit of a more complete picture of past life. Archaeological textbooks barely touch on caves. One reason might be that caves are not artificial structures that can be studied from an architectural point of view. Yet intentionality is not solely expressed in a creative act but can be the result of a series of choices and preferences for natural traits and features that, in the case of caves, best suit an intended activity. A second reason may be that, apart from a handful of caves of tourist value, most caves are not signposted and they are rarely prominent features in the landscape, which makes them hard to find (fig. 1.3). Even if a cave is found and is accessible, there is no way of telling how likely it is to contain archaeological remains and testing a cave's archaeological potential through excavation is laborious, costly, and time consuming.

Nearly 1,000 caves are known to exist in Ireland, of which 91 are of archaeological or historical significance (Dowd 2015, 56). Only 10 have been excavated to modern archaeological standards within the past 23 years, which Dowd calls *'a sobering statistic'* (2015, 60). However, the lack of caves that have been assessed for archaeology also means that there is high research potential. Finding new caves, especially archaeological

Figure 1.3: Seven caves that penetrate a cliff in the background are not visible from the trackway that leads to the top of Knocknarea Mountain, Co. Sligo.

ones, requires field visits and much time; the new research tools that Google Maps and Bing Maps offer are of little help since they only cover what is visible directly on the ground. Global high resolution aerial imagery allows researchers to assess large areas from the comfort of their home and find suitable research targets, but do not offer any view below the surface. Similarly, other non-invasive methods are of no use in cave environments. For example, high precision topographical surveys using RTK enabled GPS and LiDAR allow for surveys of small sites and large landscapes in a short period of time but require unobstructed views to global positioning satellites. Geophysical surveys are only of limited use in cave archaeology and can be employed either to assess a cave's morphology, its structural integrity (Balkaya *et al.* 2012; Leucci and De Giorgi 2005), or to carry out surveys on archaeology in large caverns (Beck and Weinstein-Evron 1997). Magnetic surveys, on the other hand, have shown to be able to identify archaeological features, such as hearths, in challenging cave environments (Jrad *et al.* 2014). Arguably, large caves and caverns offer more possibilities with a greater chance of returning positive results. However, most caves in Ireland are small with a strongly irregular stratigraphy, such as calcite floors, buried ledges, and rock collapse that can obscure archaeological remains (Kopper 1972, 9). In sum, the limitations encountered in finding caves and assessing their archaeological potential requires new approaches and methods that can help to improve the identification of archaeological caves.

This body of research is a result of the new sub-discipline of cave archaeology in Ireland and it attempts to use non-invasive archaeological predictive models (APM) that can evaluate the archaeological potential of caves. This technique became popular in US cultural resource management (CRM) during the 1980s, along with the then newly emerging geographic information systems (GIS), and thereafter became more widespread as a research tool worldwide (Kvamme 1999, 2006).

To test new investigative methods in Irish cave archaeology, two different archaeological predictive models were applied to two separate geographical regions. Both models focussed on the identification of caves that were used during the Neolithic period (3,900

- 2,400BCE) as well as addressing questions about the role of caves in Neolithic religion and the treatment of the dead. The relationship between caves and Neolithic megalithic tombs as part of complex funerary rites were of particular interest. The use of two different methodological approaches, a data driven correlative-inductive model for one region and an interpretative cognitive-deductive model for the other, allowed for the exploration of their strengths and weaknesses. Both methods have been subject to some debate in the past (Balla *et al.* 2014; Ebert 2000; Graves McEwan 2012; Judge *et al.* 1988; Kamermans 2010; Sebastian and Judge 1988; Verhagen 2006; Verhagen *et al.* 2010; Woodman and Woodward 2002).

1.1 Aims and objectives

The aim of this research is to identify caves in Ireland that are most likely to have been used during the Neolithic; to explore the relationship between megalithic tombs and caves; and to evaluate archaeological predictive modelling as a tool to predict the presence of Neolithic archaeology in Irish caves.

To achieve the research aims:

1. An archaeological predictive model was developed to evaluate the Neolithic archaeological potential of caves in counties Clare, Limerick, Cork and Waterford, a region that has a sufficient number of caves known to have been used during the Neolithic based on previous research (Dowd 2004, 2008, 2015).

2. An archaeological predictive model was developed for counties Sligo and Leitrim, a region that is rich in caves as well as Neolithic megalithic monuments.

3. A sample of caves in counties Sligo and Leitrim were surveyed to evaluate existing cave databases for their location accuracy and to obtain a morphological profile for them. For this purpose, a rapid survey method was developed to capture the morphology of small caves.

4. The role of caves in Neolithic funerary and ritual landscapes in counties Sligo and Leitrim was explored.

1.2 Thesis outline

This thesis is presented in seven chapters and is dominated by two major themes: Irish cave archaeology and archaeological predictive modelling. The current chapter provides a general introduction to the research, outlines aims and objectives, and introduces the reader to caves. Irish cave archaeology is introduced through an outline of problems and challenges that pertain to the aims and objectives of the research. The basic principles of archaeological predictive modelling are introduced and presented as a possible way to address the aims of this research. Two fundamental types of archaeological predictive models are then explained which form the foundation of the two different predictive models developed for Munster and North Connaught.

Chapter 2 presents a history of research, a literature review, of the core themes of this thesis. The history of archaeological predictive modelling is intrinsically connected to the development of both archaeological theory and computer technology, which requires some consideration to put the three into context. Particular attention is given to archaeological predictive modelling in Britain and Ireland, particularly on Andrew Chamberlain's predictive model for archaeological caves in the Peak District and the Yorkshire Dales (Holderness *et al.* 2007).

Chapter 3 is concerned with the development of methodologies for different phases of fieldwork and data analysis. Desk based research consisted of a review of published and unpublished caving literature and databases to compile a geodatabase of caves for the research areas in Munster and North Connaught. Fieldwork focussed on a sample of locations in North Connaught and required the development of a data collection methodology for environmental data as well as a strategy for surveying small caves to a higher degree of accuracy than usually practiced in standard cave surveying.

Data collection for the Munster research area was entirely desk based and required the identification of suitable variables and extractions of values to the project cave database. The development of a correlative-inductive predictive model for this research area is then presented in detail. The second, cognitive-deductive predictive model is based on data collected during fieldwork alongside suitable variables that were available for North Connaught. The development of a methodology is based on intuition and interpretation of existing knowledge about cave archaeology in Ireland but parallels, where suitable, are also incorporated and the development of criteria that aid the selection of caves of high archaeological potential is detailed.

Chapter 4 presents the results of the correlative-inductive model for Munster caves. It details the individual steps and outcomes during model development and provides an insight into the rationales applied in the selection of variables and members of the calibration set. These are based on parametric and non-parametric tests of their distribution of frequencies, mean values, and their significance that are calculated for between group correlations. Chapter 4 concludes with a discussion of the results in terms of model performance and how, if at all, the identified variables can be interpreted in an archaeological context.

Chapter 5 presents the outcome of the cognitive-deductive predictive model for the North Connaught research areas. The model utilises existing knowledge about Neolithic cave use in Ireland as well as contemporaneous religious practices with a particular focus on megalithic monuments. The conclusions drawn from this analysis are presented and the process of formalising them into decision rules that allow discrimination between, or identification of, caves that were more likely to be of ritual/religious significance is elaborated upon. The model outcome in terms of significant variables and caves of highest Neolithic potential are outlined. Chapter 5 concludes with a discussion of implications and model performance.

Chapter 6 focuses on the ritual Neolithic landscape of Knocknarea Mountain as a case study where the remains of two or three individuals of Neolithic date were found in two caves. The iconic mountain is considered to have been a significant ritual complex of monuments, huts, and enclosures. I argue here that the caves formed an integral element of this religious complex and that their location and use indicate a very specific usage of different parts of the mountain.

Chapter 7 develops the most significant findings from Chapters 4, 5, and 6 within a wider national context. The three aims set out at the beginning of the thesis (Section 1.1) are evaluated in light of the results, techniques, and methods applied. This is followed by a detailed discussion of predictive modelling as an effective qualitative or quantitative method that can provide meaningful answers about Irish archaeological caves. The chapter concludes with a consideration of new insights in Neolithic cave use and religious practices gained through the project.

This thesis concludes with Chapter 8 which summarises the most relevant outcomes and discusses problems and shortcomings encountered during fieldwork, data collection, and development of a methodology. It closes with recommendations for future improvements to archaeological predictive models of this particular type and future research suggestions for Neolithic cave archaeology in Ireland.

Appendix 1 synthesises the significant body of fieldwork undertaken for this doctoral research in the form of a catalogue of all caves that were surveyed in the six research areas in the North Connaught region. It supplies comprehensive information about setting and morphology of each cave as well as references to previous research carried out, where applicable. The catalogue is presented as a stand-alone volume that can be used either separately from the main thesis or in conjunction with it.

Appendix 2, a CD-ROM, includes data sets vital to this research, which were too extensive to be included in the main body of the thesis.

1.3 Definition of a cave

A cave can be defined as *"a natural void beneath the land surface that is large enough to admit humans"* (Palmer 2007, 1). While there are countless naturally formed underground voids and crevices, only those that can be entered by humans are considered true caves (Halliday 2004, 1265). A cave can form in a variety of host materials, such as rock, glaciers (fig. 1.4 B), or corals (fig. 1.4 A). The process that leads to the formation of a cave is dependent on the host material. Volcanic (fig. 1.4 C) and the more temporary glacial caves form where liquefied host material (magma or water) drains through the solid counterpart that surrounds it. Talus and framework caves form where host material gradually (e.g. coral growth) or catastrophically (e.g. boulder collapse) accumulates (fig. 1.4 F) and leaves voids (Palmer 2007, 1-7). In coastal areas, wave action can erode considerable sized cavities out of cliffs (fig. 1.4 D). Fissure caves (fig. 1.4 E) form where movement in the earth's crust causes stress fractures in bedrock that causes large sections of cliff to gradually move away from its parent formation and form a gap between the two (Palmer 2007, 6-7). In limestone, fissures can be widened by dissolution, forming a hybrid between a fissure and a solution cave.

Solution caves (fig. 1.4 G), however, are the most common type and form where slightly acidic water enlarges small fissures in soluble bedrock through dissolution into passages and caverns of sometimes considerable size and complexity (Klimchouk 2004, 417-21). The majority of solution caves can be found in Carboniferous limestone but can also occur in other soluble rock formations such as marble, gypsum, dolomite, or rock salt. They are, however, frequently associated with karst regions; karst derived its name from the *Kras* plateau in Slovenia where this geological landform was first studied (Morlot 1848). Where Carboniferous limestone is exposed, rainwater drains through small cracks and fissures that, over time, widen through dissolution to form sink or swallow holes. As the swallow holes widen, they begin to capture increasing amounts of drainage water from the surrounding area that further the dissolution process as the draining water follows the path of least resistance through networks of conduits towards the ground water table. Pure bedded Carboniferous limestone causes the formation of deep vertical shafts, intersected by horizontal passages. These usually form where the water table is reached causing the water to flow horizontally, or where insoluble bedding planes hinder the vertical development of the cave. Once the ground water table drops, the stream begins to sink

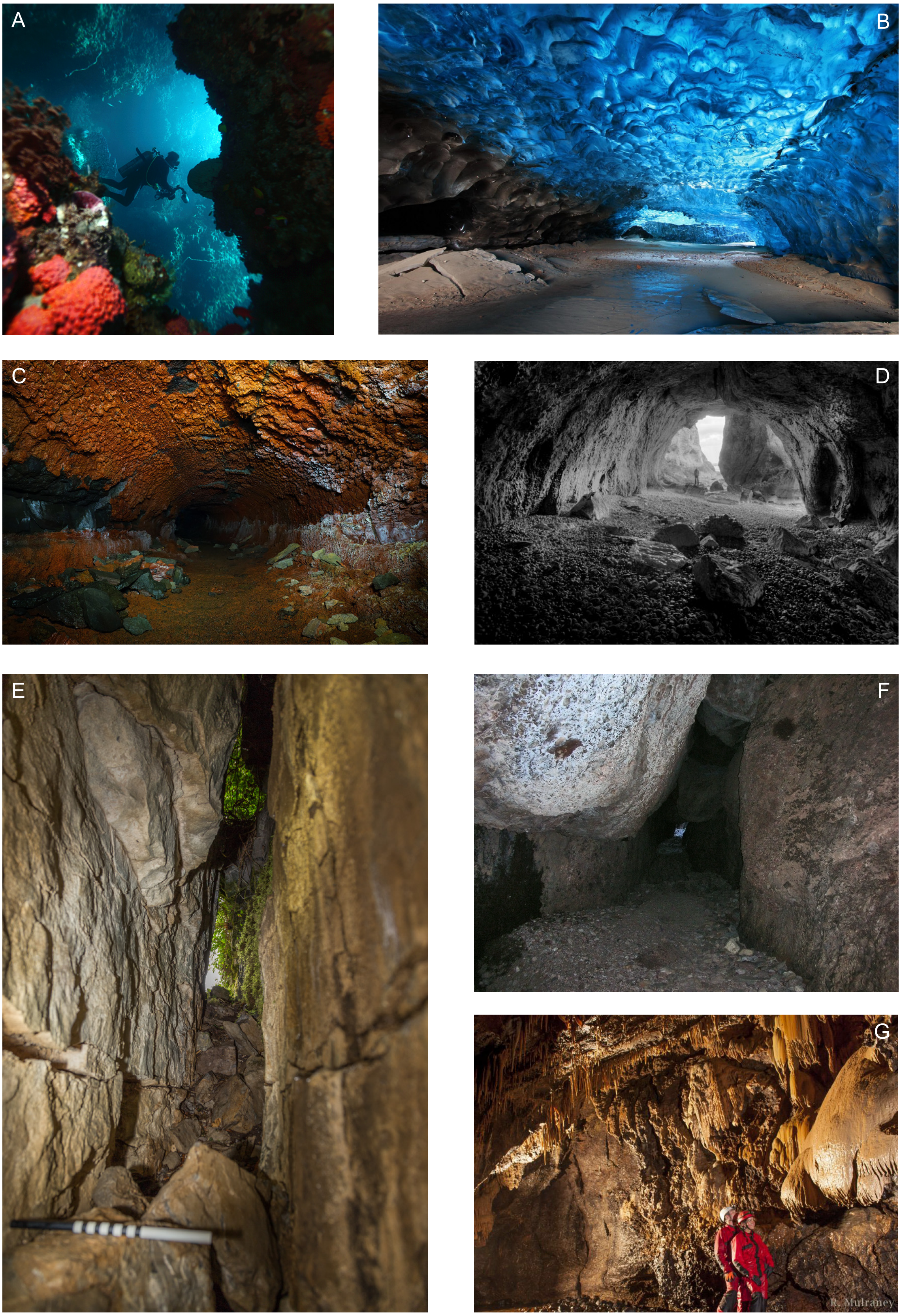


Figure 1.4: Cave forms. A - Hukurila coral cave, Ambon, Indonesia (photo: Heru Suryoko). B - glacier or ice cave at Mendenhall, Alaska (photo: public domain). C - Leidarendi Lava tube, Iceland (photo: Matthew Karsten). D - Cathedral sea cave, Co. Antrim (photo: Andy McInroy). E - Fork Rift Cave, a fissure cave in Co. Sligo. F - talus cave in Pinnacles National Park, California (photo: Karen Lac). G - Pollnagollum of the Boats, Co. Fermanagh (photo: Robert Mulraney).

vertically until it reaches the ground water table again. Carboniferous limestone that sits on impermeable bedrock or is interleaved with impermeable bedding planes, forces the water to continue horizontally and form sizable subterranean streams. Eventually, a cave exits the limestone in the form of a spring or resurgence. From the point of resurgence it continues as a river or it drains directly into the sea as an underwater outlet. Because of the permeability of limestone, developed karst is usually devoid of surface water as enough large cave systems have formed to transport it underground (Mullan 2003; Palmer 2007, 21 *ff.*).

Approximately 50% of Ireland's bedrock is Carboniferous limestone and occurs as thick, pure bedded limestone or as thinly bedded limestone, interbedded with shale, sandstone, mudstone and other sedimentary rock (Sevastopulo and Wyse Jackson 2001). Its occurrence and topography varies from forming lowland synclines in the south, such as the Dungarvan syncline, Co. Waterford, to dominating the landscape as imposing massive outcrops and mountains such as the flat topped Dartry Mountains, Co. Sligo, as well as classic karst landscapes like the Burren in Co. Clare.

Caves predominantly occur in the form of erosional and solution caves. Erosional caves are found in many of the steep cliffs along the Irish coast, such as Portbraddan Cave in Co. Antrim, where early excavations revealed Mesolithic and Neolithic artefacts (Dowd 2015, 86-7; May 1943). These are typically short straight passages or tunnels of varying dimension. Solution caves in limestone are by far the most abundant in Ireland. Some 688 caves had been compiled in a database for the Republic of Ireland by David Drew (Drew 2006a, 2006b) until 2006, but the number has increased to over 900 since then (Dowd 2015, 1). All these caves are located in Carboniferous limestone, with the exception of 13 caves in Co. Galway and one cave in Co. Donegal, which all occur in marble. Sea caves are not recorded in this database.

Based on Drew (2006b, 164), the majority of known caves are located in Co. Clare, which comprises 37.6% of all recorded caves in the Republic of Ireland, followed by counties Leitrim, Galway, Cork, and Sligo. The highest concentration of caves can be

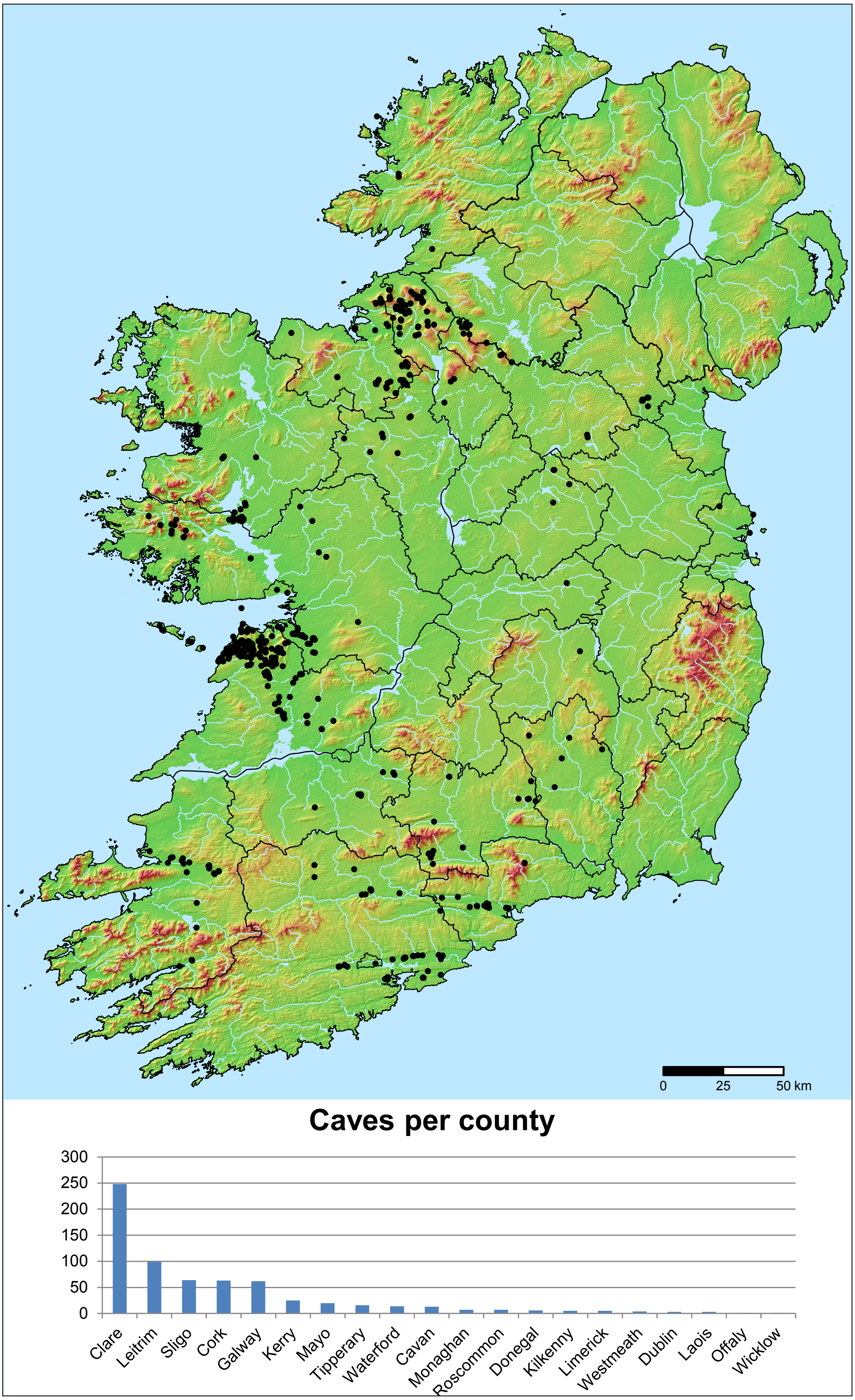


Figure 1.5: Distribution of known caves in the Republic of Ireland by county after Drew (2006a).

found in the Clare Burren and the limestone uplands of Sligo and Leitrim along with some minor concentrations in Galway, Kerry, Cork, and Waterford (fig. 1.5). In some areas, such as the Dartry Mountains of Sligo/Leitrim or the Burren in Co. Clare, limestone layers were capped by impermeable shale that prevented their rapid erosion (fig. 1.6). The Burren lost its caps and has undergone significant karstification giving the limestone hills their rounded and terraced profile (Mullan 2003, 18-9) (fig. 1.7). The chert-rich Dartry limestone on the upper layers of the Dartrys is partially capped with shales and sandstones which prohibited extensive surface erosion aiding the formation of flat-topped summits and steep cliff faces during periods of glaciation (Barry and Kennedy 2013, 2; Coleman 1965, 52). Today, most summits of the Dartrys are covered with blanket bog. Much of the drainage occurs in the form of waterfalls and deep sink holes that formed where fissures in the shale allowed for drainage into the underlying limestone layers. Apart from the sinkholes, the upper layers in these limestone formations also feature numerous short fossil or relict caves.

South of the Burren, limestone generally occurs at lower altitudes, covering the valley floors of the southern synclines. Today they are overlain by glacial deposits that protected most of the limestone beds from erosion. Caves have formed where draining surface water accumulated and can be accessed where the limestone knolls protrude through glacial deposits (Coleman 1965, 27). The majority of these caves are inactive and filled with sediments and debris where the entrances are near or below the current ground surface.

1.4 Caves and Neolithic archaeology in Munster and North Connaught

Comprising over 50% of the recorded cave sites by Drew (2006b, 164) in the Republic of Ireland, and with three publications dedicated to caves of counties Clare (Mullan 2003), Cork (Self 1981), and Waterford (Bunce and Barry 2011), Munster - along with Fermanagh - has received considerably more attention from cavers and cave researchers than any other region in Ireland. County Clare is home to some of the most extensive cave systems, only rivalled by the caves of Co. Fermanagh. With the exception of six caves, all known caves of Neolithic significance in Ireland are located in Munster (Dowd 2008,

Figure 1.6: Caps of shale and other impermeable rock aided the formation of table top mountains like Benbulben, Co. Sligo, with flat summits, high vertical cliffs, and steep scree slopes (photo: Kevin Gilmore).

Figure 1.7: The erosion of impermeable rock caps in the Burren, Co. Clare led to the formation of a karst landscape with rounded terraced hills and limestone pavements (photo: heartofburrenwalks.com).

2015), yet there is little evidence for Neolithic activity in the form of monuments in this region.

Counties Sligo and Leitrim boast almost one quarter of all recorded caves in the Republic of Ireland. The majority are unexplored or only casually reported on in caving journals such as *Irish Speleology*, *Journal of Cave and Karst Science*, *Proceeding of the University of Bristol Spelaeological Society*, or *Descent.* The caving community understandably focuses on the exploration of what they consider the more rewarding potholes in the area, as there are no horizontal caves of considerable length. This leaves small caves on the sidelines of exploration by cavers.

Focusing on more attractive caving and cave research opportunities in Fermanagh and Munster, caves in Connaught have received little attention from antiquarians and archaeologists. Since the early concerted antiquarian exploration campaigns, excavations have only occurred in response to chance discovery, which arguably occur more frequently in the more popular caving regions. The caves of Keash was the only system in this region that was excavated to any extent in North Connaught, revealing archaeological material that dates from the Bronze Age through to the Early Medieval (Bayley Butler *et al.* 1930; Dowd 2013b; Gwynn *et al.* 1940; Scharff 1902; Scharff *et al.* 1903a; Scharff *et al.* 1903b).

In addition to an abundance of caves, Sligo and Leitrim also boast a large quantity of passage tombs, court tombs, and portal tombs, most of the former are concentrated in complexes such as the larger Carrowkeel and Carrowmore passage tomb complexes, or the smaller complexes of Sheemore or Knocknarea Mountain. The presence of two caves with Neolithic human remains on Knocknarea which are contemporaneous with some passage tombs indicates that caves likely played a role in funerary traditions (Dowd and Kahlert 2014). This temporal and spatial proximity of caves and megalithic tombs in Sligo and Leitrim poses a unique opportunity to explore the relationship between the two in more detail.

1.5 Where are they? The problem of finding caves

The majority of caves in Ireland consist of horizontal and vertical passages of no great extent. Some are found in exposed locations in cliff faces where they offer commanding views across the landscape (fig. 1.8). Other caves are tucked away as small openings in limestone knolls or crags. Many entrances are concealed by vegetation and debris whereas others have been blocked by farmers in an effort to protect livestock. Caves that are obscured in this way are very difficult to locate and one can easily pass by a cave entrance without noticing it. It can take several hours of crawling through thick vegetation before the cave of interest is found, if at all. Red Cellar Cave, Co. Limerick is one such case. This cave was excavated in 1938 and palaeobotanic as well as archaeological material was found (Grogan *et al.* 1987, 501; O'Riordan 1979). Despite extensive searches of the area where the cave is marked, a small limestone crag covered in dense scrub, the cave entrance could not be found (fig. 1.9). Previous attempts (Dowd 2004) also failed to locate the site.

Caves frequently lack accurate grid referencing, which is the norm for caves that were discovered and recorded before consumer grade GPS devices became widespread. They are only referenced to the nearest 100m or the traditional grid referencing system based on offset measurements on 6" or 25" OS maps, which can lead to quite inaccurate location data depending on the mapping skills of the caver. Dónal Gilhoys, a caver based in the Northwest of Ireland left an extensive archive of notes following his death and that I had access to during my research. It provides interesting insights into how cavers used landmarks

Figure 1.8: The prominently located Diarmuid and Grainne's Cave in Gleniff, Co. Sligo. Cave indicated.

Figure 1.9: Knockfennell Hill, Lough Gur, Co. Limerick hosts Red Cellar Cave, which is believed to be located in the overgrown crags visible to the right.

to record the location of caves. Dead trees, erratics, walls, ruins, or even their own car were used as points of origin from which they took compass bearings and estimated distances to a cave they wanted to record, sometimes using intermediate steps via other landmarks or caves, which they later transferred onto a paper map. This method has varying degrees of accuracy and can lead to substantial errors on the ground. The age of high-resolution aerial photography such as Bing Maps and Google Maps has triggered a number of discoveries of archaeological sites. However, caves are invisible in aerial photos, unless they are located in dolines, therefore these tools are of very limited use. In reality, researchers have to resort to unreliable coordinates, maps, and local or caver's narratives to find caves in the field. Finding a cave this way can be very time consuming, often requiring several field visits before a single cave can be located, if at all.

1.6 Where is the archaeology? The problem of finding archaeology in caves

Finding a cave is only part of the challenge, assessing its archaeological potential can be an even greater one. Caves are dark, dirty, and inhabited by animals, some of which are protected, and others are dangerous when threatened. Movement in a cave can be very restricted and their unfamiliar atmosphere can induce notions of claustrophobia, disorientation, and imminent danger. In an otherwise complete silence, familiar noises such as dripping water become disproportionately amplified and distorted, which can create an intimidating and distracting atmosphere when working in a cave (Bjerck 2012, 58-9; Dowd 2015, 4; Montello and Moyes 2012, 389).

Non-invasive techniques to detect archaeology in a cave are few. Geophysical surveys have so far proven to be of limited use in cave environments and are chiefly deployed for investigating general topography and depth estimates of deposits (Beck and Weinstein-Evron 1997; Kopper 1972). Surface finds are not uncommon in cave archaeology due to disturbance by animals, flooding, and other natural agents, but archaeology buried in deeper strata is predominantly exposed by cavers seeking to expand a cave through digging out blocked passages, or by burrowing animals (Dowd 2013a, 2015).

Because non-invasive methods to assess the archaeological potential of a cave are limited, excavation appears to be the only alternative, which is a laborious, and slow undertaking in such a restricted environment. The number of excavators that can work in a cave at any one time is limited by the size of the cave and may be restricted to one or two people at best (fig. 1.10). Deposits are hauled out through the sometimes narrow passages by

Figure 1.10: Archaeological work in a restricted cave environment.

hand and need 100% sieving, which requires access to water that may not always be readily available. Such limitations pose considerable logistical challenges depending on the location of the targeted cave and the efforts may not even be rewarded if a cave turns out to be archaeologically sterile (Dowd 2015, 76-8).

It can be a time consuming and labour intensive task to carry out random test excavations to assess a cave for its archaeological potential. Outside a cave context, predictive modelling has the potential to pinpoint a particular area with an increased likelihood of archaeological interest. The vast majority of APMs are used to make predictions for entire landscapes and less for individual spot locations, such as caves. Predictive modelling has been criticised for its methodological and practical shortcomings (Wheatley 2004; Woodman and Woodward 2002) but it still provides information that can help channelling research efforts to the most probable locations (Chamberlain 2003). Therefore archaeological predictive modelling is not a substitute to excavation, but an aid to find promising targets for more detailed investigations.

1.7 What is archaeological predictive modelling?

Archaeological predictive modelling is a technique that aims to predict the presence of archaeological sites in a defined geographical area based on a set of environmental and social variables. The technique became popular in the USA in the 1980s as a CRM tool to meet new planning regulations imposed by the Bureau of Land Management (BLM) (Sebastian and Judge 1988, 9-10).

The technique uses statistical functions to quantify relationships between a number of social or environmental attributes, usually referred to as independent variables, and the presence or absence of archaeological sites, the dependent variable. The relationship between dependent and independent variables can be expressed as an equation and applied to specific locations or entire landscapes of unknown archaeological status. Independent variables can be continuous measurements, such as elevation, or categorical data, such soil types. The dependent variable is commonly expressed as a simple binary category: either an archaeological site is present or it is not (*site* vs. *non-site*). Complex categories also exist that can sub-divide the dependent variable into different site types, periods or feature densities.

The underlying theoretical framework assumes that places that are fit for human habitation have to meet a set of vital environmental requirements that enable long-term survival and prosperity of a community. Access to fresh water, food sources, as well as fuel and the presence of some form of shelter, constitute essential human needs (Kohler 1988, 19-20; Kvamme 2006). Their presence and accessibility may vary between different regions, but the absence of any one of them will render a location unsuitable for long-term occupation. Absence in this context means that the cost to procure a specific resource is greater than the yield (Wheatley and Gillings 2002, 133 *ff.*). If resource abundance and spatial distribution can be quantified and correlated to the presence or absence of human settlements, then predictions can be made about where these sites are more likely to be located. Activity sites that require the presence of specific natural resources or geographical setting are more predictable. This means that long-term habitual spaces are easier to predict than, for example, overnight camps and shelters that usually have very few requirements. Similarly, for sacred or religious activities, site location preferences were probably based on abstract religious or ideological ideas. Such concepts cannot be easily quantified nor can they be deduced without being familiar with the belief system in question. Much of the religious beliefs and social fabric of prehistoric societies is irretrievably lost today, and unless religious activities have left behind detectable physical remains their presence is hard to establish. The significance of a natural sacred place may have derived from its topography, location in the landscape, proximity to other places of religious significance, or attributes which, due to lack of written accounts, can only be conjectured. This results in fragmented knowledge of a past society's social, political, and religious fabric that hinders the development of a coherent and testable narrative about past societies (Kohler 1988, 19-20; Kvamme 2006).

High levels of uncertainty about past human behaviour and incomplete data diminishes the reliability of any explanatory model, be it a correlative-inductive predictive model, a cognitive-deductive predictive model that relies on expert knowledge and reasoning. In its early days, archaeological predictive modelling suffered much from disputes between the adherents of the processual and post-processual schools of thought (see Chapter 2.1). Such concerns no longer dominate the field and currently archaeological predictive model development focuses on improving model performance (Balla *et al.* 2014; Ducke 2011; Fernandes *et al.* 2011; Jin *et al.* 2013; van Leusen *et al.* 2010; Verhagen *et al.* 2010; Verhagen *et al.* 2012; Verhagen and Whitley 2011; Whitley 2010; Zwertvaegher *et al.* 2010).

The majority of APMs today are developed in Geographic Information Systems (GIS) where data from different sources can be compiled and overlain to extract site-specific values (fig. 1.11). GIS offers a range of tools to extract values from data layers that can also be automated for large data sets. Digital elevation models (DEM) can be transformed into slope or aspect values or used to re-construct ancient river courses (Graves 2011).

In APM the term 'site' refers to a specific location where remains that indicate past human activity were found. Contrasting 'site' is the 'non-site', which refers to a specific location where no traces of past human activity have been detected; it is also commonly

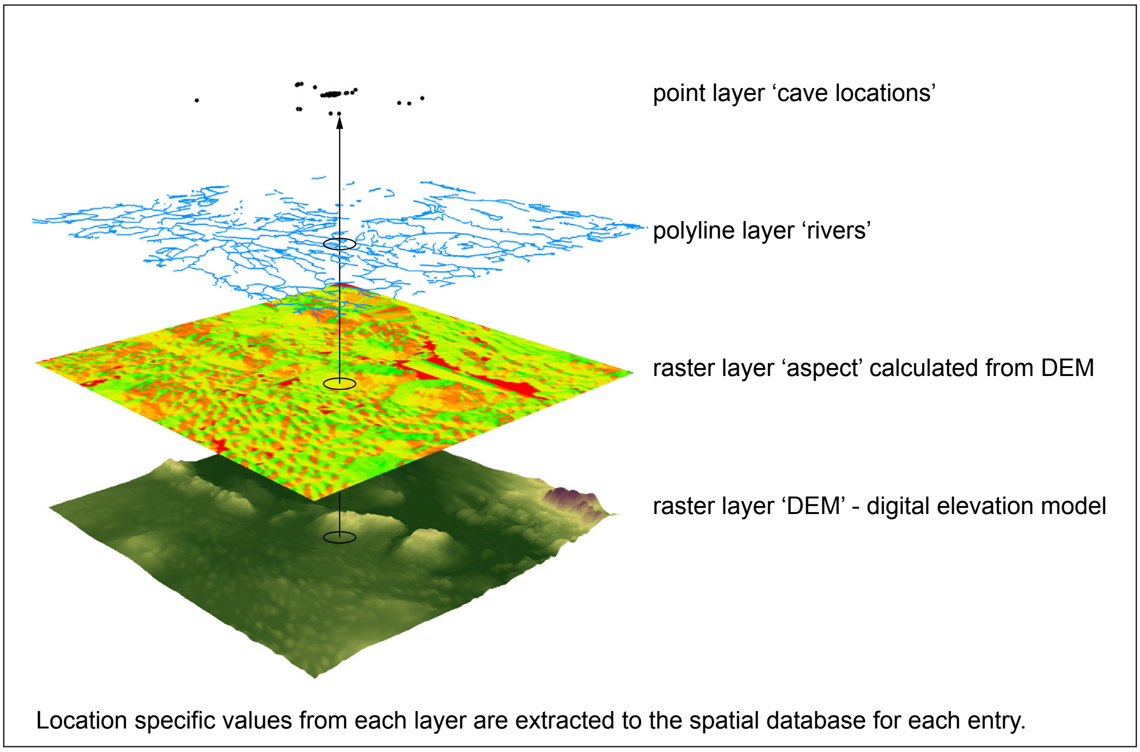


Figure 1.11: Different types of data can be easily layered in their spatial context within a GIS.

used to refer to locations of unknown archaeological status, depending on the sampling procedure. Where systematic sampling is applied, 'sites' and 'non-sites' are determined by the presence or absence of archaeological material. Other models use existing databases of archaeological sites and monuments, such as the Irish sites and monuments record (SMR), to sample sites and use a random sample of loci of unknown archaeological status as the contrasting set of 'non-sites'. While the latter sampling strategy is faster and more cost-effective, there is always the possibility that a number of undetected archaeological sites are included in the 'non-site' sample.

The smallest unit in an archaeological predictive model is the land parcel (Kvamme 1990, 258), which is represented by the smallest unit in a raster dataset: the pixel. The raster forms a regular grid of equally sized squares that represents the value of a given variable on the ground. This can be a continuous grey value in a DEM, or a categorical black and white value that indicates the presence of a specific trait. The higher the raster resolution, the smaller the area represented by each pixel. For example, in a DEM with a resolution of 10m each pixel represents a square on the ground with the dimensions of 10m x 10m (fig. 1.12). During data extraction it is imperative that the resolution of each raster layer has the same ground pixel resolution, in this case 10m, so that the pixels of each layer match each other in size and overlay. Some GIS also support vector files. A GIS vector is a two dimensional polygon of any shape or size that stores information that is the same for the area covered by the vector. Point or line data are the one and two-dimensional equivalents of vector shapes. In archaeological predictive models, points usually mark archaeological sites and are used to extract and store data from other data layers.

Two different general approaches are used to develop predictive models. The inductive, or more precisely, correlative-inductive approach (Whitley 2005, 126), is purely data driven and makes no prior assumptions about the significance of the various input variables; its predictions have been described as almost exclusively correlative, non-explanatory, non-causal and deterministic (*ibid.*). These models use multivariate and univariate analysis to find correlations between the dependent and independent variables and quantify

Figure 1.12: Concept of land parcel as a unit: in extreme magnification, the individual elements that make up an image, the pixels, become visible. Each pixel represents a specific area in real life. In this case, a 10m by 10m square. The colour value of a pixel can indicate different topographic events. The light grey and white here shows the presence of a built structure. In other cases different shades of grey may represent the elevation at a location.

the interaction between the two. Most commonly used are multivariate techniques such as logistic regression and discriminant function analysis (Kvamme 1990, 274-8). Correlative-inductive make no statements about the quality of the relationship between dependent and independent variables and thus lack an explanatory dimension. These model types are popular in CRM because they are easy to create, statistically robust, and provide sufficient information to aid decision making in an environment where conservation, not interpretation, is of primary concern (Altschul 1988, 66-7). Variables used in correlative-inductive predictive models incorporate environmental factors such as topography, soil cover, bedrock geology, hydrology, distance to water, vegetation *etc.* For example, Woodman (2001) developed a correlative-inductive model for Mesolithic activities on the island of Islay. She utilised data from Mesolithic sites on mainland Scotland to derive variables, identify correlations between the environment and sites, and applied those to her research area. While her initial selection of predictor variables relied on basic assumptions about hunter-gatherer behaviour (i.e. distance to fresh water, distance to food sources *etc.*), correlation analysis guided the inclusion in the final model. Her 'non-site' calibration set consisted of locations of known archaeological sites and those of unknown archaeological status. The model was divided into two general areas on Islay: inland and coastal. The main finding was that Mesolithic groups followed different settlement strategies depending on whether they were coastal or inland. As with most models, however, Woodman's model was not tested in the field by sampling or excavation of high and low potential sites.

In academic research, and increasingly in CRM (Verhagen 2006), deductive or cognitive archaeological predictive models (Whitley 2005, 130) utilise intuition and expert knowledge to create an explanatory framework to make their predictions. Bayesian inference (Finke *et al.* 2008; Millard 2005; Verhagen *et al.* 2008), Dempster Shafer Theory (DST) (Canning 2005; Ducke 2010; Verhagen and Whitley 2011), and decision-making trees (Limp 1985) use expert knowledge and intuition instead of induction to identify and quantify predictive weight in the model. Belief and uncertainty about the input data, two major factors in Bayesian inference and DST, can be factored in by adjusting model parameters. These models are generally more difficult to develop and require expert knowledge of the archaeology and the landscape that are covered by the model. It is possible to develop some of the models without calibration data, however this consequentially does not allow for internal model testing and requires some form of field assessments instead. Ducke (2010) developed a DST based model for the German federal state of Brandenburg by using a sample from the 8,500 archaeological sites and monuments registered for the county. He calibrated the model parameters and increased the sample until the model placed most of the remaining sites in regions of high potential. Apart from identifying locations of high archaeological potential, the multi-period predictive model showed how settlement patterns changed over time and how people apparently followed specific patterns in their settlement strategies, which often lead to an increase of settlements around already established nuclei (Ducke 2010, 298).

While there is a clear differentiation between correlative-inductive and cognitive-deductive models in the literature, in practice many correlative-inductive models use deductions at some stage in their development. So-called *inclusion criteria* are cognitively derived decision rules that are commonly used to preselect independent variables. For example, *water* is a necessary resource for settlement and its proximity is likely to be correlated to the presence of settlement sites. Conversely, *elevation* is unlikely to have any significant influence on the presence of medieval coastal shell middens since they are bound to be close to sea level (Sebastian and Judge 1988, 1).

Model testing attempts to establish the performance of a predictive model by establishing how much better a model predicts sites over chance and, more importantly, how well a model performs in real life. Primarily, archaeological predictive models can only make predictions based on the predictor variables fed into the model. Those variables transform an infinitely complex reality into generalised, and therefore more digestible, subsets and categories. Statistics rely on these categories to be highly representative of the real world so that inferences and accurate predictions can be made. A model that is based on inaccurate data, unrepresentative categories, or poor sampling strategies may still perform well within its virtual framework, but that framework does not relate to reality and the model outputs are meaningless.

In non-spatial predictive models, standard statistics such as R^2 are calculated by statistical software packages and can be used to assess the internal performance of a model (Field 2009, 201). In binary logistic regression, for example, classification tables provide this data as percentages before and after variables are inserted into the model. If the contrasting data sets are equal in size, chance dictates that half of the set is correctly classified. This figure changes once the predictor variables are taken into account. Each variable improves the number of correctly predicted instances, depending on the strength of the correlation between predictor and outcome. The *model gain* can be seen as the difference between an empty model and a model with included variables. In APM, Kvamme's gain statistic has been used to assess the performance of spatial models (Kvamme 1990). It can be applied to any spatial archaeological predictive model, regardless of the statistical approach it was built on. Balla *et al.* (2014) used Kvamme's gain in their comparative study of various archaeological predictive models. The equation '*gain=1-((percentage of total area covered by model)/(percentage of total sites within model area))'* takes into account the size of the area of predicted high archaeological potential as an indicator for model performance (Kvamme 1988a, 287-8). If the model correctly predicts a high percentage of sites, but the area of high potential is equally large, then the model is not very useful. A good model places a high number of sites in a small area of high potential, which causes the gain to approach 1. For example, if 75% of sites are located in an area of high archaeological potential, and that area makes up 20% of the total model area, then *gain=1-(20/75)=0.73*. But if the covered area is 40%, then *gain=1-(40/75)=0.47*. The higher the gain, the more accurate the model.

1.8 Nomenclature and terms of reference

Archaeological cave

Archaeological cave refers to a natural cave that has produced archaeological deposits in the form of artefacts, occupation debris, human remains, modified faunal remains or any cave that has been altered by humans through structural modification as well as application of paint or engravings in pre-modern times (Dowd 2015, 56-7).

Neolithic archaeological cave / Neolithic cave

Neolithic archaeological cave or Neolithic cave follows the same definition as an archaeological cave but is exclusive to activity that took place between 3,900BCE and 2,500BCE.

BCE - before common era

BCE is used throughout this thesis as a religiously neutral term in preference to the commonly used Gregorian calendar.

Munster and North Connaught research areas

The provinces of Munster and Connaught contain the counties that are the focus of this research project. Here *Munster* refers to counties Clare, Limerick, Cork, and Waterford, but not Tipperary and Kerry. Similarly, *North Connaught* refers to counties Sligo and Leitrim, but not Roscommon, Mayo, and Galway. For Munster, the term *research area* refers to the counties outlined above, including all caves, and all sites and monuments of Neolithic date contained within the boundaries. For North Connaught, *research area* refers to six discrete areas that are located within counties Sligo and Leitrim that were assessed during fieldwork.

1.9 Abbreviations

APM - archaeological predictive model

CRM - cultural resource management

RMP - Record of Monuments and Places

SMR - Sites and Monuments Record

NMI - National Museum of Ireland

OSI - Ordnance Survey Ireland

OSNI - Ordnance Survey Northern Ireland

GSI - Geological Survey Ireland

GIS - Geographic Information System

BLM - Bureau of Land Management

DEM - digital elevation model

LRUD - left-right-up-down

DST - Dempster Shafer Theory

Chapter 2: A history of archaeological predictive modelling and cave research

This chapter presents a critical analysis of the key works on archaeological predictive modelling and Irish cave archaeology. Although archaeological predictive modelling was not defined as a clear discipline until the 1970s, its origins reach as far back as the 19th century when economists looked at correlations between spatial organisation and yield in agricultural settings to maximise profitability (Frobenius 1898; Thünen 1910). From these early beginnings, I outline the influence culture history, processualist, and post-processualist theory had on the development of archaeological predictive modelling in the USA, and how it was perceived by the advocates of these various schools of thought. Following a brief contextual background of predictive modelling in Europe, I then focus on the application of this method in Britain and Ireland. The core concepts and different types of archaeological predictive modelling that are outlined in Chapter 1 and are only briefly mentioned here.

The second section discusses the available literature and history of research in Irish cave archaeology with a brief consideration of early cave explorations of the 18th and 19th centuries. This is followed by a more in-depth review of the development of cave archaeology from being part of naturalist and antiquarian research in the late 19th and early 20th centuries, to a modern archaeological sub-discipline in the late 20th and early 21st century.

2.1 Historical background to archaeological predictive modelling

Early considerations of the relationship between space and humans

As a spatial analysis tool with predictive capability, archaeological predictive modelling has its origins in the growing awareness of spatiality in culture history and the resulting processualist school of New Archaeology. In the early 19th century, German economist and landowner Johann Heinrich von Thünen observed that returns from production sites diminished the further away they were from production centres, while time and effort increased to achieve similar returns (Clarke 1979, 21; Thünen 1910). To counter the effect, he organised land use and activity in a way that low volume production activity took place further away from the production centre whereas high volume activities remained in closer proximity. In his book *'Der Isolierte Staat'* (The Isolated State), first published in 1826, von Thünen (1910) formalised his theory of the interaction between spatial organisation and economics. Later, economists and geographers expanded on von Thünen's work and formulated theories that attempted to describe how the environment influences human subsistence strategies in an industrial context (Christaller 1933; Weber 1922).

Inspired by the works of von Thünen and Friedrich Ratzel, a German geographer, early anthropo-geographers Churchill Semple (1911), Sauer (1925), and Huntington (1913) formulated theories about human migration and cultural change that had a profound influence on early anthropologists and archaeologists. Julian Steward's theory of cultural ecology (Steward 1937, 1938, 1955) is described by Kohler (1988, 26) as supporting the neo-evolutionist school of anthropological thought of the 1930s. Steward became one of the more influential contributors to the development of a theoretical framework for archaeological spatial analysis. His theory of cultural ecology (Steward 1955) broke with cultural particularism, which focussed on the development of increasingly complex typologies and categorisations of the archaeological record instead of formulating unifying theories about past societies. His theory engulfed three important concepts that would later significantly influence archaeological location modelling. Rather than looking for inter-site correlations, he was more interested in explanatory models that helped understand spatial phenomena. Secondly, he realised that cultural variation happened on a micro level which was triggered by specific aspects of the local environment. His third new concept described the ways in which environmental factors triggered such variations and he combined the most influential aspects into a culture core concept. Other less influential aspects were categorised as secondary features (Kohler 1988, 26). The discrimination between core and secondary factors was achieved by the application of empirical methods. Steward argued that environmental settings influenced culture in a particular way and that those could be empirically investigated. This led him to focus his investigations on the search for similarities between different cultures rather than looking for differences (Trigger 1989, 293) which, in the early 20th century, was the default approach of archaeologists and anthropologists when looking at archaeology and which also significantly hindered the introduction of scientific methods to the discipline (Kvamme 2006, 4).

Environment and settlement patterns in the Virú Valley, Peru: the dawn of processualism

Steward's work was substantiated in the course of the Peruvian Virú Valley expedition undertaken by Gordon Willey in 1946. It contributed significantly to the development of New Archaeology, which provided the theoretical framework on which the principals of predictive modelling are based (Altschul *et al.* 2004, 1-2; Binford 1962, 217; 1968; Clark 1999, 6; Kohler 1988, 30; Renfrew and Bahn 2004, 78; Sabloff and Gordon 1967; Verhagen and Whitley 2011, 2; Willey and Phillips 1958). Just like Steward, Willey (1956) observed that site types and their distribution followed particular patterns and that these patterns varied between the valley and the surrounding uplands (fig. 2.1). As formulated by Central Place Theory, Willey subsequently observed that the Virú Valley people seemed to have developed a specific order in which space could be organised. This was based on units of activity that were spatially ranked according to functionality as well as social meaning, and ordered into villages and larger administrative units. He eventually synthesised his research in *Introduction to American archaeology, Vol. 1, North America* (Willey 1966), which marked the departure from culture history towards processualism as the dominant theoretical framework in archaeological thinking.

While Willey was finalising his seminal work, Louis Binford published an article in which he decried that "*archaeologists have not made major explanatory contributions to the field of anthropology because they do not conceive of archaeological data in a systemic frame of reference. Archaeological data are viewed particularistic and "explanation" is offered in terms of specific events rather than in terms of process*" (Binford 1962, 217). He proposed that cultural historic explanatory models do nothing to explain changes

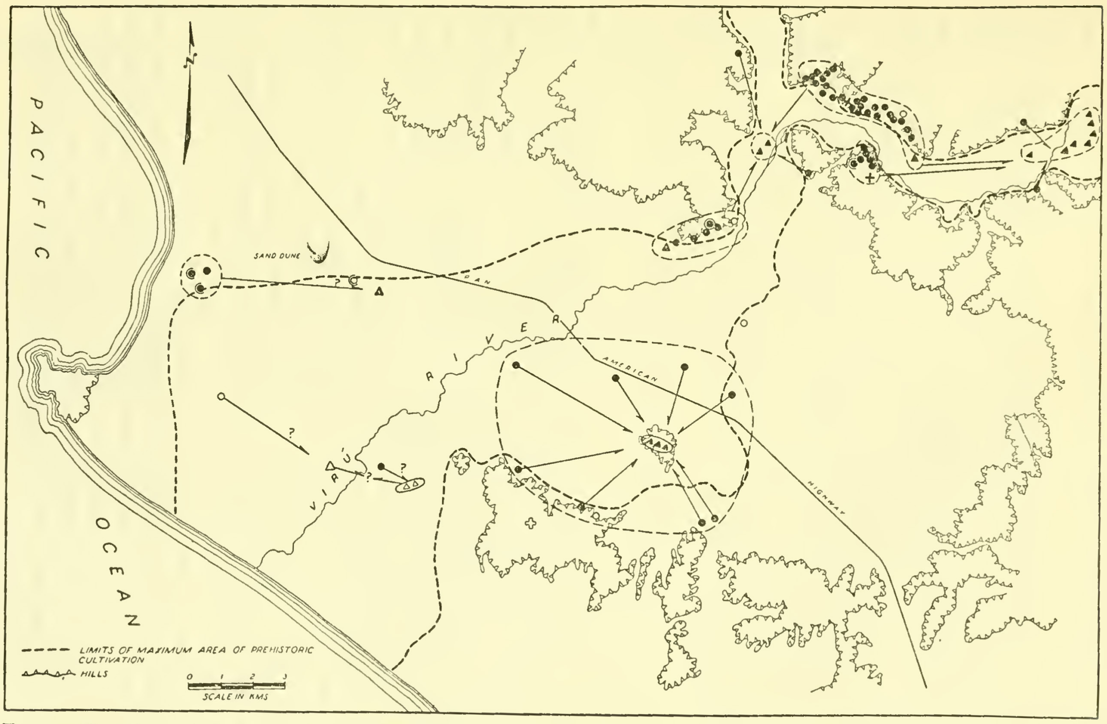


FIGURE 82.—Suggested community patterns for the Puerto Moorin Period. Early phase and unplaced as to phase, black; Late phase, white.

Figure 2.1: Gordon Willey's distribution and map outlining the proposed spatial organisation of ancient settlement sites in the Virú Valley in Peru (Willey 1953, 375).

within a culture but rather are material expressions of changes that took place within a broader eco-cultural system in which societies develop. Flannery's (1967) review of Willey's work furthered the argument for the adaptation of 'culture process' and by the end of the decade processualism and the New Archaeology had all but replaced cultural particularism (Binford 1964, 1965, 1968; Binford and Binford 1968; Fritz and Plog 1970).

The introduction of processualist theory in US archaeology led Watson (2008) to describe the 1960s, 1970s, and 1980s as "*a lively affair with big, interdisciplinary projects funded by the National Science Foundation pursuing culture processual issues, not just in the Americas but also in various portions of the Old World*" (Watson 2008, 30). Archaeology had become a discipline where researchers adopted methodologies from natural sciences such as geology, chemistry, biology, and physics to approach archaeological problems. Research design became important in which research questions were scientifically approached and tested. Archaeologists began to apply quantitative methods and statistical analyses to test their hypothesis and base their conclusions on data-driven models

(Heizer and Cook 1960). At the same time, computer technology became increasingly more affordable for research, and archaeologists began to use computer applications for storage, analysis and presentation of archaeological data (Wilcock 1973).

Predictive modelling, GIS, and the digital revolution

One of the disciplines that substantially benefitted from these developments was spatial analysis, an area that has always been of concern to archaeologists but "*has been limited to visual and subjective inspection*" (Hodder 1977b, 223). One of the reasons multivariate spatial analysis on a macro-scale was not carried out more frequently was because it was a labour intensive undertaking. The development of GIS was still in its infancy in the early 1970s, with a first computerised GIS having been developed by the Canadian government in the 1960s for the Canada Land Inventory using large mainframe computers (Tomlinson 1967). Some states in the USA also attempted to develop a GIS, but available programmers often lacked skill and experience in developing these complex systems (Marble 1990). The computers required to run GIS applications could only be afforded by universities, governmental agencies and other large institutions and corporations, thus access remained a problem for many researchers (Kvamme 2006, 6).

Using a personal account of his early career, Kvamme (2006, 6-8) describes the statistical analysis of multiple environmental data layers to manually create a probability surface for an entire geographically defined area. Prior to this, the conventional way predictive models were applied was to develop a discriminant function from a sample set and calculate the archaeological potential of a certain grid square of interest. To populate the equation, data had to be hand measured from various map sources and typed into a calculator that could store pre-defined formulas on a small magnetised paper strip. Similar models, using discriminant function equations, were developed and tested by Williams *et al.* (1973) and Hodder (1974a, 1974b, 1977a, 1977b) focussing on specific points of interest on a map. A similar approach was taken by Kvamme for a small region near Glenwood springs, Colorado. This differed in that it produced a complete map of locations that displayed the probabilities of an entire area within their spatial context

(Kvamme 1980). Kvamme also used discriminant function analysis which he applied to multiple variables covering an 800m x 800m site. His research area was divided into 50m grid squares, which resulted in 256 individual grid cells. The cells were populated with 1,536 values based on six variables that were hand measured from six individual map layers. Probabilities and significance or p-values were calculated with a programmable calculator and transferred onto a new map layer that formed a probability surface, the classic output of an archaeological predictive model. The resulting map led him to the conclusion that predictive modelling was a valuable tool to explore human interactions with the environment and that "*an automated mechanism was absolutely necessary to map the model functions over broad regions*" (Kvamme 2006, 8).

During the early 1980s, image based GIS in the USA were run by large main frame computers that were fed with instructions encoded on countless punch cards to automate the manual measurements of extracting values from geographic variables and to generate digital probability surfaces. To make use of the potential of these new computers, Kvamme teamed up with: Sandra Scholtz who had previously applied approaches similar to Kvamme's to create her own predictive maps (Kvamme 2006; Scholtz 1981); Alan Strahler who introduced logistic regression to remote sensing (Press and Wilson 1978); and Bob Hasenstaab who programmed a GIS application from scratch (Maynard and Strahler 1981). Their combined efforts went into furthering the development of GIS applications and predictive modelling in archaeology which led to the first symposium for computer-based GIS and archaeology in 1985 in Denver, Colorado (Kvamme 2006, 8-9).

The 1980s and the breakthrough of archaeological predictive models in CRM in the USA

The implementation of the Archaeological Conservation Act in the USA in 1974, which required the allocation of 1% of development budgets to archaeological conservation, significantly increased available funds for archaeological investigation and the development of new methods in CRM (Watson 2008, 31). Additionally, by the 1980s computer technology had become powerful, compact, and affordable enough that fully automated systems could be developed with relative ease. From then on, GIS and predictive models became widespread and cost-effective decision making tools in CRM (Berry 1984; Custer *et al.* 1986; Foley 1981; Kohler and Parker 1986; Schermer and Tiffany 1985).

With the increase of archaeological predictive models, several trends emerged that would lead to a prolonged dispute about the usefulness of predictive modelling in archaeology. The first trend came in the form of a dichotomy of two different types of predictive models (Altschul 1988, 64 *ff.*), although the two were not mutually exclusive and used commonly in mixed model designs. The first was the data driven correlative model that seeks to detect correlations between the presence of archaeological sites and their environmental setting (Berry 1984; Custer *et al.* 1986; Foley 1981; Kohler and Parker 1986; Scholtz 1981). These types of models were not concerned with providing an explanatory framework for the predictions they made and were ideally designed with no concern for causality or the application of previous knowledge about sites (Moon 1993, 15). Models were built on regression, discriminant function (Press and Wilson 1978), multivariate analysis (Parker 1985), or t-tests (Rose and Altschul 1988). Their application is predominantly found in CRM environments where the interpretation of predictions is of little interest, and emphasis is put on precision and accuracy of a model. Contrasting the correlative-inductive models, cognitive-deductive models were developed to apply expert knowledge and intuition to identify predictor variables and assign weights to them through careful analysis (Kohler and Parker 1986, 432). Bayesian inference (Millard 2005; Verhagen 2006) and, more recently, Dempster Shafer methods (Canning 2005) were applied to derive explanatory models about the interaction between humans and their environment as well as incorporating a socio-cultural dimension (Jochim 1976; Kohler and Parker 1986, 432 *ff.*).

The second trend that arose was an increasing concern about the lack of a formalised methodology in terms of application of suitable statistical methods, data collection, data management, and model validation (Kohler and Parker 1986; Sebastian and Judge

1988, 10; van Leusen 2002, 1). In 1981 the US Bureau of Land Management released an instructional memorandum following a meeting that proposed the exploration of predictive modelling in CRM and to address issues that were raised concerning methods and application of archaeological predictive models as a valid decision making tool in CRM (Sebastian and Judge 1988, 8-10). The stated goals were:

"*1. To evaluate trends in the development of predictive modelling critically, using knowledge gained through past research;*

2. To explore the feasibility and practicality of predictive modelling for meeting management objectives;

3. To analyse and define the components of the model-building process, particularly with respect to cultural resource management;

4. To develop a set of standards for the archaeological and environmental data to be used in modelling efforts; [..]

5. To provide BLM field offices with information on data collection for modelling purposes and statistical manipulations of those data (*ibid.*, 10)"

The result of that meeting was an expanded pilot project and critical evaluation of the state of archaeological predictive modelling in the USA. The findings were published in the seminal book '*Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modelling'* (Judge *et al.* 1988). As a result, archaeological predictive models boomed in CRM and predictive models were developed for several US counties (Carmichael 1990; Kvamme 1992; Warren 1990) as well as for entire states, such as Minnesota which was commissioned in 1995 (Hudak *et al.* 2011), and later in Vermont and North Carolina (Madry 2006; Madry *et al.* 2006).

As predictive modelling became more widely used, not only in the USA but also in Europe and Australia, efforts were made to address criticisms against predictive modelling in archaeology. Cognitive-deductive modelling based on Bayesian inference and Dempster

Shafer theory were used to enter beliefs about past processes and social dynamics into modelling (Canning 2005; Finke *et al.* 2008; Millard 2005; Verhagen 2006) and were refined using equations that could account for uncertainty about data and knowledge of the past. Eventually, such techniques were adapted for use in correlative-inductive models (fig. 2.2) (van Leusen *et al.* 2010; Verhagen *et al.* 2008).

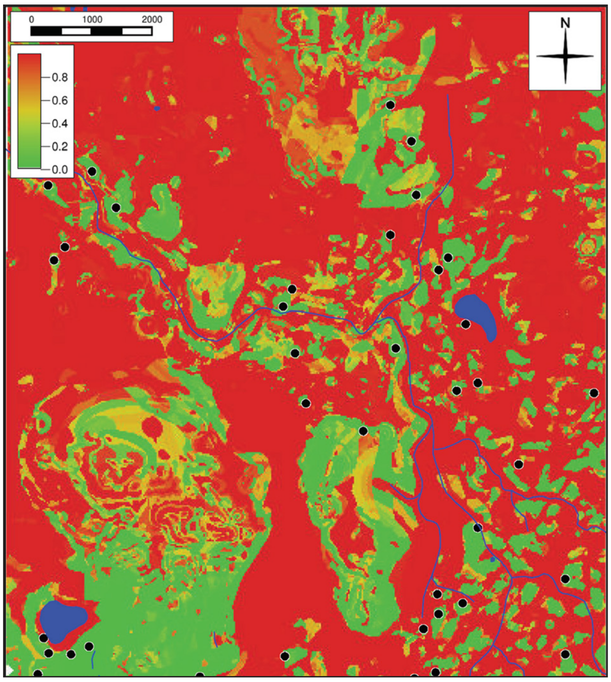


Figure 2.2: Archaeological predictive model outcomes incorporating DST layers of uncertainty (after Verhagen et al. 2008). Areas of high probability are indicated in green.

Archaeological predictive modelling in Europe in the 1990s

In Europe, processualist archaeology of the 1960s and 1970s was perceived with scepticism and was seen as being "*materialist, functionalist, technological, and economic processes, pursued within an explicitly deductivist, social scientific framework*" (Watson 2008, 33). As a response, post-processualism emerged, not as much as a contradicting but rather complementary expansion on processualist theory. For Shanks (2008, 3), "*the case of post-processual archaeology is that of a committed quest for a better and more thoughtful, but not more exclusive, archaeology*" and "*it was clear from the beginning that post-processual archaeology had a very different overall agenda, often aiming less at knowledge of the past for its own sake, than a knowledge that linked intimately with contemporary issues and interests, such as different values placed upon the past.*" It was the lack of explanatory capabilities and its reductionist framework that made predictive modelling a target for criticism from post-processualists. This criticism resulted in a lack of interest from both archaeologists as well as heritage managers in Europe where predictive modelling never reached the same level of popularity as it did in the USA.

By the end of the 1980s, archaeological predictive modelling reached Europe. The Netherlands initially spear-headed its application in academic research, at the University of Leiden (Brandt *et al.* 1992; Wansleeben 1988). The technique was later adapted for CRM by the State Service for Archaeological Investigations (ROB) in the form of the Indicative Map of Archaeological Values of the Netherlands or *Indicatieve Kaart van Archeologische Waarden* (IKAW) (Kamermans 2007, 72-3; Kamermans and Wansleeben 1999; Roorda and Wiemer 1992; van Leusen 1992). The development of the IKAW was fuelled by the Valletta Convention of 1992, which obliged its signees to protect their archaeological heritage; and new ways of implementing the protocol were sought (Kamermans *et al.* 2009, 9). The Netherlands adopted archaeological predictive modelling as a CRM tool for their stringent planning and resource management system (*ibid.*). The IKAW was controversial, even amongst proponents of predictive modelling. In 2007, Hans Kamermans, who carried out pilot studies in predictive modelling in the Netherlands (Kamermans and Wansleeben 1999; van Leusen and Kamermans 2005), published a critical analysis of the predictive model for the Netherlands. Its title made no secret of his verdict: *'Smashing the crystal ball: A critical evaluation of the Dutch national archaeological predictive model (IKAW)'*. He criticised the Dutch CRM system for falling into the same methodological traps as model developers had in the USA 20 years prior (Kamermans 2007).

In other European countries archaeological predictive modelling received less attention as a CRM tool but was adapted by some archaeologists as a research tool. For example, García Sanjuán (1999) and García Sanjuán & Rodríguez López (1996) used archaeological predictive modelling to predict social status in Iberian Bronze Age communities, represented by the presence of precious metal in burial monuments, by regressing soil quality, material culture, and tomb morphology against the presence of metal objects. Similarly, Stančič (Stančič and Kvamme 1999) used Boolean methods to create an archaeological predictive model to predict the location of Bronze Age settlements on the island of Brac, Croatia. His model integrated environmental (e.g. elevation, slope, and soil) and social (e.g. distance between hillforts, site inter-visibility, and distance to sea) variables to avoid being environmentally deterministic, without sacrificing the potential influence environmental factors had on site location choices. Regardless of the variables used, Stančič's model was based on cognitively derived rules, for instance 'hillforts would contain fertile soils and be in close proximity to the next hillfort' (Stančič and Kvamme 1999).

The Dempster Shafer theory of uncertainty, which is related to Bayesian inference (Dempster 1968; Shafer 1976), was applied by Ducke (2010, 298) for an archaeological predictive model for the state of Brandenburg, Germany. Developed as a CRM tool, Ducke's decision to use the statistically less restrictive Dempster Shafer method diverted from the data driven regression and discriminant function analyses often seen in US CRM predictive models. This, according to Ducke, enabled "*researchers to study interactions between site locations and landscape variables of any type on any scale and facilitate insight into complex relationship*s".

Archaeological predictive modelling: an on-going debate

The debate over the validity of predictive modelling as a useful quantitative tool continued between its proponents and critics. In a 1990s published debate between Gaffney and van Leusen, Gaffney proposed that, rather than using environmental reductionism to make simple correlations between human behaviour and the environment, archaeology should seek to provide explanations for the archaeological record presented to the researcher (Gaffney and van Leusen 1995, 373). In a counter argument, critics were accused of misrepresenting the function of the role of GIS and archaeological predictive modelling in general. Predictive modelling is not an explanatory tool but a descriptive tool, detecting patterns in the data rather than offering interpretations. Such interpretations always hinge on objectively collected data that, by itself, is neutral and is given context and meaning through interpretation by experts (Church *et al.* 2000, 146; Gaffney and van Leusen 1995, 379). Or as van Leusen (Gaffney and van Leusen 1995, 379) put it, "*Gaffney argues that archaeologists should be concerned with interpretation of the historical processes, which result in patterns in the data. I will not argue with that except to note that this* *begs the question of how such patterns can be detected in the first place.*" They also posed new questions about the causalities that resulted in these patterns and observed that archaeologists who work with predictive modelling are more often than not aware of the limitations of their predictive models (Altschul *et al.* 2004, 13; García Sanjuán and Rodríguez López 1996; Graves 2011, 12; Vaughn and Crawford 2009, 552-4). As a non-invasive research tool, it has been shown that archaeological predictive models are used as a guidance tool for targeting areas for further investigation (Balla *et al.* 2014; García Sanjuán and Rodríguez López 1996; Jasiewicz and Hildebrandt-Radke 2009; Vaughn and Crawford 2009; Verhagen and Gazenbeek 2007; Woodman 1997).

Proponents of archaeological predictive modelling continue to address issues by improving sampling strategies, data quality, analytical methods, and model validation (Canning 2005; Ducke 2011; García Sanjuán and Rodríguez López 1996; Jasiewicz and Hildebrandt-Radke 2009; Kamermans 2007; Verhagen 2006, 2008; Verhagen *et al.* 2008; Verhagen *et al.* 2012). The majority of predictive models rely on internal testing procedures to rate their success, such as Kvamme's gain statistic, which assesses the ratio of predicted area over known sites and gives a measure of how much a model improves prediction above chance (Kvamme 1992). Wheatley (2004, 8) notes, "*These* [internal model tests] *are not measures of the performance of the model, because if it means anything, 'performance' must mean the extent to which the model predicts undiscovered archaeology. Instead, these are measures of the extent to which the model is internally consistent.*" A recent study on predictive model performance on two US military training facilities by Green *et al.* (2012) conducted systematic field tests on over 35,000 spot locations to test how well the models performed in the field; the results confirmed the predictions in both cases. The model was created based on an almost equal number of test sites that were probed for model creation.

This type of double validation (Rose and Altschul 1988, 202) is the most efficient type of model validation as both samples are completely independent. However, such a validation method also defeats the purpose of archaeological predictive modelling, which is to minimise the need to conduct field surveys (Ducke 2011, 437). Moreover, the convenience archaeological predictive modelling offers to CRM-managers can lead to a total reliance on a model and disregard of the need to conduct field testing (Butler 1987, 825-6). But as Ducke (2014, 14) explains, *"The attribute "predictive" is actually somewhat misleading in this context. The output of an archaeological predictive model (APM) is really an indication of an area's assumed suitability or potential for e.g. prehistoric farmsteads rather than the actual existence of a preserved site at any given location. The latter is subject to a variety of sources of uncertainty which makes a straight progression from "there should be a site" to "there is a site" impossible."* In this context, areal predictive models do not produce definite locations of archaeological significance but areas of high potentiality, and further fieldwork to find sites is always required, which seemingly makes them more suitable for CRM by allocating developments to areas of low archaeological potential. Recently, Carlson and Baichtal (2015) developed an archaeological predictive model to locate early Holocene coastal settlement sites in Alaska. Re-creating a palaeo-shoreline for their target area, their model identified a zone along the ancient coastline between 17m and 22m above sea-level where target sites were most likely to occur. Subsequent field tests revealed 70 sites at altitudes between 0m and 32m along that shoreline, of which 17 were of the target age and fell into the predicted elevation bracket. Her model illustrates how a predictive model can be successfully used to guide field survey by limiting the target area to a manageable size.

Model verification in the field is often prohibited by limitations on time and budget, but some examples exist. Balla *et al.* (2014) conducted a review of 11 predictive models, examining archaeological predictive models and their outcomes. The review was unsystematic, in that inclusion criteria were not provided and case studies included one conference poster (Luczak 2013). Balla claimed that five models led to the discovery of new sites. His findings, however, were not verified by the original literature (Al-Muheisen and Al-Shorman 2004; Luczak 2013; Vaughn and Crawford 2009), excluding only two out of eleven models that aided in the discovery of new archaeological sites (Aubry *et al.*

2012; Fry *et al.* 2004), whereas the remaining models were verified and assessed for their performance using existing data.

Until methodological issues are sufficiently addressed and resources allow for a thorough sampling and validation procedure, archaeological predictive modelling seems to be more useful as a complementary research tool rather than a stand-alone decision making tool. Since the 1970s, vast advances have been made to refine underlying methodologies and conceptual frameworks and the advent of the digital age has allowed for the development of ever more effective archaeological predictive models (Diggs and Brunswick 2006; Hatzinikolaou 2006; Jasiewicz and Hildebrandt-Radke 2009; Jin *et al.* 2013; Krist 2006; Lieskovský *et al.* 2013; Llobera *et al.* 2004; van Leusen *et al.* 2010; Verhagen and Dragut 2012; Verhagen *et al.* 2010; Verhagen *et al.* 2008; Verhagen and Whitley 2011; Wescott 2006; Whitley and Burns 2008; Zwertvaegher *et al.* 2010). However, the need for collecting first-hand input data to address issues of data reliability, and to thoroughly test model performance in the field by equally testing predicted sites as well as non-sites (Wheatley 2004, 9), makes archaeological predictive modelling a time- and money-consuming undertaking.

Archaeological predictive modelling in Ireland and Britain

In Ireland and Britain, archaeological predictive modelling has not received much consideration as a valid research tool. Hodder's criticism of processual archaeology, which formed the theoretical foundation of predictive modelling, triggered the development of post-processualism in Europe (Earle *et al.* 1987; Hodder 1982, 1984, 1985a, 1985b, 1986), which was further advocated by British archaeologists such as Christopher Tilley (Shanks and Tilley 1993), Daniel Miller (Miller and Tilley 1984b, 2-3; 1984a), Michael Shanks (Shanks 2008), and Peter Ucko (Ucko 1995). Few predictive models were developed in Ireland and Britain (Graves 2009, 2011; Hosfield 2001; Legg and Taylor 2006; Wilcox 2010; Woodman 1997, 2001) and commercial developers commented on their usefulness with a positive outlook by acknowledging their potential both in academic research

(Graves McEwan 2012) and CRM (Wilcox 2010), as well as fundamental criticism that echoed the general perception of predictive modelling in post-processual academia (Woodman and Woodward 2002).

The few examples from Britain illustrate the potential contribution predictive models could have in archaeological research. Graves (2009) developed a cognitive-deductive model to assist in the identification of Neolithic settlements in mainland Scotland using environmental data from which hybrid variables were calculated. Data from contemporary sites and monuments - such as megalithic tombs, timber halls or pits - were also tested for inclusion in the model of which only chambered cairns qualified for inclusion and a second model was created using qualified corresponding variables. The resulting models were weighted for precision and accuracy respectively, but ultimately the more conservative accuracy weighted model was seen as more appropriate for research purposes (fig. 2.3). Her models reached a gain of 0.79 (Model 1) and 0.72 (Model 2) (Graves 2011, 644). Building on this and an earlier model, she evaluated her results via a series of field tests on high and medium potential sites she selected from her model outputs. She concluded that poor model performance was mostly due to poor data resolution, such as too coarse digital elevation models and uncertainty regarding changes in the environment over time, such as changes in water courses since the Neolithic (Graves McEwan 2012, 539-43).

Woodman (1997, 2001) developed a predictive model for the Isle of Islay, Scotland. In her doctoral thesis, Woodman (1997) drew from various ethnographic studies to construct a predictive model to identify Mesolithic sites. She used linear regression and logistic regression to build a qualitative and quantitative model. The first model used ethnographic data from Norway and Canada as a training set, whereas the quantitative model was built on Scottish training data. In comparing her results with field samples undertaken in the course of the Southern Hebrides Mesolithic Project (Mithen 2001; Mithen and Lake 1996), she could assess her predictive model with an independent sample set, which resulted in a failure to predict her independent samples correctly, but showed significant differences in a randomised non-site sample in some areas. However, her experiences in

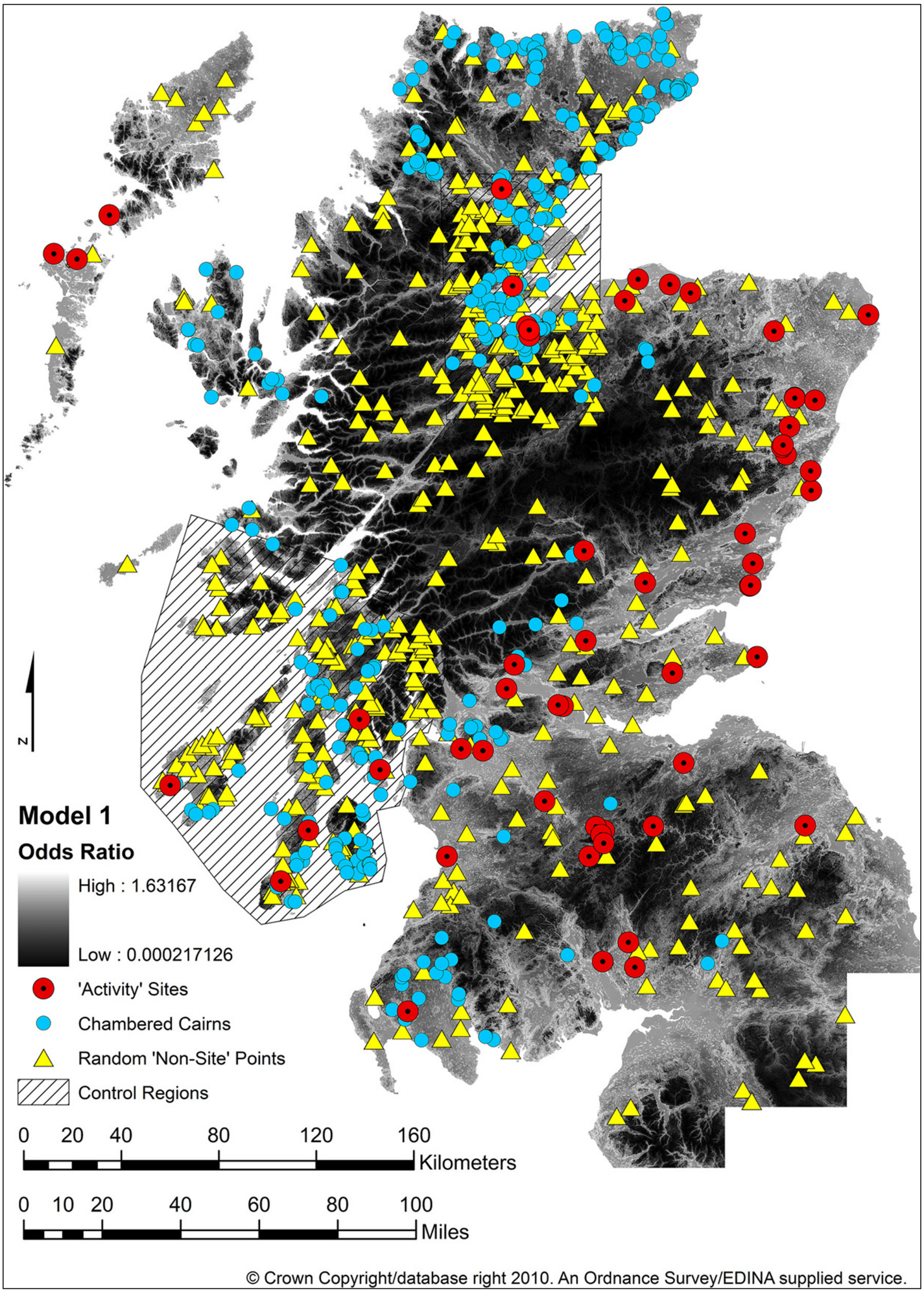


Figure 2.3: Predictive model for Neolithic settlement sites in mainland Scotland (after Graves 2010).

archaeological predictive modelling led her to co-author "*The use and abuse of statistical methods in archaeological site location modelling*" (Woodman and Woodward 2002), a paper that outlined the methodological shortcomings and poor practice in archaeological predictive modelling.

In Ireland, to date only one archaeological predictive model has been developed to identify environmental factors that may have influenced site location choices - in this case for the construction of Early Medieval ringforts and to predict possible locations where ringforts may have once existed (Legg and Taylor 2006). The model was developed using the River Inny catchment in Co. Westmeath and applied to the Lough Ramor, Co. Cavan and the Blackwater Valley, Co. Meath catchments, both adjoining the River Inny catchment. The model applied binary logistic regression to establish correlations between a number of variables such as soil, vegetation cover, altitude, aspect, slope, and proximity to water. The resulting predictive model produced two very different accuracy levels when tested. Legg and Taylor opted not to use Kvamme's gain statistic (Kvamme 1988, 329) and, instead, relied on the model R^2 and χ^2 (Legg and Taylor 2006, 211-12). The resulting probability surface located the majority of ringforts in areas with a probability level of 50 - 66%, which is only slightly above chance. However, the APM has not yet been tested in the field.

When compared to the USA's pro-active approach to APM, the lack of academic support and governmental funding for archaeological predictive models has left this technique dead in the water in Ireland and Britain. The models that were developed mostly suffered from a lack of proper field-testing to validate and refine predictive models. Graves' call for better data (Graves McEwan 2012, 541-2) and Woodman's criticism of poorly designed archaeological predictive models (Woodman and Woodward 2002) echo the criticism predictive modelling has received elsewhere, but rather than dismissing the technique entirely, they both acknowledge its potential if shortcomings can be adequately addressed.

Predictive models in cave archaeology

At the time of writing, there has been only one attempt to use a predictive model to test the archaeological potential of caves. Developed as part of a conservation audit for the Peak District and Yorkshire Dales, England, between 2004 and 2006 (Chamberlain 2003; Holderness *et al.* 2007), Andrew Chamberlain applied discriminant function analysis in a non-spatial predictive model. Caves and rock shelters are usually excluded from predictive models as their location is not determined by human choice but rather by a set of geological variables, and their exclusion from the modelling process has been deemed as an improvement (Kvamme 2006). However, archaeological caves have been successfully integrated into a cognitive-deductive predictive model that explored Mesolithic settlement and subsistence strategy patterns in southwest Germany (Jochim 1976). While the aim of Jochim's model was not to predict their archaeological potential, data from caves were tied into the model as part of the known settlement strategies of hunter-gatherer communities. The effectiveness of caves in providing shelter was based on a number of morphological and environmental aspects, such as orientation, valley shape, elevation, slope, proximity to water, seasonal usability, and size. Furthermore, food refuse was analysed to help model subsistence strategies.

Chamberlain's model (Holderness *et al.* 2007) to predict the archaeological potential of caves in the Yorkshire Dales and Peak District has to be seen as a pilot study. His model differed from conventional archaeological predictive models as it assessed individual points of interest (caves) rather than generating entire map layers. In that respect, Chamberlain's approach returns to the very beginning of predictive modelling of the 1970s when probabilities were calculated only for specific points (Kvamme 2006, 6-8). This particular predictive model relied on collected field data and was developed using non-spatial analytical tools (Excel, SPSS). The predictive model was part of a general audit of caves *"to review the state of the current knowledge of the caves of a defined region of England, to devise a programme of visits to survey and assess the condition of known caves and their contents, to develop a predictive model that uses topographical and geomorphological data to identify caves that have a high potential* *for containing archaeological evidence, and to generate recommendations for future research and management of the cave archaeological resource"* (Holderness *et al.* 2007, 1). The research areas encompassed over 800km^2 of karst with over 750 caves meeting Chamberlain's inclusion criteria. Of these, a non-random stratified sample of 399 caves were recorded and analysed. Of the 399 caves, 80 caves were of archaeological significance; an equally sized group of non-archaeological caves was used as a contrasting group (*ibid.,* 80). Analysed attributes were altitude (m), aspect, entrance size (*log*m^2), entrance width (*log*m^2), depth (*log*m^2), entrance height (*log*m^2), ground slope outside cave (degrees), ground slope inside (degrees), sediment condition, and proximity to water (m). Using univariate tests, Chamberlain identified altitude, cave entrance height, and cave depth as the core predictors for his model; and cave entrance width, distance to water, slope inside, and slope outside the cave as subsidiary predictors for the Peak District. For the Yorkshire Dales, he identified cave entrance height, cave entrance width, and cave depth as the strongest predictors; with east-west aspect, slope inside, and slope outside the cave making subsidiary contributions (Holderness *et al.* 2007). In both of Chamberlain's research areas, the model worked at a success rate of *c.* 80%.

The resulting predictive model assigned continuous probability values ranging from 0 to 1 to the tested caves. The 20 highest model outcomes were presented for each research area. For the Peak District, six caves scored a probability above 0.5, with only one cave scoring a probability value above 0.75 of being of archaeological significance. For the Peak District, 20 caves scored probabilities above 0.5, 13 of which exceeded 0.75. Chamberlain concluded that by using a GIS, more environmental proxy variables (viewshed, geology *etc*.) could be introduced to the model in future research (Holderness *et al.* 2007, 105).

While offering promising correlations between caves, altitude, orientation, distance to water, and entrance size, Chamberlain's model suffered from a significant shortcoming. The model did not take into account the chronology of activities within caves, pooling caves that were used during different periods into one body of archaeological caves. In doing so, he assumed that location preferences for caves have not significantly changed over time. Dowd (2004, 2015) has already established that there is significant variation in location and morphology of archaeological caves in Ireland that were used in particular periods, which is also likely to be the case in Britain. This suggests that caves were subject to distinct preferences that changed over time. A separation of caves into chronological periods of use would have made possible an interpretation of the observed patterns and possible changes in preferences for caves in different locations or with specific morphological traits. However, being part of a cultural resource management project, priority was probably given to correlation over explanation.

2.2 Irish cave archaeology: an overview

Until the end of the 20th century, caves were under-researched in Irish archaeology. Twohig (1975, 36) commented that, "*While many of the caves are mentioned in the literature from time to time throughout the post-medieval period there appears to have been no serious attempt to investigate the caves as a study in its own right.*" Similarly, Dowd (1997, 2004, 2015) notes in her review of the history of Irish cave exploration that interest in cave investigation coincided with an increasing interest in the natural sciences in Ireland and Britain, mainly by the gentry who were "*visiting caves as part of leisurely or scholarly outings*" (Dowd 2015, 25). These early explorations often resulted in the discovery of paleontological and archaeological remains such as Berkeley's discovery of a large quantity of human remains at Dunmore Cave, Co. Kilkenny (Berkeley 1901; Walker 1773).

19th century cave explorations

Twohig (1975) compiled a history of Irish cave exploration. He names Brenan's investigation in Shandon Cave, Co. Waterford as the "*first in Ireland for which a pleistocene* [*sic*] *fauna could be claimed"* (*ibid.*, 36). The first recorded archaeological finds from a cave, however, come from early 19th century investigations by Thomas Andrews in a cave on Rathlin Island where he discovered "*a rude piece of antiquity formed of iron and* *resembling the handle of a sword"* (Andrews 1835, 660). In the same year, geologists Bryce and Scouler reported on the discovery of faunal remains in three caves on Rathlin and three caves along the Antrim coast (Bryce 1835). Several excavations of Dunmore Cave, Co. Kilkenny (fig. 2.4) by Robertson, Graves and Prim in 1854 (Robertson 1854); by Graves, Foot and Burchtaell in 1869 (Foot 1878); and in 1874 by Hardman (Hardman 1874) turned up several hundred human bones along with over 100 Viking artefacts (Dowd *et al.* 2007). During the construction of a pier at Redbay, Cushendall, Co. Antrim the remains of at least six individuals along with two bronze axes, a stone axe and two 9th century coins were presented to the Royal Irish Academy in 1849. The remains appear to have come from what was once a cave that had been quarried away (Jones and Smith 1847).

Naturalist interest in caves dominated research in the following decades, which was predominantly focussed on finding paleontological material but frequently unearthed archaeological human remains and artefacts. The foundation of the *Committee Appointed for the Purpose of Exploring the Fermanagh Caves* resulted in a series of cave excavations in Northern Ireland (Dowd 2015, 31). Plunkett (1876, 1879b, 1898) reported on the excavation of a series of caves around Knockmore Mountain where he discovered artefacts and human remains in at least 14 caves. Parallel to his excavations at Knockmore, Plunkett also excavated Knockninny Cave where he discovered a cist containing a Bronze Age cremation burial in an encrusted urn and the remains of at least two further urns, Neolithic lithics and disarticulated human bones suggesting a continuous use spanning several millennia (Dowd 2015, 140; Plunkett 1879a; Plunkett *et al.* 1875).

Between 1870 and 1880, research work by A. L. Adams, G. H. Kinahan, and R. J. Ussher in the southwest of Ireland led to the establishment of the *Committee for the Purpose of Exploring Caves in the South of Ireland* in 1880 with widespread dissemination of the results of their excavation campaigns (Adams *et al.* 1881; Scharff *et al.* 1905; Scharff *et al.* 1906; Ussher 1881, 1882; Ussher *et al.* 1879). Their excavation at Ballynamintra Cave, Co. Waterford (Adams *et al.* 1881; Ussher *et al.* 1879) produced the first Neolithic

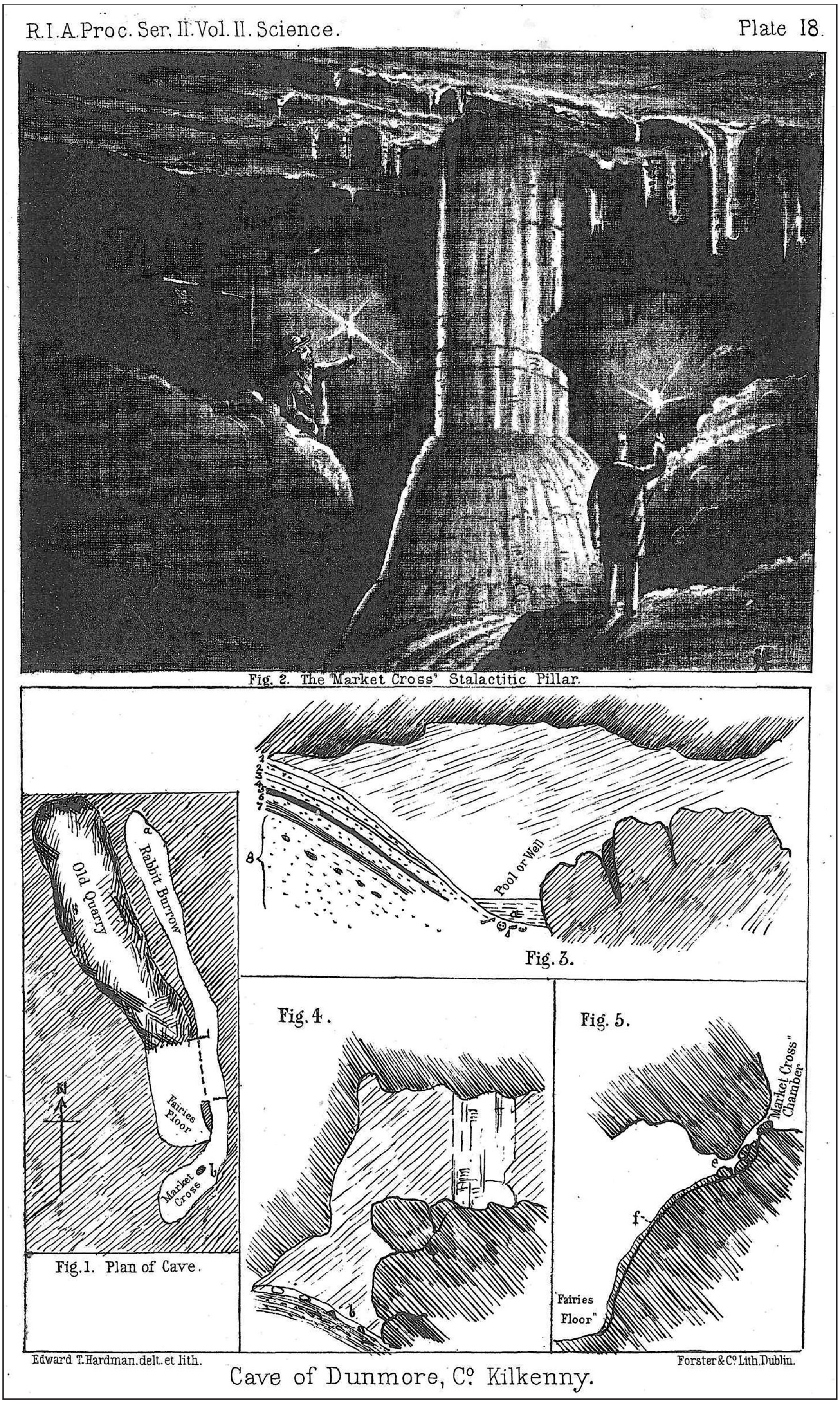


Figure 2.4: Antiquarian drawings of Dunmore Cave, Co. Kilkenny (after Hardmann 1874).

archaeology from a cave context, which also saw the implementation of a more systematic excavation and recording process (Dowd 2015, 35-6). The Neolithic date of some of the finds, however, was not established until 1997 (Woodman *et al.* 1997, 133-4).

Paleontological cave research in the early 20th century

The foundation of the *Committee Appointed to Explore Irish Caves* by C. I. Forsyth Major, R. F. Scharff, R. J. Ussher, R. L. Praeger, G. A. J. Cole, and G. Coffey saw the most intense period of systematic cave exploration in the last decade of the late 1800s and the early 1900s. Archaeology dating to all periods from the Mesolithic through to post-Medieval times was discovered at caves in the Dungarvan valley, Co. Waterford, the Edenvale-Newhall complex, Co. Clare, and the Keash Caves, Co. Sligo (fig. 2.5) (Scharff *et al.* 1903a; Scharff *et al.* 1903b; Scharff *et al.* 1906; Ussher 1881, 1902), although their research focussed on the recovery of paleontological material and the periods were not recognised until much later (Dowd 1997, 2004). These pioneers of Irish cave research were succeeded by a new generation of cave researchers, consisting of archaeologists, cavers from the Bristol Speleological Society, and members of the Royal Irish Academy. Their research was primarily aimed at the recovery of Pleistocene faunal remains, with a secondary objective to find evidence for a Palaeolithic in Ireland (Dowd 2015, 39). The resulting excavation campaigns stretched over a period of 11 years between 1929 and 1940 and focussed on previously excavated caves, as well as a series of caves along the Antrim coast (*ibid.*). Excavation campaigns predominantly focussed on the south of

Figure 2.5: Antiquarian excavation trench in Keash Cave L.

Ireland, an area "*that was not covered by the Southern Irish End Moraine of the last glaciation and that therefore it would be in that area that evidence of Pleistocene, man would be most likely to be found*" (Tratman 1929, 109). Excavations and test-excavations were carried out in caves in the Dungarvan valley, Co. Waterford (Movius *et al.* 1935; Tratman 1929, 1937), in Killavullen, Co. Cork (Dowd 2015, 104), and Connaberry, Co. Cork (Gwynn *et al.* 1941). Following an unsuccessful attempt to excavate further caves in Cork, Gwynn shifted his focus to the Keash Caves, building on earlier investigations (Gwynn *et al.* 1940, 81; Scharff 1902; 1903a; 1903b).

Jack C. Coleman, regarded as the father of Irish caving (Dowd 2013c), conducted a number of excavations and explorations in caves of Co. Cork (Coleman 1934, 1940, 1942, 1944a, 1944b, 1947; Coleman and Stelfox 1945). Following a summary of cave excavations undertaken before 1945 (Coleman 1947), Coleman compiled the first dedicated book on cave research in Ireland. His seminal work, *The Caves of Ireland* (Coleman 1965), contained over 350 written descriptions of caves from across the country. Additionally, the book provides an overview of karst formation, the geology of Ireland, caving in general, and the first review of archaeological finds from Irish caves. In 2012, a part of Coleman's extensive caving archive was rediscovered. The archive holds significant unpublished information on Irish caves but also documents the history of Irish caving from the 1930s until the late 1960s (Dowd 2013d). Coleman's work led to the identification of over 40 caves of archaeological and historical significance, and Dowd endorses his deep understanding of Irish cave archaeology that is apparent in observations that still hold true today (Dowd 2013d, 2013c; 2015, 42-4).

The decades between 1940 and 1990 are described as being mostly devoid of academic cave archaeological research in Ireland (Dowd 2015, 40). However, publications from the Irish and British caving community, who are often responsible for the discovery of archaeology in caves, provide valuable information for cave archaeologists. Journals such as *Irish Speleology, University of Bristol Spelaeological Society*, *Journal of the Craven Pothole Club, Descent,* along with discontinued journals and newsletters such as *The*

Irish Caver, *Cave Explorers in Fermangh*, *Cork Speleological Group Newsletter*, *The Reyfadeer*, *Kilkenny Speleological Group Newsletter*, and *the Cork Caver* frequently published reports on excursions, excavations, surveys, and new cave discoveries, occasionally including archaeological finds (Anderson and McCarthy 1991; Coleman 1966; Meiklejohn *et al.* 2012; Schulting *et al.* 2010; Schulting *et al.* 2013; Schulting and Wysocki 2002; Thomas 1995; Thomas and Critchley 1995; Twohig 1975).

Modern cave archaeology: the late 20th and early 21st centuries

Since 1985, ten caves of archaeological significance have been archaeologically excavated to modern standards (Dowd 2015, 60). Two of the excavations unearthed human remains and material dated to the Neolithic. An undisturbed Neolithic cave burial in Annagh Cave, Co. Limerick was excavated by Ó Floinn in 1992 (Ó Donnabháin 2011; Ó Floinn 1992, 2011). This was followed by the excavation of the multi-period site of Killuragh Cave in 1996 (Woodman 1996). Seven further caves produced remains and materials of later prehistoric and historic date (Connolly *et al.* 2005; Dowd 2007, 2009, 2010a, 2010b, 2013a, 2015; Dowd *et al.* 2007; Logue 2008; Moore and Forsythe 2004b, 2004a; O'Brien and Comber 2008). Recently, the discovery of an archaeological cave on Knocknarea, Co. Sligo by the author during fieldwork for this doctoral thesis led to a rescue excavation (Dowd and Kahlert 2014). Thirteen human bones, representing two or three individuals were recovered and dated to the Middle Neolithic (fig. 2.6).

Figure 2.6: Excavating Knocknarea Cave K (photo: M. Dowd).

Since the turn of the 21st century there has been a renewed interest in cave archaeology, making it an important field of archaeological research. This is mostly due to the work of Marion Dowd who has published extensively on the subject (Dowd 1997, 2001, 2002, 2004, 2007, 2008, 2009, 2010b, 2010a, 2012, 2013b, 2013a; Dowd and Corlett 2002; Dowd *et al.* 2006; Dowd *et al.* 2007). Her research has moved cave archaeology in Ireland from an under-developed field of study to one of the best developed worldwide.

Dowd's 2001 and 2002 publications (Dowd 2001, 2002; Dowd and Corlett 2002) for the first time brought to light the archaeological significance of caves in Ireland and their contribution to our understanding of the past, in particular to prehistory. Her examination of antiquarian excavation records from the Edenvale-Newhall complex and the Dungarvan valley revealed that caves played a significant role in Neolithic religion and funerary rites in a region that barely features any megalithic monuments. She drew a picture of complex funerary customs that ranged from simple inhumations to multi-phase burials, including excarnation rituals and carefully selected caves.

Dowd, together with Woodman, addressed the lack of radiocarbon dates for human remains from Irish caves and started a radiocarbon dating programme that culminated in ten new Neolithic dates and one Mesolithic-Neolithic transition date (Dowd 2015, 71). These new dates from caves put a number of antiquarian finds into their temporal context, provided a wider base of data, and allowed for interpretations of cave use during the Neolithic and other periods. Additionally, osteological analysis of a large number of human bone finds from 24 non-archaeological cave excavations was undertaken by the *Human Remains from Irish Caves Project* (Dowd *et al.* 2006). One of the key findings was that two individuals from Kilgreany Cave suffered violent traumas (*ibid.* 18) - a rare occurrence for the Irish Neolithic (O'Donnobhain and Tesorieri 2014; Schulting 2012; Schulting and Wysocki 2005). Dowd's book *The Archaeology of Caves in Ireland*, synthesised almost 20 years of research and, for the first time, presented radiocarbon dates for human bone assemblages from Irish caves (Dowd 2015, 71).

Being the first book to comprehensively address Irish cave archaeology, *The Archaeology of Caves in Ireland* provides an overview of the development of the discipline over a period of more than 200 years, as well as synthesising 20 years of Dowd's extensive research on this subject. In his foreword to the book, Bradley describes Dowd's work as highly significant in that *"it sets a new agenda for Irish archaeology and provides a model for research in other countries*" (Bradley 2015). Dowd introduces the reader to the basic concepts of cave geology and cave research as well as highlighting how caves were perceived over time, and how ritual activities in the same caves could span over millennia, and inspire continuous use of these venerated natural places. She applies archaeological and anthropological concepts such as van Gennep's *The Rites of Passage* (van Gennep 1960), Tilley's phenomenology theory (Tilley 1994), and psychological approaches to the unique human experience in caves (Lewis-Williams 2002; Montello and Moyes 2012) to the often fragmented archaeological record to develop a continuous narrative of cave use in Ireland.

The multi-period nature of caves is rarely recorded as intact stratigraphy as examples from Bats' Cave, the Keash Caves, and Brothers' Cave illustrate. These and other caves occur as recurring themes, during which Dowd gradually reveals their complex biographies. Often the same caves *"became theatres in which a variety of different rituals were enacted. These were places at which votive material, human bodies and bones were deposited, places that were linked to the dead and the spirit world"* (Dowd 2015, 93). Dowd sees a particularly strong link between Neolithic and Bronze Age activities in caves. Almost every excavated cave that produced Neolithic material also contained evidence of Bronze Age usage. During both periods, ancestor veneration with inhumations and secondary depositions took centre stage along with the ritual deposition of pottery, lithics, axes, adornments, and bronze items - the latter was, of course, limited to the Bronze Age (*ibid.* 140). In other cases, similar activities took place in different caves. For example, Dowd lists Ó Donnobháin's interpretation of the Annagh Cave burials as people who enjoyed a special status within their Neolithic communities as accomplished warriors (Dowd 2015, 103; Ó Donnabháin 2011, 47) as one possibility. A Bronze Age analogy could be the high status burial in Knockane Cave, Co. Cork, which was likely a highly respected person within his own community (Dowd 2015, 137).

Dowd's observation of religious cave use, that spanned two or more distinct archaeological periods, is of profound significance when interpreting archaeological remains from these multi-period sites. If, as Dowd theorises, Neolithic material in caves was not only acknowledged but of high religious significance to Bronze Age people, to what degree did they interact with these human remains and objects? Did they manipulate Neolithic human bones, remove them from one location and deposit them in another, or use them for specific rituals to connect to ancient ancestors?

Over time, caves have been subject to a multitude of uses and perceptions, ranging from the mundane to the supernatural, but it is the supernatural context in which caves were used that dominates the corpus of evidence. Bias can lead interpretations of past cave use astray and Dowd remains cautious about her own interpretations as well as dismantling ones that lack conclusive evidence (Connolly *et al.* 2005; Dowd 2015, 69). In her own work, Dowd (2008) departs from a hypothesis proposed by Osterbeek, Bradley, Barnatt and Edmonds (Barnatt and Edmonds 2002; Bradley 2000; Osterbeek 1997), about the relationship between caves and Neolithic passage tombs as being seen as one and the same by Neolithic people and that passage tombs may have been built as artificial caves. Putting Neolithic caves into their spatial context with passage tombs, or lack thereof, and using the very differing corpus of archaeological material within them, Dowd argues that caves and tombs were perceived as two very distinct places with different, albeit complementary, functions (Dowd 2015, 109-15). With that, she cautions the reader to neither jump to conclusions nor adhere to a single interpretation when considering the evidence from archaeological caves.

The failure to recognise caves as important archaeological sites is evident by their absence or marginalisation (Dowd 2015, 109-15) in Irish archaeological literature (e.g. Cooney 2000, 129; Edwards 1996, 47; Eogan and Herity 1977, 193; O'Kelly and O'Kelly 1989, 5; Waddell 2000, 8). Dowd (2015, 62) suggests that archaeological researchers failed to notice many early reports on archaeological caves because they were not published in standard archaeological publications. In the archaeological literature, caves were mentioned in general discussions that lacked consideration of morphology or landscape aspects. Another plausible explanation might be that, unlike built structures, caves can contain material of any date but hold no guarantee that they are of archaeological significance at all. Only through thorough excavations can this be established and increased costs and logistics may deter many researchers from excavating a cave (Dowd 2015, 76-8).

The nature of Neolithic archaeology in Irish caves

The combined works of the late 19th century and early 20th centuries resulted in the discovery of almost all recorded Neolithic archaeology from Irish caves, a circumstance that was not largely recognised until much later (Dowd 2015, 78). Neolithic material frequently comes from caves that occur in clusters with one or more caves, such as the caves at Connaberry, Co. Cork (Dowd 2008; Dowd *et al.* 2006), the Dungarvan syncline caves, Co. Waterford (Gwynn *et al.* 1941), the Edenvale-Newhall complex, Co. Clare (Adams *et al.* 1881; Forsayeth 1909; Gwynn *et al.* 1940; Jackson 1936; Movius *et al.* 1935; Stelfox 1930; Tratman 1937; Ussher 1881, 1882). In some instances clusters of caves were also located on the grounds of demesne estates, such as the caves at the Edenvale-Newhall complex (Dowd 2013b, 76), Brothers' Cave, and Oonaglour Cave, which are located on the Whitechurch Estate, Co. Waterford. The close proximity of the caves to one another allowed antiquarian researchers to quickly move between cave sites when test-excavations proved unfruitful (Scharff *et al.* 1905; Scharff *et al.* 1906). This strategy has almost certainly caused an uneven distribution of known caves of Neolithic significance. This has implications for the understanding of cave use during the Neolithic with regards to spatial patterning, perceived site location choices, and their relationship to other Neolithic sites and monuments.

The Neolithic evidence from Irish caves provides some interesting insights into their use, which is primarily associated with funerary activities and, to a lesser degree, votive deposition (Dowd 2008, 2015). The types of activity can be divided into (after Dowd 2015):

1. Burial: corpses were placed in an extended or crouched position, sometimes accompanied by grave goods. Only in two cases, Annagh Cave, Co. Limerick and Kilgreany Cave, Co. Waterford, have burials survived undisturbed. Dowd mentions three further possible inhumation sites were found: Quinlan's Quarry Cave, Co. Waterford; Killavullen Cave 3, Co. Cork; and Lisduggan North, Co. Cork (Dowd 2015, 95*ff.*).

2. Excarnation: bodies were laid out inside a cave for a period of time until they decomposed. Large skeletal elements were removed to a secondary location and surviving elements in cave deposits are dominated by phalanges, vertebra, and small fragments, often representing more than one individual. Lack of animal interference suggests that caves were sealed for the duration of excarnation. Examples where this type of burial occurred are Knocknarea Cave K, Co. Sligo, Elderbush Cave, Bats' Cave, and Barntick Cave, all in Co. Clare (*ibid.*, 104 *ff.*).

3. Token deposition: represented by small quantities of skeletal elements of various sizes. These often resemble excarnation remains, which makes a correct classification sometimes difficult in cases where small quantities of human bones come from unexcavated caves (Dowd 2015, 104). Human bones from Knocknarea Cave C, Co. Sligo, Connaberry Cave C, Co. Cork, and Killura Cave, Co. Cork may have been token deposits. However, Knocknarea Cave C has not been excavated and the records for Killura Cave are scant (*ibid.*, 93).

Evaluating the potential of APM for caves in Ireland

The discussion of archaeological predictive modelling as a valid research tool has occupied researchers since its conception in the late 1970s. The eagerness of US cultural resource managers to implement this method as a cost effective solution to new demanding legislation, led to a failure to develop and implement a theoretical framework and a practical methodology for model developers. In a way, it is an example of how New Archaeology attempted to replace culture historical studies in favour of empiricist research designs, whilst failing to acknowledge that archaeology is not a hard science that can be grasped with data and equations, but requires context and careful interpretation to transform objective data into narratives about past societies. In this respect, archaeological predictive modelling has not failed as a method as such, but rather researchers have failed to acknowledge that its strength lies in data exploration that paves the way towards new insights about the past and offers quantitative and replicable results in support of cognitively derived interpretations of archaeological phenomena. The European scepticism towards archaeological predictive modelling is justified. However, it should not hinder the further development and refinement of modelling techniques to further explore the interaction between humans and their environment.

Despite the shortcoming of Chamberlain's models (Holderness 2006), archaeological predictive modelling as a tool to support the search for archaeological caves should be further evaluated and, especially in Ireland, there is a need to identify new archaeological caves that can be investigated to modern scientific standards. Dowd (2015, 38-9) has established the importance of caves throughout Irish history and prehistory, not only as archaeological sites but also as places that are intrinsically connected to Irish mythology, folklore, and local memory. Much of our current knowledge about archaeological caves stems from old and incomplete records and a handful of recent excavations, and while each of these contributions is valuable to our understanding of cave use in the past, the picture we have today is vastly incomplete due to its poor temporal and spatial resolution. New excavation data is needed to expand our understanding of past cave use. The identification of promising research targets through non-invasive techniques is a first step.

Chapter 3: Going underground, gathering data and crunching numbers - methodologies

The aims and objectives outlined in Chapter 1 required the development of an individual methodology for each task at hand. Each was developed to successively proceed from one step to the next:

1. A desk-study to identify suitable research areas
2. Surveying of caves and digitisation of survey data
3. Data processing and extraction in GIS
4. The development of correlative-inductive and cognitive-deductive predictive models using statistical software applications.

This chapter follows this basic layout, while familiarising the reader with standard practices as well as methods that were developed specifically for this research. Cave surveying, data digitisation, and the cognitive-deductive APM required novel approaches. These were not entirely new developments but were based on existing methods and practices found in cave surveying and APM.

3.1 Primary sources

The identification of research areas with enough caves that met preliminary inclusion criteria, such as accessibility and hydrological inactivity, formed the foundation of this study. These areas were selected based primarily on clusters of horizontal relict caves. According to Dowd (2008, 2015) these were the caves that were most likely to have been chosen by Neolithic people for funerary activities. A secondary condition was the presence of megalithic tombs within an area, preferably close to cave sites as this offered an opportunity to examine potential relationships. Using Drew's database (2006a) and the GIS version of the SMR, six areas in Sligo and Leitrim were selected that fulfilled these two conditions, which included as many suitable caves in a research area as possible. The research areas were labelled after prominent landscape features within them:

1. Knocknarea, Co. Sligo
2. Deerpark, Co. Sligo
3. Leean, Co. Leitrim
4. Bricklieves, Co. Sligo
5. Muckelty Hill, Co. Sligo
6. Sheemore, Co. Leitrim

With the exception of Muckelty Hill, each of the research areas also included Neolithic or possible Neolithic monuments. The total size of the six research areas is 82.7km^2; originally containing 48 horizontal relict caves (fig. 3.1). This number increased to 96 after Dónal Gilhoys' archive (unpublished) was assessed and fieldwork revealed previously unrecorded caves.

At the commencement of this study, the majority of existing cave surveys from North Connaught were of larger cave systems that are frequently visited by cavers. These were predominantly published in Irish and British caving journals such as *Irish Speleology*, *Proceedings of the University of Bristol Spelaeological Society* and the *Journal of the Craven Pothole Club*. Comprehensive publications on caves that are available for Munster (Bunce and Barry 2011; Bunce *et al.* 2009; Mullan 2003; Oldham 1981) do not exist for North Connaught. Coleman's *The Caves of Ireland* (1965) still provides the most comprehensive overview of caves for this part of Ireland, although some publications exist that focus on smaller geographic regions in the northwest (Barry and Kennedy 2013; Bunce and Sweeney 2003; Dixon 1973; Gilhoys 1987; Thorn *et al.* 1990; e.g. Wilson 1965) but vary in comprehensiveness and quality.

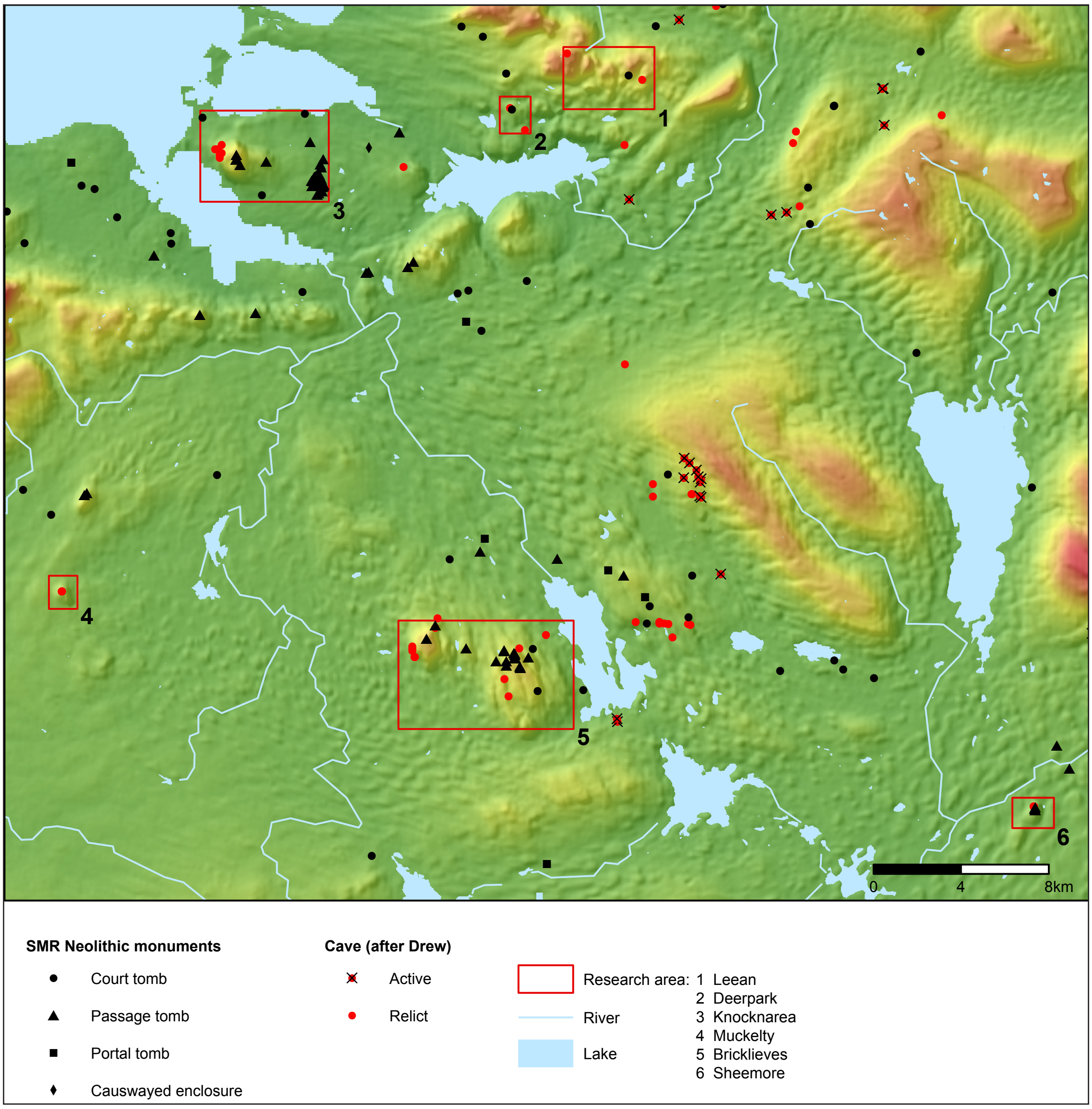


Figure 3.1: Overview of the North Connaught research areas.

Dónal Gilhoys archive

In the course of research, I examined the unpublished archive of the late Dónal Gilhoys (unpublished), a local caver, who attempted to compile an inventory of caves in Sligo and Leitrim. The book never left the manuscript stage and now only survives fragmented in several stages of editing. Many sites are not grid-referenced. Despite its incomplete and fragmented state, the archive provided valuable information on previously unrecorded caves. It consists of 16 notebooks, an incomplete manuscript of a cave book for Sligo and Leitrim, as well as several loose papers including maps, drawings, and letters. The notebooks contained descriptions of caves Gilhoys had visited but these were of limited value, as entries were not labelled with cave names or locations. The manuscript revealed 91 caves and other karst features that Gilhoys (unpublished) recorded within the Bricklieves, Sheemore, Leean, and Muckelty research areas. Sixty-eight of the recorded caves were horizontal, of which 48 were grid-referenced to the 6" OS maps (fig. 3.2). The remaining caves were either not grid-referenced or used as points of reference.

Of archaeological significance is a case of 'mistaken identity' that came to light during the review of two specific entries for Keelogyboy/Sramore, both located within the Leean research area. The first cave, called The Ravens Wing, matches the description of an archaeologically significant cave first described by Dowd (2008) which she named Sramore Cave. However, while Dowd and Gilhoys obviously describe the same cave, Gilhoys attributes the archaeological find to a cave with a very different morphology. The cave had the telling name of Graineaters Cave. The record describes how Gilhoys and fellow caver Robert Stewart discovered a human mandible and femur in 1995 (Dowd 2013d, 34; Gilhoys unpublished). The worn state of the teeth still present in the mandible inspired the name of the cave.

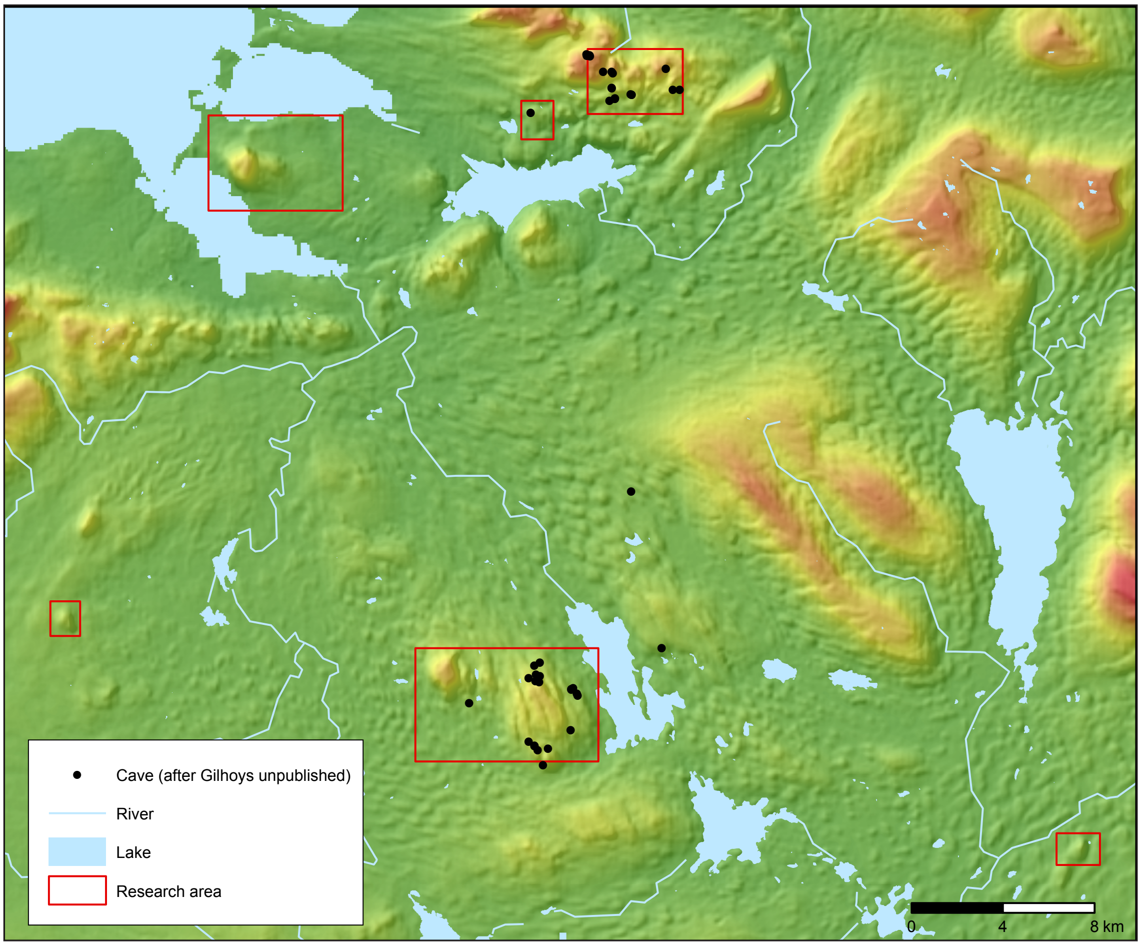
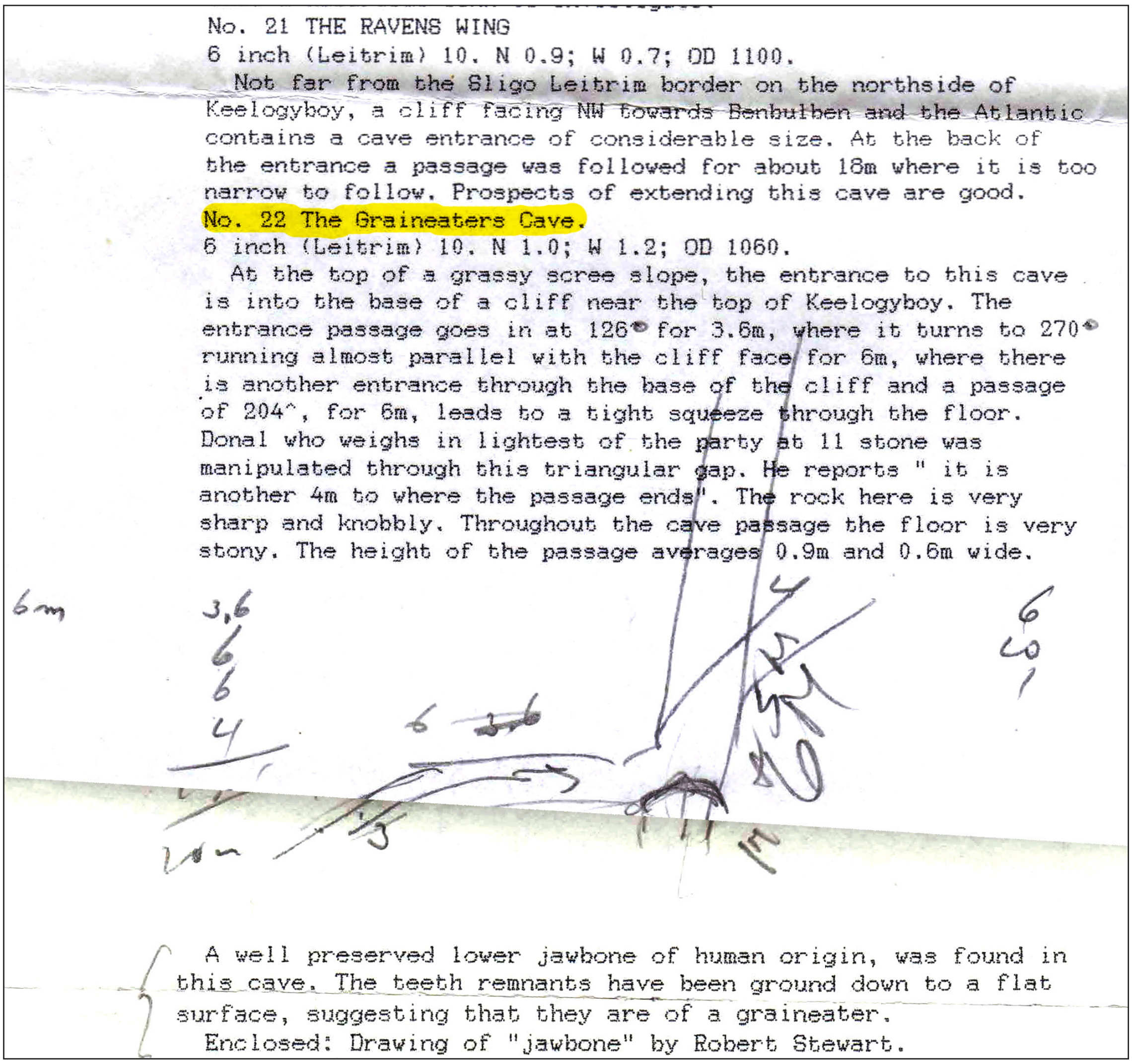


Figure 3.2: Grid-referenced horizontal caves surveyed by Dónal Gilhoys (unpublished).

In his account, Gilhoys describes Graineaters Cave as a small cave passage with a secondary entrance that takes a sharp turn and then slopes down into a tight passage where the two human bones were found (fig. 3.3). The Topographical Files at the National Museum of Ireland (NMI) contains the original report filed by Gilhoys and Stewart. The two descriptions of Graineaters Cave differed only in some small details and it is now clear that the human remains attributed to Ravens Wing came from Graineaters Cave; its location is currently unknown.



No. 21 THE RAVENS WING
6 inch (Leitrim) 10. N 0.9; W 0.7; OD 1100.
Not far from the Sligo Leitrim border on the northside of Keelogyboy, a cliff facing NW towards Benbulben and the Atlantic contains a cave entrance of considerable size. At the back of the entrance a passage was followed for about 18m where it is too narrow to follow. Prospects of extending this cave are good.

No. 22 The Graineaters Cave.
6 inch (Leitrim) 10. N 1.0; W 1.2; OD 1060.
At the top of a grassy scree slope, the entrance to this cave is into the base of a cliff near the top of Keelogyboy. The entrance passage goes in at 126° for 3.6m, where it turns to 270° running almost parallel with the cliff face for 6m, where there is another entrance through the base of the cliff and a passage of 204^, for 6m, leads to a tight squeeze through the floor. Donal who weighs in lightest of the party at 11 stone was manipulated through this triangular gap. He reports " it is another 4m to where the passage ends". The rock here is very sharp and knobbly. Throughout the cave passage the floor is very stony. The height of the passage averages 0.9m and 0.6m wide.

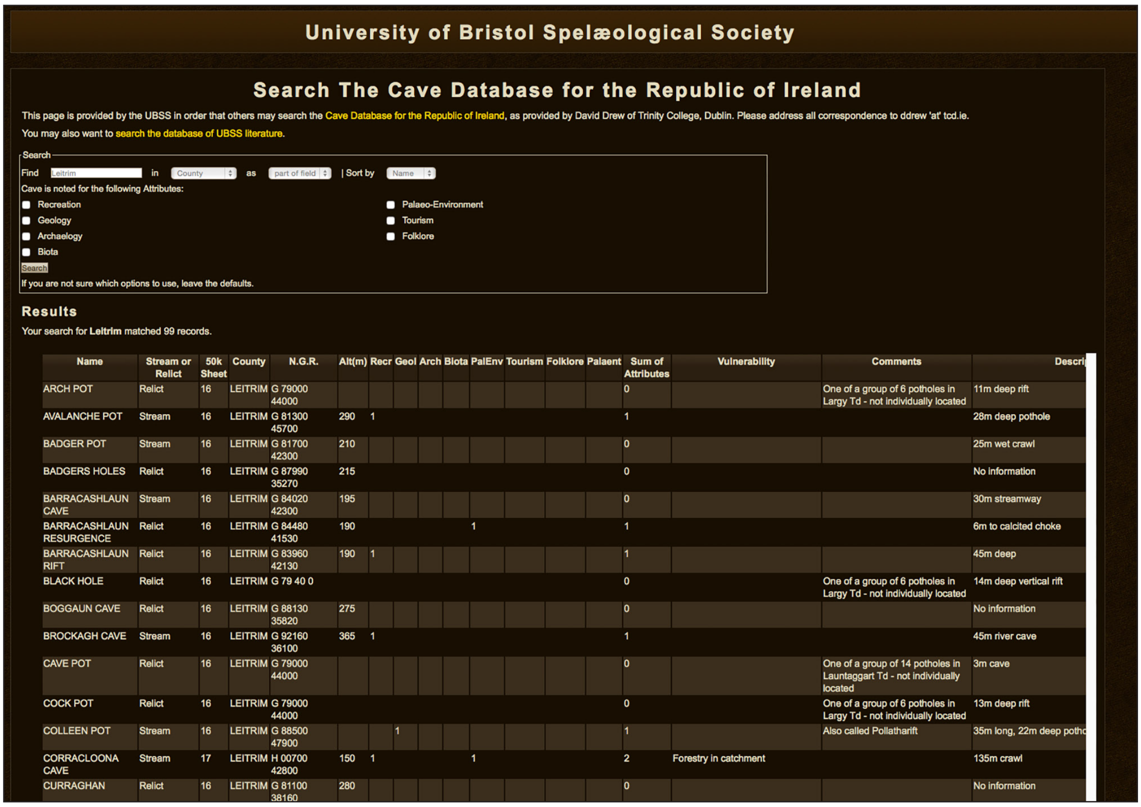
A well preserved lower jawbone of human origin, was found in this cave. The teeth remnants have been ground down to a flat surface, suggesting that they are of a graineater.
Enclosed: Drawing of "jawbone" by Robert Stewart.

Figure 3.3: Dónal Gilhoys' manuscript entries for Raven's Wing and Graineaters Cave, which includes a sketch drawing of the latter.

David Drew's cave database for Ireland

In 2004, David Drew completed and published online the first comprehensive database of caves in the Republic of Ireland on the University of Bristol Speleological Society website (Drew 2006a, http://www.ubss.org.uk/search_irishcaves.php). It compiles over 100 years of cave research in Ireland from various sources into a single geo-referenced and searchable database. The database originally comprised 688 entries including only naturally formed caves by either solution (karst) or tectonic agency. Marine and artificial caves were excluded (Drew 2006b). The database provides extensive information about each cave (see below). Drew made the database available to me as an Excel file that could be converted into a point feature class in ArcGIS (fig. 3.4). The resulting site distribution map was then projected onto various base maps such as aerial images, OSI Discovery Maps, OS 6", and 25" maps which provided additional information about cave locations (fig. 3.5). Transferred to a handheld GPS unit, the spatial information was also used to locate caves in the field. This worked to a lesser degree where trees or high cliff faces obstructed a clear view to the navigation satellites. Additional desk assessments prior to each field visit were necessary to identify landmarks that helped locating a cave in the field should the GPS lose satellite signals.

Drew's location data for caves were noted in national grid reference (TM65). Its accuracy spanned from 10m to 1km, as Drew had taken spatial data from various publications such


University of Bristol Spelæological Society

Search The Cave Database for the Republic of Ireland

This page is provided by the UBSS in order that others may search the Cave Database for the Republic of Ireland, as provided by David Drew of Trinity College, Dublin. Please address all correspondence to ddrew 'at' tcd.ie.
You may also want to search the database of UBSS literature.

Search
Find Leitrim in County as part of field | Sort by Name
Cave is noted for the following Attributes:
Recreation
Geology
Archaelogy
Biota
Palaeo-Environment
Tourism
Folklore
Search
If you are not sure which options to use, leave the defaults.

Results
Your search for **Leitrim** matched 99 records.

Name	Stream or Relict	50k Sheet	County	N.G.R.	Alt(m)	Recr	Geol	Arch	Biota	PalEnv	Tourism	Folklore	Palaent	Sum of Attributes	Vulnerability	Comments	Descri
ARCH POT	Relict	16	LEITRIM	G 79000 44000										0		One of a group of 6 potholes in Largy Td - not individually located	11m deep rift
AVALANCHE POT	Stream	16	LEITRIM	G 81300 45700	290	1								1			28m deep pothole
BADGER POT	Stream	16	LEITRIM	G 81700 42300	210									0			25m wet crawl
BADGERS HOLES	Relict	16	LEITRIM	G 87990 35270	215									0			No information
BARRACASHLAUN CAVE	Stream	16	LEITRIM	G 84020 42300	195									0			30m streamway
BARRACASHLAUN RESURGENCE	Relict	16	LEITRIM	G 84480 41530	190					1				1			6m to calcited choke
BARRACASHLAUN RIFT	Relict	16	LEITRIM	G 83960 42130	190	1								1			45m deep
BLACK HOLE	Relict	16	LEITRIM	G 79 40 0										0		One of a group of 6 potholes in Largy Td - not individually located	14m deep vertical rift
BOGGAUN CAVE	Relict	16	LEITRIM	G 88130 35820	275									0			No information
BROCKAGH CAVE	Stream	16	LEITRIM	G 92160 36100	365	1								1			45m river cave
CAVE POT	Relict	16	LEITRIM	G 79000 44000										0		One of a group of 14 potholes in Launtaggart Td - not individually located	3m cave
COCK POT	Relict	16	LEITRIM	G 79000 44000										0		One of a group of 6 potholes in Largy Td - not individually located	13m deep rift
COLLEEN POT	Stream	16	LEITRIM	G 88500 47900			1							1		Also called Pollatharift	35m long, 22m deep potho
CORRACLOONA CAVE	Stream	17	LEITRIM	H 00700 42800	150	1				1				2	Forestry in catchment		135m crawl
CURRAGHAN	Relict	16	LEITRIM	G 81100 38160	280									0			No information

Figure 3.4: David Drew's Cave Database for the Republic of Ireland, section on Co. Leitrim.

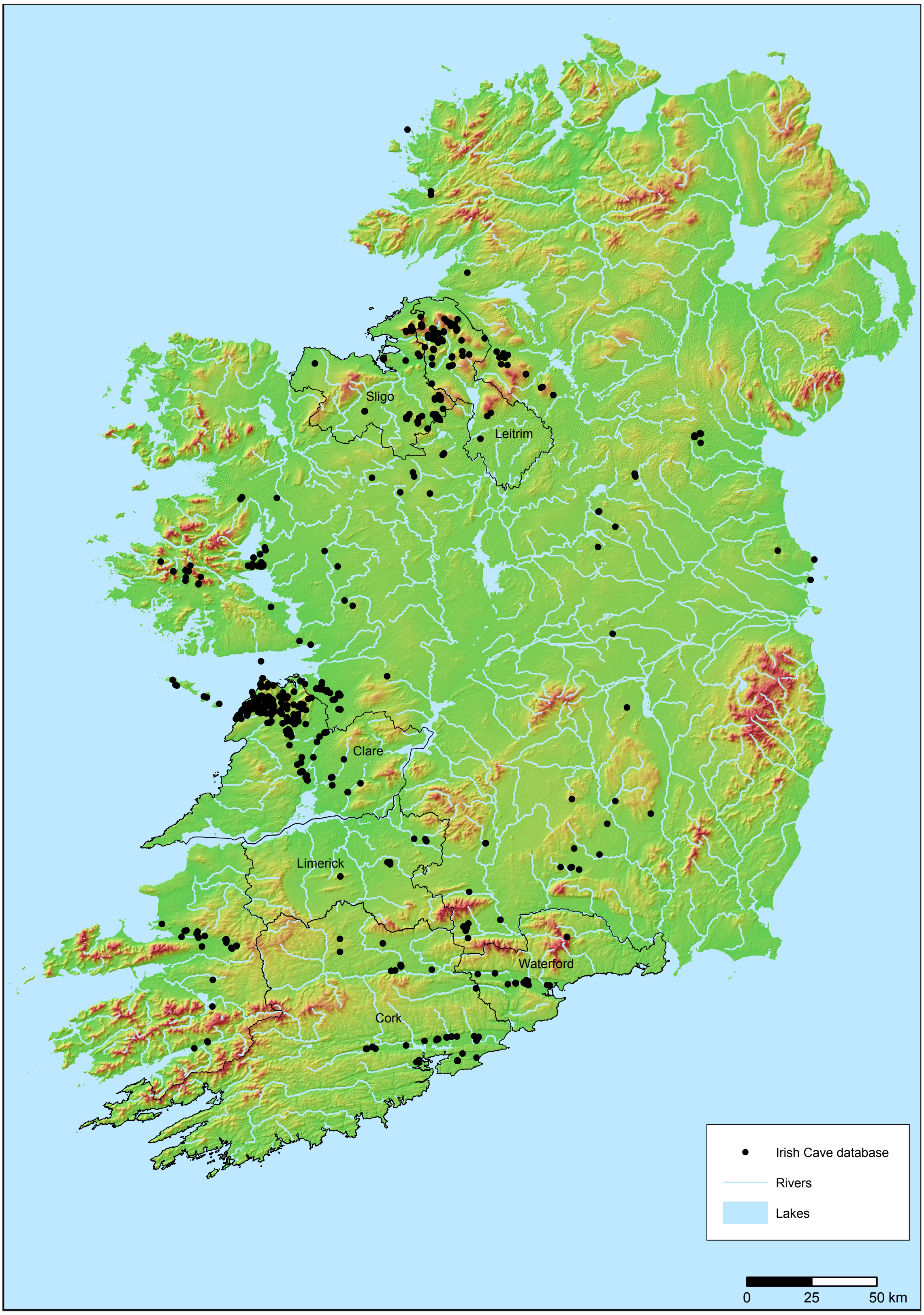


Figure 3.5: Map of Irish caves (after Drew 2006a) and counties covered by this research.

as Coleman (1965), Mullan (2003), Oldham (1981) as well as a number of articles taken from *Irish Speleology*, the *Proceedings of the University of Bristol Speleological Society,* and personal communications. While Drew's database was a valuable resource to identify areas of interest with a high density of horizontal relict caves, the often inaccurate grid-references sometimes required several field visits to find a particular cave and in some instances proved to be futile.

The database has not been maintained since its launch in 2006 (Drew 2011, pers. comm.) and excluded caves located in Northern Ireland as well as caves that were not solutional in origin, such as an extensive body of coastal sea caves. Furthermore, some of the caves listed as archaeological sites have turned out not to be so and new sites have since been discovered (Dowd 2015, 265-8).

The Geological Survey of Ireland

The Geological Survey of Ireland (GSI) contains, amongst other geological data, a GIS database of karst features in the country. Of the 3,928 features included in the database, 570 were categorised as caves. The database provided information on location, location accuracy, geological context, and, occasionally, the name of a cave. The absence of common cave names frequently posed a significant problem when trying to correlate the caves from the GSI with other sources. An overlay with Drew's data revealed that only 39 of the 67 caves recorded by the GSI in Sligo and Leitrim coincided with a cave in Drew's database. A lack of description for the caves made the GSI database less useful for the Sligo/Leitrim research area because the unnamed caves could not be correlated with the known caves from Drew's database (fig. 3.6). However, GSI data was integrated into field visits where locations fell into research areas.

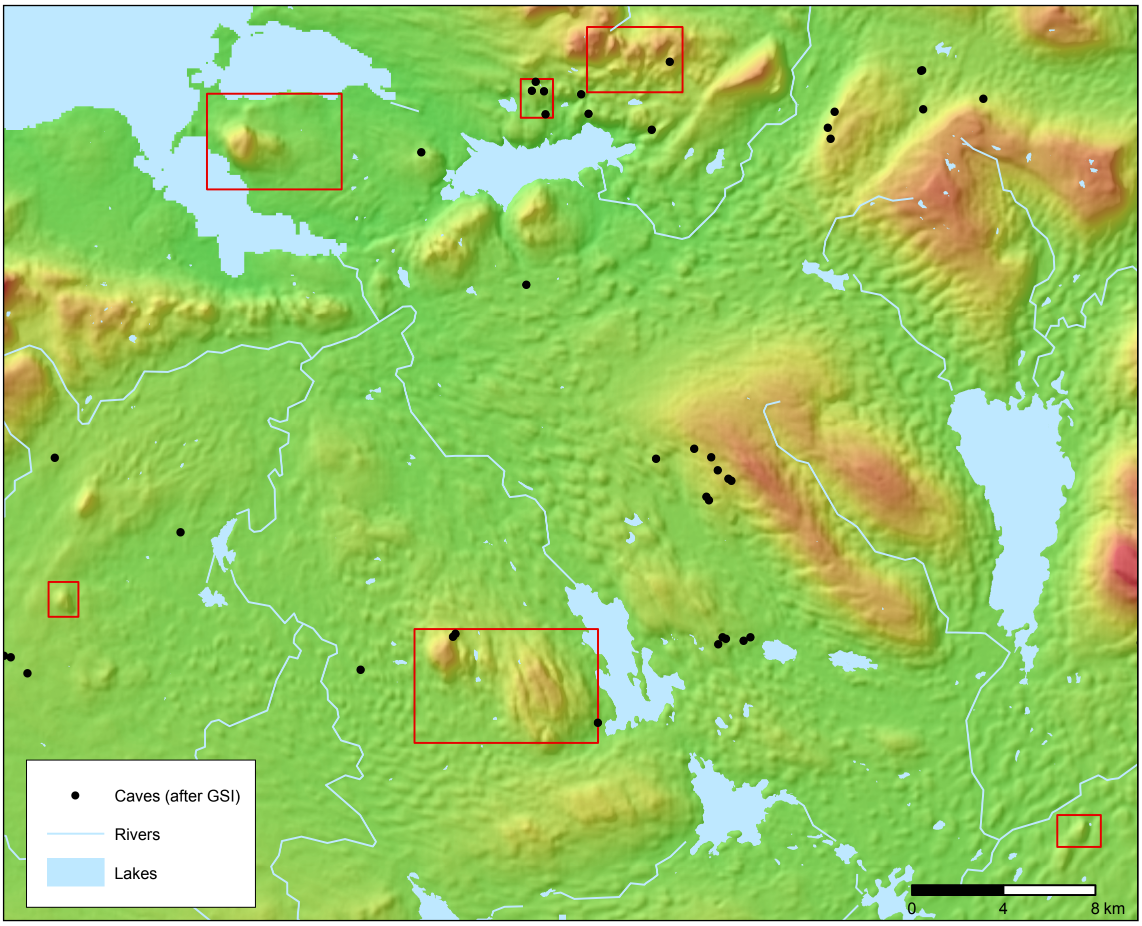


Figure 3.6: Caves recorded by the GSI in relation to the Connaught research areas.

3.2 Fieldwork

Survey equipment

Since the beginning of this century, digital equipment has progressively become widespread among cave surveyors (Cooper 2007; Warild 2007, 171). Laser distance meters (LDM) are highly portable and, unlike tape measures, suitable for accurate long-distance measurements and their ability to measure out-of-reach targets such as high narrow fissures (Cooper 2007; Day 2002, 10; Sluka 1999; Wookey *et al.* 2002). In recent years some cavers have developed their own integrated digital survey instruments that combine compass and clinometer with a laser pointer (Edwards 2004), or have modified LDM to house a clinometer (Todd 2008) and/or a digital compass unit (Heeb 2009, 172). LDM equipped with a compass only became available recently. For this project, in the absence of readily available LDM with an integrated compass, the Leica Disto

D8 was chosen as the most versatile and accurate instrument. It comprises a 360˚ tilt sensor that functions as a clinometer, and it features built-in trigonometric functions to calculate horizontal distances. A Brunton Pocket Transit compass was used for bearing measurements. The instruments were mounted on either a large tripod where cave dimensions allowed, or a small and less sturdy tripod for smaller passages. Quick release plates allowed for quick changing of tripods or instruments. A ball head and 3D head were used to level the instruments and a panning base with a 360˚ scale in 1˚ increments allowed for controlled rotation of the instrument for passage width measurements without having to use a compass again (fig. 3.7).

A RTK enabled GPS unit with an external antenna for improved accuracy and reception in areas with sub-optimal satellite coverage provided a horizontal accuracy of up to 0.02m and was used for finding caves where accurate location data was available. The device was used to record cave locations, obtain external measurements of slope inclination, set up base stations for total stations, and to record various points of interest (fig. 3.8). A waterproof survey notebook was used to collect measurements and sketches (fig. 3.9). Environmental data and notes on the caves were kept on custom survey sheets (fig. 3.10).

Figure 3.7: Cave survey equipment: 1 - digital distance meter. 2 - compass. 3 - 360˚ panning base plate. 4 - instrument bracket. 5 - large tripod with 3D head. 6 - small tripod with ball head.

Figure 3.8: Slope measurements at the Keash Caves, Co. Sligo using RTK enabled GPS.

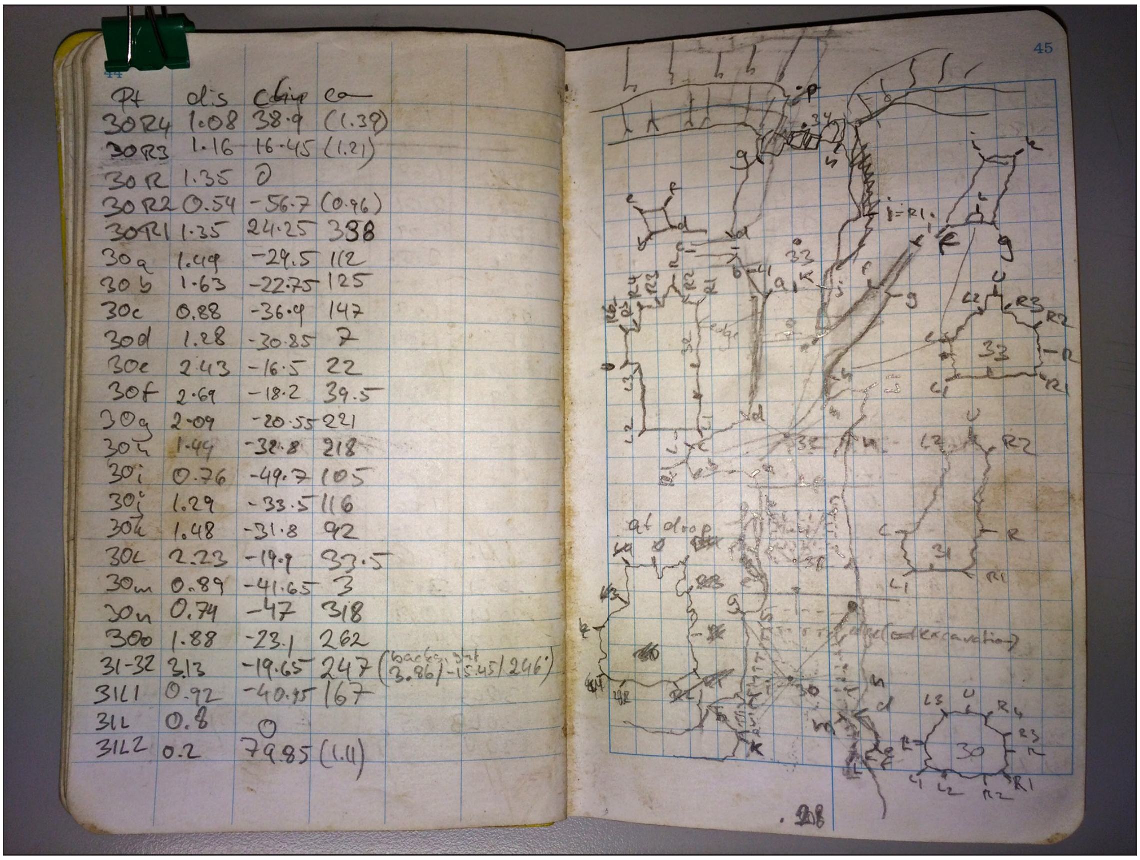


Figure 3.9: Note book used during fieldwork showing survey of Plunkett Cave, Keash. The left page shows the four data columns for point ID, distance, inclination and compass bearing.

Cave recording sheet

Date visited	County	Surveyors:
Cave Name	Td.	
GPS Location		

Owner Data:

Notes:

Pool		Stream		Speleothems		Platform	

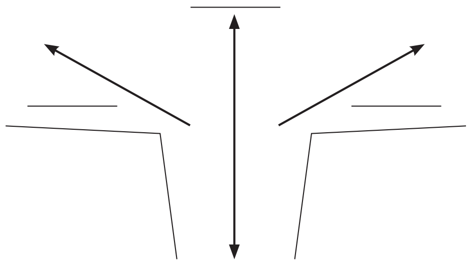
Bones:

Cave setting:

Elv.	Slope
Vegetation	

Speleothems:

FOV



Photographic Record:

Notes:

Figure 3.10: Field recording sheet for caves.

Field surveys

Fieldwork was carried out intermittently between March 2011 and December 2013. Each field visit involved the collection of a variety of data including location, setting, cave dimensions, and a photographic record. Survey instruments, a high resolution camera, multiple flash lights, tripods, RTK-GPS, protective clothing, and provisions resulted in *c.* 15kg of equipment that needed to be brought into the field on each visit.

In the course of fieldwork, inadequate location data (e.g. Drew 2006a) was corrected or completed using a RTK enabled GPS with sub-centimetre accuracy. At some locations where the local topography - such as forests or tall cliff faces - obstructed the GPS signals, or data connection failed, reading accuracy could decrease to sub-10m. Each cave was photographically recorded internally and externally. Caves less than 20m in length with low complexity were surveyed using a general base bearing with left, right, and up measurements. Larger and more complex systems received a more detailed distance, bearing, and inclination type survey with survey stations set up every two to four metres, depending on the size and morphology of the cave.

Orientation consisted of a single compass reading taken from the deepest point inside a cave where the entrance was still visible. Viewshed measurements were used to assess what potential landmarks could be observed from a cave's entrance. It consisted of two compass readings taken from the centre of the entrance; the reading was taken along the point where topographical features obstructed the distant view. Both bearings were subtracted from each other to give the general field of view. External slope was also taken as a continuous measurement from either the base of the slope leading up to the cave, or the top, just at the break of the terrain.

Surveying a cave presents a number of challenges not necessarily encountered in above ground surveys. Space restrictions prohibited the use of standard survey equipment such as a total station, theodolite, terrestrial LiDAR, and GPS in almost all caves. Constant darkness paired with muddy cave deposits, dampness, and dripping water, meant extra care was needed when taking and recording measurements. Traditional cave survey techniques as well as basic topographical survey techniques were tested to develop a suitable methodology for this project. Several trial surveys were conducted to develop the best survey strategy in terms of accuracy and time spent on each cave. Terrestrial LiDAR was not considered due to unavailability of the equipment for this research.

The British Cave Research Association (BCRA) has divided cave surveys into five different qualitative grades depending on measurement accuracy, that range from simple sketches (Grade 1) to high accuracy instrument surveys such as total station or laser scanners (Grade 6) (Day 2002; Ellis 1976, 2-7). A BCRA Grade 5 survey for larger caves and Grade 3 for smaller caves were used as standards for the surveys conducted throughout this project.

Ideally, caves are surveyed in a team of two or three people but this was not feasible for this doctoral research, which included the assessment and survey of 120 caves and potential cave sites. It was necessary to go into the field on short notice when weather conditions were good enough to ensure clear views onto distant landscape features. While receiving occasional help from volunteers, much of the survey work was done solo.

Solo surveying of caves required an extra stringent health and safety regime. Caves that required climbing up precipitous slopes or any rigging were considered unsafe to access for one person. Some caves were set in extremely dense undergrowth that was impenetrable with the amount of equipment that was required. There was also concern over interfering with wildlife, such as badgers and foxes. Upon consultation with the Irish Wildlife Trust, I was advised not to enter caves on my own that showed signs of animal occupation (fig. 3.11). GPS location and expected duration of every cave visit was forwarded to two persons and a check-in deadline of two hours after the expected duration passed was set before alarming the Irish Cave Rescue Organisation (ICRO). No incidences occurred throughout the fieldwork phase.

Figure 3.11: A badger in one of the Gully Caves near Keash, Co. Sligo.

Cave surveying is usually done manually and consists of three basic measurements: distance, compass bearing, and inclination. Measurements are taken as far into a passage as possible to minimise the amount of measurements needed. At each point, five measurements are taken: distance to the next point and a left, right, up, down (LRUD) to record the passage height and width (Day 2002, 13-4; Ellis 1976, 8). Measurement accuracy for a grade 5 survey should remain within 1cm/ 1° to minimise accumulative errors in surveys that consist of many stations (legs).

The BCRA 5 survey methodology has been developed to conduct surveys of extensive and complex cave systems that can encompass several hundred accumulative legs (survey sections) done by multiple survey teams over a long period of time (Ellis 1976, 1). The primary aim of the surveys undertaken for this thesis was to collect data for an APM and to create maps of small caves. To capture a cave's dimensions and general morphology, key measurements were taken along the cave's passage where strong morphological changes occurred, such as breaks in slope, narrowing of a passage, as well as ledges and overhangs that restrict movement.

Two different survey strategies were tested. One survey was carried out to traditional BCRA 5 standards, while a secondary survey was conducted based on topographical archaeological field survey methods. The latter utilises a base line from which offset measurements are taken using plumb line and hand tapes. This strategy works well if a cave does not skew or turn. Ceilings heights were estimated where they were out of reach. This approach was further simplified and used to survey simple straight caves and small caverns. Measurements were taken along a straight line beginning at the rear of the cave and gradually moving towards the entrance. Each leg was measured back onto a target at the rear of the cave and standard LRUD measurements provided height and width of a passage. Inclination was averaged along the passage from mouth to rear. Extra slope measurements were taken where washed in material had resulted in steep entrance slopes that led onto the actual cave floor.

The first test survey was carried out at a series of five small caves on Doons Hill, Co. Leitrim (see Appendix 1). Doons Cave 1 was surveyed using the multi-station cave survey method with compass and Disto D8 (fig. 3.12). The considerably smaller Doons Caves 2, 3, and 4 were surveyed off a base line using conventional line survey equipment. The initial survey of Doon 1 did not produce any usable results due to a number of errors made during the survey:

1. No additional notes or sketch drawings were made which would have helped to capture the general shape of the floor plan and the cross sections. A sketch drawing would also have helped to indicate the direction of the section measurements.

2. Survey stations were laid out along cave walls. Masonry nails were inserted into small fissures in the cave walls as survey stations. This led to problems sighting the bearing towards the next station as the cave hindered the exact positioning of the compass. Survey stations needed to follow a proximate central line through the cave with as much space as possible around it to allow for the compass to be sighted towards the next survey station and to allow for adequate LRUD or section measurements.

3. No tripod was engaged for measurements. A tripod should be set up above a survey station for precise compass sighting and distance measurements.

4. No backsights were taken. Systemic or reading errors could have contributed to the failed survey. By taking a backsight on each survey station, any error would have become evident immediately and corrected accordingly.

Figure 3.12: Test survey of Doons Cave 1.

The lessons learned from that survey led to the development of a new strategy which adhered more to the standard BCRA methodology for cave surveys (Day 2002; Ellis 1976). Targets were laid out centrally along the cave floor. A tripod was set up over the survey station and levelled to as close a vertical position as possible. A three-way tripod head was used for fine adjustment of the instrument bracket while a rotating platform with a one-degree scale allowed the instrument to be rotated quickly for LRUD measurements. Readings were taken as laid out above, along with sketch drawings of the cave plan and profiles, relative positions of the stations, and profile points. Stations were always surveyed consecutively and back sight measurements were used to ensure foresight measurements were recorded correctly. Additionally to the conventional LRUD measurements, several intermediate measurements were taken along each profile and labelled L1, L2, R1, R2 etc. where L and R indicated measurements taken on opposing sides of the cave wall.

Photography

Apart from plans and field recording sheets, each cave was also recorded photographically. Initially, a Canon G12 (a small, but versatile compact camera) was used to photograph caves. The size of the camera was convenient for long walks and crawling into tight spaces. However, the small sensor and slow aperture often resulted in sub-optimal pictures, especially when moisture from breathing and body heat caused the cave passage to fill with very fine mist, which caused the light from the integrated flash to bounce off the mist and reflect back into the camera (fig. 3.13). As a result, images were 'foggy' and blurred. Moisture and dirt soon crept into the camera body caused the camera to fail. A full frame DSLR camera with multiple flashguns was used to address the shortcomings of a compact camera. Positioning the flashguns independent of the camera allowed me to illuminate deeper passages or features within a cave and eliminate problems with fog. More control over aperture and exposure time paired with a large, more light-sensitive sensor, resulted in better-lit and more detailed photographs (fig. 3.14). Photographing within a cave's

Figure 3.13: The fog obscuring the view into a cave passage stems from the direct flash light reflected off water vapour that forms inside a humid cave.

Figure 3.14: Left - most of the rear of the passage remains invisible. Right - speed-lights placed along the passage reveal its full depth.

daylight zone required exposure times to be adjusted accordingly, followed by adjusting the flash light output to balance the exposure of areas outside the daylight zone. Photographs were taken in RAW format and edited in Adobe Lightroom and Adobe Photoshop. Photos were edited to compensate for lens distortion and chromatic aberration, to balance light and dark areas, and to adjust for contrast, exposure, sharpness, and saturation.

Integrating a total station into cave surveys

The Keash Caves is the most complex cave system within the North Connaught research areas. It comprises 21 cave entrances with a combined passage length of more than 600m. Individual cave dimensions varied from large chambers of over 4m in width and height to tight passages barely large enough to accommodate a person of small stature (as opposed to the author). The entrance chambers of Caves D, E, F, J, and K were large enough to set up a total station, while smaller sections of caves were surveyed using the adapted BCRA 5 standard. For the larger parts, a reflector and, later, a reflectorless total station were used. Using non-permanent spray paint, the deepest reaches of the total station were marked along the cave passages. These markers acted as reference points to tie-in the manual surveys for the remaining cave sections. A reflectorless total station was also used to survey and subsequently draw the dimensions of the cave entrances.

The survey of the complex Keash caves married together three different survey techniques: manual tape and compass, reflector based, and reflectorless total station survey. Each had their advantages and disadvantages. The manual survey technique, being the most basic, allowed for the survey of even the most restricted sections of the Keash system but was also the one most prone to errors. Reflector based total station surveys were fast, accurate, and output was in NGR xyz files but only applicable to chambers large enough to accommodate the instrument. The reflectorless total station proved the more versatile as it could be aimed at the lofty ceilings of Keash Caves D, E, and F. The uneven surface of the limestone often caused the instrument to stall or to deliver reading errors and often required multiple attempts before a reading was taken.

Each survey method employed at the Keash Caves was most suitable for the task at hand, but also posed individual challenges. In my opinion, a combination of reflectorless total station with the use of an optional reflector plus an integrated clinometer, distance, and compass unit such as the DistoX (Heeb 2011) is the most advantageous set-up for detailed cave surveys. A recently published evaluation of these survey methods supports this recommendation (Ballesteros *et al.* 2015), and this combination probably secondary only to advanced terrestrial LiDAR techniques (Lerma *et al.* 2010).

3.3 Digitising cave survey data

Digitising consisted of several editing steps during which the raw data from the survey notebook was transferred into a spreadsheet, converted into grid coordinates, transferred into a GIS, and finalised in a vector illustration application.

The base station or station 0, located outside the cave, was grid-referenced to allow the plan to be displayed in ArcGIS in its correct spatial context. Manual measurements from the compass, distance, and inclination surveys were copied into a customised Excel spreadsheet that converted raw measurements into Irish National Grid (ING) coordinates in a xyz format. In a final step, the xyz file was imported as a point feature class in ArcGIS where the points were used to create the final line drawings.

The spreadsheet for the automatic conversion into ING consisted of two tables. However, as ING has now superceded by ITM, all coordinates are given in both systems in Appendix 1. The principal data table (table 3.1) consisted of twelve columns: five contained raw measurement data, one contained a constant for declination adjustment, and the remainder were used to calculate the grid reference. The second table contained the instrument height at different stations. Each subsequent measurement was associated with its correct predecessor. A simple sequential approach, where each subsequent row related to the previous one, could not be used since several measurements were taken from the same point. For example, sequential measurements were taken at single passages (1 -> 2; 2 ->3 etc.) but at passage crossings, several measurements radiated out into the different galleries and passages from a single point (1->2; 1->3; 1->4; followed by 2->5; 5->6 *etc.*). The [VLOOKUP] command was ideal to query data columns for specific point IDs to find a specific data point at any location within the spreadsheet. It was also used to find corresponding station heights that were stored in a separate table.

J3 =SUM(VLOOKUP(A3,I:L,2,FALSE),G3)

	A	B	C	D	E	F	G	H	I	J	K	L
1	@ Station	To Station	Hor Dis	Clino	Comp	comp adj	x	y	PT	E	N	Z
2									STNL	170591.73	312110.61	170.28
3	STNL	1	2.47	-24.55	92.5	82	2.45	0.34	1	170594.18	312110.95	170.03
4	STNL	S	2.05	-14.6	13.5	3	0.11	2.05	S	170591.84	312112.65	170.63
5	STNL	S	1.99	-14.45	169	158.5	0.73	-1.85	S	170592.46	312108.75	170.65
6	1	2	2.97	-8.15	99	88.5	2.97	0.08	2	170597.14	312111.03	170.34
7	1	1L1	0.99	-34.55	9	-1.5	-0.03	0.99	1L1	170594.15	312111.94	170.08
8	1	1R1	1.25	-29.6	189	178.5	0.03	-1.25	1R1	170594.21	312109.70	170.05
9	2	3	2.06	-6.45	107	96.5	2.05	-0.23	3	170599.19	312110.79	170.78
10	2	2L1	0.73	-35	17	6.5	0.08	0.73	2L1	170597.23	312111.75	170.51
11	2	2R1	0.92	-32.4	197	186.5	-0.10	-0.91	2R1	170597.04	312110.11	170.43
12	3	4	2.72	-6.4	96	85.5	2.71	0.21	4	170601.90	312111.01	171.16
13	3	5	0.95	-26.6	178	167.5	0.21	-0.93	5	170599.40	312109.87	170.99
14	3	3c	0.74	-29	27	16.5	0.21	0.71	3c	170599.40	312111.50	171.05
15	3	3e	1.29	-23.45	352	341.5	-0.41	1.22	3e	170598.78	312112.02	170.90
16	3	3b	2.42	-6.5	345	334.5	-1.04	2.18	3b	170598.15	312112.98	171.19

Table 3.1: Data calculation sheet. Input fields are orange with black characters; output fields are grey with orange characters.

The data columns illustrated in table 3.1 contained the following data:

A: From station number (origin)

B: To station number (current)

C: Distance

D: Inclination

E: Compass bearing

F: Declination adjusted compass bearing

G: Difference between previous and current x coordinate:

=+SIN(PI()*G3/180)*C3

H: Difference between previous and current y coordinate:

=(+COS(PI()*G3/180)*C3)

I: Point ID: =B3

J: National grid easting (E) calculation:

=SUM(VLOOKUP(A3,J:M,2,FALSE),H3)

K: National grid northing (N) calculation:

=SUM(VLOOKUP(A3,J:M,3,FALSE),I3)

L: Elevation OD (Z) calculation:

=(VLOOKUP(A3,J:M,4,FALSE)+F3)+(TAN(PI()*D3/180)*C3)

The conversion of raw measurements into xyz coordinates was achieved using standard trigonometric functions. Inclination and compass bearing were measured in degrees but to apply Excel's trigonometric functions, they were converted into radians. This was achieved using $x = \frac{y\pi}{180}$ where *y* is the measured inclination in degrees and *x* the inclination in radians. If θ needs to equal *x* then $\left[\sin\left(\frac{y\pi}{180}adj\right) = hyp\right]$. The resulting value (*x*) was then added to the previous NGR easting (E).

The value for the northing (*y*) was calculated using the cosine function where θ was the compass bearing, *hyp* the horizontal distance (*hor dis*) and *adj* the distance from one station to the next along the NS axis (*x*). Incorporating the conversion to radians the equation was $\left[\cos\left(\frac{y\pi}{180}adj\right) = hyp\right]$. The resulting value (*y*) was then added to the GPS northing of the previous point and the value displayed in the column adjusted GPS northings (N).

Elevation values (*z*) were calculated using the Pythagorean function $b = \sqrt{c^2 - a^2}$ where *a* is the horizontal distance (*hor dis*), *c* distance (*dis*), and *b* the elevation of station^{n+1}. The result was added to the elevation column.

Each surveyed cave received a unique catalogue identification number (Cat_ID). The Cat_ID functioned as the key to all collected data for a cave and could be used to relate and join different database tables during compilation and analysis.

Survey data that was stored on instruments (GPS, total station) was exported as csv (comma separated values) files and imported as a feature class into ArcGIS. Data from field notes and surveys was added to the principal cave database via excel spreadsheets and matched to the Cat_ID.

3.4 Data acquisition and analysis for the Munster correlative-inductive model

A correlative-inductive approach was chosen to explore the relationship between environmental factors and Neolithic cave use in Munster. Predictive modelling uses independent or predictor variables to predict an outcome or dependent variable. The dependent variable can be continuous, ranked, or categorical. In archaeological predictive modelling, the outcome is often a binary category: site present or site absent (Altschul 1988; Kohler 1988; Kvamme 1990; Rose and Altschul 1988). More recently, fuzzy logic and multivariate analysis have been used to create three or more categories that can distinguish various probabilities (high, medium, low *etc.*) (Hatzinikolaou 2006; Jasiewicz and Hildebrandt-Radke 2009; Kvamme 2006). These categorisations are useful in cultural resource management (CRM) where probability surfaces assess entire geographic regions for their archaeological potential. For the Munster model, small sample sizes and non-parametric nature of the data limited the choices of which analysis could be applied and not always is it considered useful to load a model with complex statistical functions (Whitley and Burns 2008, 7). Binary logistic regression is the most commonly used statistical analysis in archaeological predictive modelling because it is robust and makes no assumptions about the data (Kvamme 1988a, 1990; Rose and Altschul 1988). Like other statistical analyses that make predictions, a calibration set or training group is required with known outcomes (*e.g.* archaeological site present vs. site absent) to evaluate and weigh independent variables against which samples of unknown outcome can be compared. In this case, the training group was:

- Caves used during the Neolithic (Group 1)

- Caves not used during the Neolithic (Group 0)

The correlations between environmental variables and the presence or absence of Neolithic archaeological caves within the training group could then be used to calculate a likelihood ratio of Neolithic archaeological material occurring in the target group of caves of unknown archaeological status, i.e. caves that have not been investigated and for which no archaeological discoveries are known (Group 3 from hereon).

For Group 1, a reference collection was compiled that was used to develop a standard profile for means, frequencies, and distributions of caves that were used during the Neolithic. Dowd's research on archaeological material from Irish caves (1997, 2002, 2004, 2008, 2014; 2015) was used to isolate those that were used during the Neolithic. The aim was to only include caves that produced material indicative of use that went beyond shelter and short-term occupation. Existing literature and reports were evaluated and the body of caves was divided into two groups:

1 - Caves that were definitely used during the Neolithic

2 - Caves where evidence was insufficient for a definite classification

The latter group was excluded from the calibration set and moved to Group 3 (target group). For example, a polished sandstone axe from Cappagh Cave, Co. Waterford is possibly of Neolithic date, but the circumstances that led to its deposition remain inconclusive (Dowd 2015, 114).

Inclusion criteria for Group 1 were:

A - Cave must be within the modelling area (Clare, Cork, Limerick or Waterford)

AND

B - Location must be grid-referenced to at least the first order of magnitude (within 10m)

AND

C - More than one human bone must be present

AND

D - At least one radiocarbon date must fall into the Neolithic

OR

E - Neolithic artefacts must be present where only one human bone is present

OR

F - Results from excavation/investigation must strongly suggest Neolithic activity

Criteria B had to be met to ensure correct sampling of environmental data in the GIS. Criteria C was applied to make sure that no cave was included in Group 1 where a single human bone of Neolithic date was formed that could have been deposited by natural agents or introduced at a later date. To eliminate the possibility that human bones were not later insertions, at least two of the subsequent criteria (C - F) had to be met for a cave to be included in Group 1 (fig. 3.15). Caves such as Elderbush Cave, Co. Clare, Kilgreany Cave, Co. Waterford, or Annagh Cave, Co. Limerick met all five criteria and were placed in Group 1. Caves such as Grange Hill Cave, Co. Limerick, Brothers' Cave, Co. Waterford, or Alice and Gwendoline, Co. Clare required more consideration to be included. Finds were either of a single artefact type (polished stone axes in the case of Grange Hill Cave) or the body of finds was inconclusive (no Neolithic dates from human bones in the case of Alice and Gwendoline). However, the quality and context of the finds from Alice and Gwendoline strongly suggests that they are likely the result of human activities during the Neolithic (Dowd 2015, 121-2).

Group 0 included all caves that were excavated in the past but where no Neolithic material was found. It is inherently difficult to prove with certainty the absence of activity through excavation. Firstly, caves are only ever partially excavated, varying from a few small test trenches to the removal of large portions of deposits, but there is always a possibility that significant finds remain undiscovered. Even if 100% of a cave were excavated, an absence of Neolithic archaeology does not automatically imply that no activities took place at the site, however it makes it less likely. For his predictive model for archaeological caves in the Peak District and the Yorkshire Dales (Holderness *et al.* 2007), Chamberlain used a subset of all caves where no archaeology has been found as the 'non-site' group in the

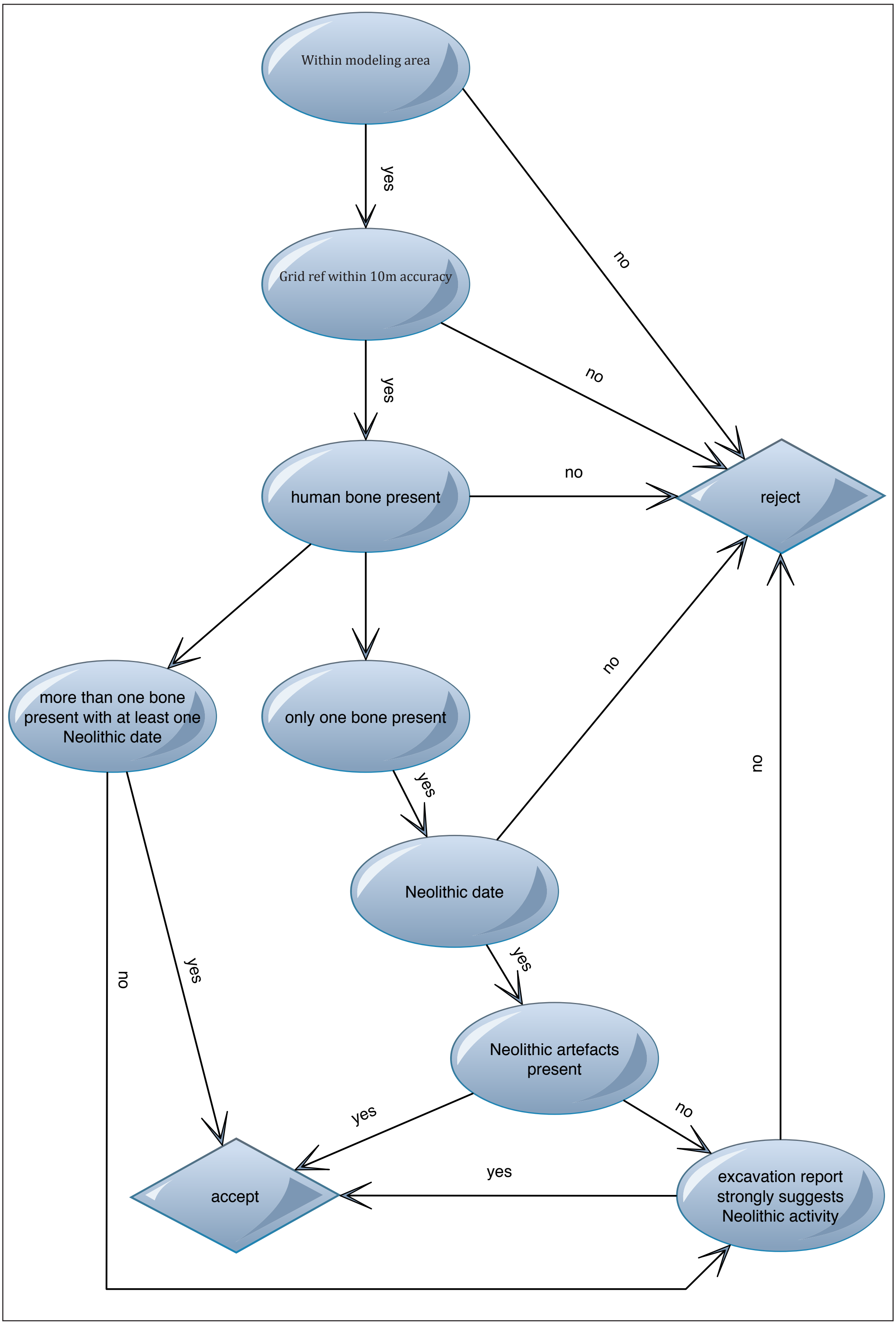


Figure 3.15: Flow chart illustrating inclusion criteria for Neolithic caves into the predictive model.

calibration set. While this is common practice in archaeological predictive modelling, it has been criticised elsewhere as these assumed non-sites may contain undetected actual sites and thus compromise the calibration set (Woodman and Woodward 2002). The use of at least partially excavated caves, where no Neolithic archaeology was found, reduced this possibility of misclassification. Similar to Group 1, the data derived from caves that did not yield Neolithic archaeology was used to generate an environmental profile of caves that were not used during the Neolithic. Dowd (2004, 2015) identified and isolated this group. Additionally, other sources, such as the Irish Excavations database (http://www.excavations.ie/), were consulted along with available reports and literature on antiquarian as well as modern archaeological cave excavations within the target area.

All inclusion criteria had to be matched for a cave site to be included in this group. Inclusion criteria were:

A - Cave must be within the modelling area (Clare, Cork, Limerick or Waterford)

AND

B - Location must be grid-referenced to at least the first order of magnitude

AND

C - Excavations did not produce Neolithic material

Group 3 comprised caves of unknown status that were evaluated in the predictive model. To be included in this group, the caves had to meet all inclusion criteria:

A - Cave must be within the modelling area (Clare, Cork, Limerick or Waterford)

AND

B - Caves must be grid-referenced to better than 100m accuracy (5 digit easting/northing)

AND

C - Grid reference must be unique (no clustering of caves at exact location)

AND

D - Cave must be accessible (i.e. not high up in a cliff, no deep vertical shafts, unblocked, not submerged)

AND

E - Cave must be relict (no resurgence, sink, tidal or river caves)

Clustering of caves on the same grid reference or notation of grid references above 100m (4 digit easting/northing) suggested insufficient location accuracy. Because location data for caves was collected by different people, means and often a considerably long time ago, this method was the only means to filter out location data that was obviously notated at a low resolution. Two major sources were used to source location data for caves in the target area. Building on earlier work by Tratman (1969) and Self (1981), Mullan (2003) updated a catalogue of caves for Co. Clare listing NGR mostly to the first order of magnitude, and altitude for each cave. Oldham (1981) compiled a guide to the caves of Co. Cork, which was recently updated by Bunce and Barry (2011). Cave locations for the remaining caves in Limerick and Waterford were derived from various publications (Coleman 1965; Dowd 2015; Drew 2006a; Ryder 1989; Thomas 1995; Williams 1966).

Material of Neolithic and potential Neolithic date from Irish caves

Quantity, type, quality and find circumstances of recovered material from caves can vary and have a significant impact on interpretation and classification of the possible activity associated with them. Complexity of archaeological finds ranged from isolated chance finds to fully excavated burials along with grave goods. In order to assign caves to the correct groups, finds quantity and quality as well as find circumstance for each cave that had produced Neolithic material were assessed.

Where Neolithic artefacts occur in small isolated quantities, it cannot be ruled out that they are later secondary deposits. This is mostly the case where a polished stone axe or a lithic occurred without any other associated material and where later activity, predominantly Bronze Age or Early Medieval, offers an alternative explanation for their occurrence (Dowd 2015, 114).

Table 3.2 summarises the nature of the funerary activities and artefacts from caves with the resulting selection of caves included in Group 1. The categorisation of human remains and archaeological materials was based on Dowd's catalogue (2004) but followed a conservative approach, which does not follow her classifications for excarnation and token depositions.

Cave Name	County	Burial	excarnation	token / secondary	grave goods	Neol. artefacts (not ass. with human remains)	Excavated	Human bones	Neol. lithic	Neol. stone axe	Neol. pottery	Neol. Date	worked animal bone	Inclusion criteria met
Alice and Gwendoline Cave	Clare	yes	yes	no	no	yes	yes	yes	2	no	no	no	yes	yes
Annagh Cave†	Limerick	yes	yes	yes	yes	no	yes	>300 (5 MNI)	2	no	yes	yes	yes	yes
Ballynamintra Cave	Waterford	yes	no	no	no	yes	yes	40	no	1	no	yes	no	yes
Barntick Cave	Clare	yes	no	yes	no	no	yes	3	no	no	no	yes	no	yes
Bats' Cave	Clare	no	yes	yes	no	yes	yes	>1	no	no	yes	yes	yes	yes
Brothers' Cave	Waterford	no	no	no	no	yes	yes	>1	1	1	yes	no	yes	yes
Carrigmurrish Cave	Waterford	no	no	yes	no	no	yes	1 -> skull!	no	no	no	yes**	no	yes
Connaberry Cave C	Cork	yes	no	yes	no	no	yes	15	no	no	no	yes	no	yes
Elderbush Cave	Clare	no	yes	yes	no	yes	yes	>50	1	no	no	yes	yes	yes
Grange Hill Cave	Limerick	no	no	no	no	yes	no	no	no	>1	no	no	no	yes
Kilgreany Cave	Waterford	yes	yes	yes	yes	yes	yes	>100 (9 MNI)	4	1	no	yes	yes	yes
Killavullen Cave 3	Cork	yes	no	no	no	no	yes	25	no	no	no	no	no	yes
Killuragh Cave	Limerick	no	yes	yes	no	yes	yes	1	2	1	no	yes	no	yes
Knocknarea Cave K	Sligo	no	yes	no	no	no	yes	13	no	no	no	yes	no	yes
Oonaglour Cave	Waterford	?	?	?	no	yes	yes	>1	no	3	yes	yes	no	yes
The Catacombs	Clare	no	no	no	no	yes	yes	>50	>1	no	no	no	yes	yes
Badger Cave	Cork	no	no	no	no	yes	yes	no	1	no	no	no	no	no
Boat Cave	Antrim	no	no	no	no	yes	no	no	6	no	no	no	no	no
Cappagh Cave	Waterford	no	no	no	no	yes	no	no	no	1	no	no	no	no
Cloghermore Cave	Kerry	no	no	no	no	yes	yes	> 1	no	no	no	no	no	no
Killura Cave†°	Cork	?	?	?	no	no	yes	3	no	no	no	yes		no
Knocknarea Cave C	Sligo	?	?	?	no	no	no	1	no	no	no	yes	no	no
Moneen Cave	Clare	no	no	no	no	yes	yes	no	1	no	no	no	no	no
Plunkett Cave	Sligo	no	no	no	no	yes	yes	no	no	1	no	no	no	no
Portbradden Cave	Antrim	no	no	no	no	yes	yes	>1	6	no	no	no	no	no
Quinlan's Quarry Cave†	Waterford	yes	no	no	no	no	yes	>1	no	no	no	yes	no	no
Red Cellar Cave°	Limerick	no	yes	no	no	no	yes	3	no	no	no	yes	no	no

**potentially suspect, depleted   †cave destroyed   °location not known

Table 3.2: Inclusion assessment based on qualification criteria. Evaluations displayed were highly conservative, i.e. some caves classified as containing no burial or no grave goods may have been interpreted differently elsewhere.

Funerary activities in Irish caves can be divided into three categories: inhumation, excarnation, and secondary, or token deposits (Dowd 2008; 2015, 95-101). However, in many instances the data is incomplete, because either the cave was never excavated, only partially excavated, or it was excavated by antiquarians. This makes a clear distinction, particularly between excarnation and secondary deposits, difficult or impossible, where the assemblage consists only of a few surviving remains.

Artefacts can be found as grave goods associated with inhumations or as isolated occurrences where contemporaneous human remains are absent or where a clear association could not be made. This is often the case where sediments were disturbed by later human activity or natural agents. Caves that were used for habitation during the Neolithic are not known in Ireland. Only two sea caves on the Antrim coast may have been used as short-term shelters (Dowd 2015, 120-1).

Independent variables

Independent variables or predictor variables interact and change the outcome of the dependent variable, in this case the probability of whether a cave was used during the Neolithic or not. If a relationship exists then a change in the value of a predictor variable causes a change in the outcome variable. The strength of the relationship is defined by a coefficient that reduces the change an independent variable can cause in the outcome of the dependent variable.

Freely available data on soil, geology, topography, and archaeology are popular in archaeological predictive modelling as they are already optimised for GIS (available either as shapefiles or spreadsheets).

Soil types

Soil types supply information about general make-up, acidity, and drainage that can be useful in predicting past settlement and farming activity. For example, in their archaeological predictive model, Legg and Taylor (2006) established soil, along with elevation and slope, as the most probable factors to have influenced the location of ringforts in the Irish landscape. They identified five out of ten different soil types prevalent in the Inny River catchment, Co. Meath, that correlated with the occurrence of ringforts. High regression coefficents for these soil types (β = 0.718-1.563) made them the dominant predictors over slope (β = 0.74) and elevation (β = 0.024). It seems plausible that good agricultural soil on level, low-lying land would have been the preferred landform to establish a farmstead. But would soil types and soil wetness have been a noticeable factor in the selection of caves for religious activities and funerary rites during the Neolithic? There does not seem to be any reason to assume that these factors would have played a role in choosing a particular cave for activity. Cave sediments differ very much from soil types on the outside and, unlike agricultural activity, religious rituals, and funerary rites do not require a particular soil type to be carried out successfully. However, this rejection derives from a modern perspective and assumptions about past behaviour. Testing the hypothesis that soil types did not influence cave use during the Neolithic statistically makes the answer quantifiable.

Free GIS data sets from the Environmental Protection Agency (EPA) for Ireland were available for soil-types, subsoil-types, and soil wetness (http://gis.epa.ie).

The EPA provided three different data sets that relate to drainage, topsoil type, and subsoil type. The latter two also extend to soil acidity. The soil classes were abbreviated and further re-coded into numeric variables for statistical analysis (tables 3.2, 3.3, 3.4).

Soil - soil formation is influenced by several factors such as underlying geology (parent), slope, vegetation, and drainage. The latter two are particularly subject to anthropogenic interference resulting from land drainage and agriculture (Fealy and Green 2004, XII - XIII). The data set was divided into 12 categories and 26 sub-categories, including categories for water bodies (Water) and absent classification (A). Nine of which occurred within the research areas.

Subsoil - the subsoil type influences the formation of topsoil and is less prone to anthropogenic influence. The data set was divided into 41 categories, including categories for water bodies (Water) and absent classification (A). Eight of which were present within the research areas.

Soil Code	Soil Type	Code
AminDW	Deep Well Drained Acidic Mineral	11
BminDW	Deep Well Drained Basic Mineral	12
AminSW	Shallow Well Drained Acidic Mineral	21
BminSW	Shallow Well Drained Basic Mineral	22
AminPD	Deep Poorly Drained Acidic Mineral	31
AminSRPT	Acidic Podzols (Peaty), Lithosols , Peats	43
BminSRPT	Basic Lithosols, Peats	64
AlluvMIN	Mineral Alluvium	51
FenPt	Fen Peat	66

Table 3.3: Coding for soil type

Soil wetness - classifies the soil by its drainage properties and is divided into six categories including categories for water bodies (Water). For of which ocurred within the research areas.

Soil Code	Soil Type	Code
FenPt	Fen Peat	1
GLs	Limestone sands and gravels	2
KaRck	Karstic Rock	3
Rck	Rock	4
TDSs	Sandstone till	5
TLs	Limestone till	6
TNSSs	Shales and sandstones till	7
GDSs	Sandstone sands and gravels	9

Table 3.4: Coding for subsoil/ bedrock

The EPA data was extracted as nominal data and re-coded as numeric categorical data in SPSS. An alternative way of coding would have been the establishment of a ranked set in which well-drained soil would have been ranked higher than poorly drained soil.

Type	Well Drained	Alluvial Minerals	Poorly drained	Peats
Code	3	1	5	2

Table 3.5: Coding for soil wetness

However, initial Kolmogorov-Smirnov (K-S) tests did not show any significant difference between the two calibration groups (p>0.05) and soil data were ruled out as possible predictor variables (see section 4.3).

Distance to freshwater bodies is a recurring variable in archaeological predictive modelling (Custer *et al.* 1986, 573; de Vries 2008, 4; Graves 2011, 634; Holderness *et al.* 2007, 96; Kvamme 1988b, 335; Legg and Taylor 2006, 208). Likewise, Dowd (2015, 122-3) proposed a potential correlation between caves of the Edenvale-Newhall complex and Edenvale Lake which may have served as a secondary funerary location. However, Chamberlain's model detected a negative correlation between archaeological caves and water, insofar as caves in the Peak District showed a tendency to be further away from freshwater sources (Holderness *et al.* 2007, 96). Initially, data for water sources was obtained from the EPA but the data for rivers has proven to be highly inaccurate at the scale used (fig. 3.16). Higher accuracy data for rivers is available from the OSI but these were not accessible for the Munster Predictive Model due to their high cost. Distances to water sources were measured manually within ArcMap for the 31 caves in the training group. One nominal and four continuous datasets were created to detect relationships between different water bodies and the training group:

1. Distance to stream - measured in metres, distance between target cave and the nearest second class flowing water body
2. Distance to river - measured in metres, distance between target cave and the nearest first class flowing water body

3. Distance to lake - measured in metres, distance between target cave and nearest lake

4. Distance to nearest water - measured in metres, nearest distance to a freshwater source (lake, river or stream)

5. Nearest water class - categorical, nominal variable classifying the nearest freshwater source (lake, river, or stream)

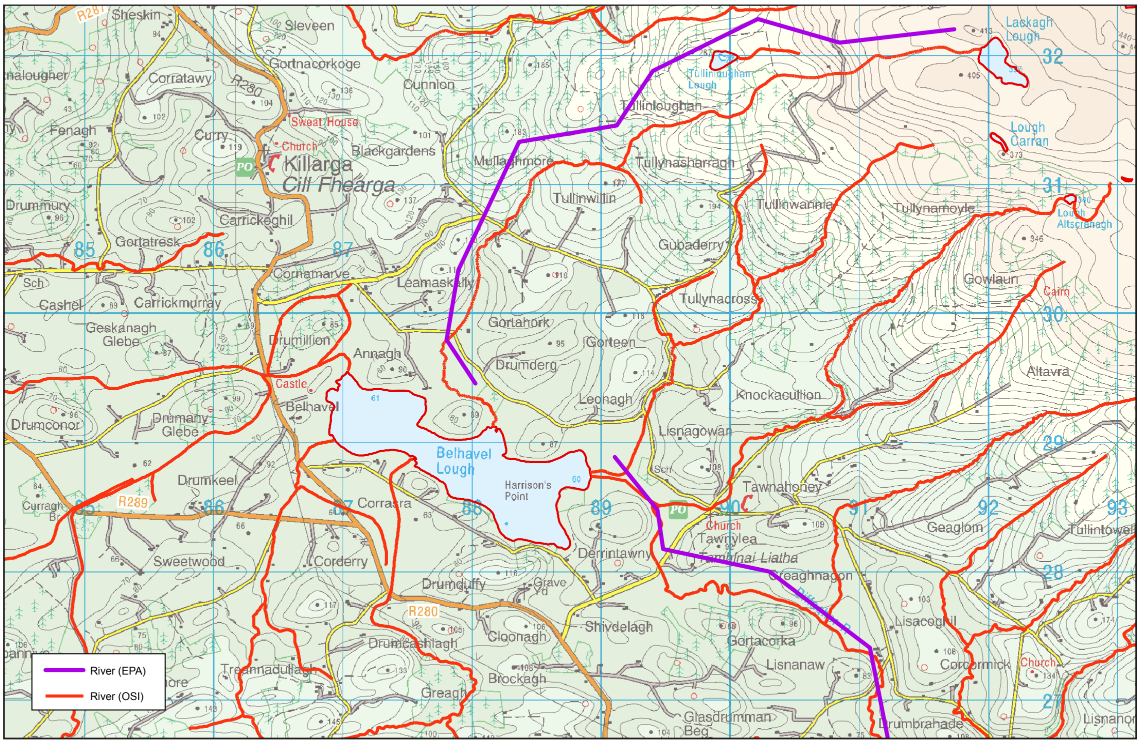


Figure 3.16: Example of river courses (after EPA and OSI).

Multinominal categorical data was re-coded into different numerically coded categories (e.g. lake → 3; river → 2 *etc.*) that were later re-coded into binominal dummy variables (lake present: yes/no).

Data for elevation, slope, and aspect was calculated from the freely available global digital elevation model (DEM) from the NASA Shuttle Radar Topography Mission (SRTM). The SRTM derived DEM has a three arc second ground resolution, which translates to *c*. 90m data resolution between 51° and 55°N with an absolute height error of 6.5m (3.7m STD) (Rodriguez *et al.* 2005). The ground resolution of 90m is 1/16 lower than comparable

DEMs available from the OSI, which can lead to errors due to averaging of spot heights within a grid square (pixel). However, this pitfall may be relativised by inaccuracies in cave location data. The lack of topographical contrast, such as steep slopes on mountains or deep valleys, probably kept differences between calculated heights and actual heights low. However, errors could not be quantified and thus not accounted for. DEM data was converted to raster DEM in ArcGIS at a ground pixel resolution of 90m. From this data set, three different independent variables were calculated. Slope and aspect data was computed with ArcGIS raster tools for aspect and slope at a ground pixel resolution of 90m. The OSI offers a DEM with a ground pixel resolution of 30m. These data were only available to the author for Co. Sligo and partially for Co. Leitrim.

ELV - elevation data was obtained in metres (m) from the DEM. The 'Add Surface Information' tool of ArcGIS instead of the 'extract' tool was used to derive elevation data. While the 'extract' tool simply reads out the elevation value from the raster surface of the DEM at the relevant xy coordinate, the 'Add Surface Information' uses bilinear interpolation to derive a more accurate value.

ASP - aspect data calculated from the DEM using the ArcGIS 'Aspect' tool. It calculates the orientation in degrees of downslope based on the height differences of neighbouring raster data. The algorithm used by ArcGIS $aspect = \left(axis_{cellsize} * 8\right) atan2\left[\left(\frac{dz}{dy}\right), -\left(\frac{dz}{dx}\right)\right]$ where *d* is the rate of change (delta). *X*, *y*, *z* refer to the three dimensional coordinates and axis stands for either the x or y coordinate. The resulting data is stored as 360° compass directions in a raster surface. *Aspect* reflects the general orientation of the terrain in which a cave is located but not necessarily the orientation of the cave passage itself.

A nonlinear measurement such as the 360° absolute compass direction posed a challenge for statistical analysis. The values 1° and 359° describe, within a 2° margin, the same cardinal direction north, whereas 90° and 270° are directional opposites but numerically closer to each other than the former northern bearings. SPSS cannot process non-linear scale measurements and a work-around had to be devised. The linear measurements were converted into eight categories representing the cardinal directions north, northeast, east, southeast, south, southwest, west, and northwest each representing a 45° section of the compass scale starting at 12.5° (east-northeast) and treated as categorical data. These were later reduced to four categories, representing north (315°-45°), east (45°-135°), south (135°-225°), and west (225°-315°), due to under-population of the eight group categories. ArcGIS 'Extract to Multiple Points' script was used to read out aspect values from the raster surface and recoding into categorical data was done in SPSS.

SLP - slope of the ground surface, calculated from the neighbouring raster data using ArcGIS' 'nearest' tool. The tool calculates rates of changes between adjacent raster cells using the algorithm where *d* is the rate of change (delta); *x*, *y*, *z* refer to the 3 dimensional coordinates and *axis* stands for either the x or y coordinate:

$$slope_{\deg rees} = ATAN\left(\sqrt{\left[\frac{dz}{dx}\right]2+\left[\frac{dz}{dy}\right]2}\right)*\left(axis_{cellsize}*8\right)$$

The resulting slope data was obtained in positive degrees (°) ranging from 0° to 90° and stored in a raster layer. ArcGIS' 'Extract to Multiple Points' script was used to read out aspect values from the raster surface.

After data extraction from the described data sources in ArcGIS, all data was exported to an Excel spreadsheet to be transferred into a statistical software package.

Data analysis with SPSS

All analysis for correlative-inductive modelling was done with SPSS statistical software package. ArcGIS spatial analysis and spatial statistics tools only offered limited functionality for data with binominal outcomes. Spatially weighted logistic regression and exploratory spatial regression require numerical outcome variables in the form of discrete or continuous measurements, which did not apply to the Munster Predictive Model.

Descriptive and exploratory analysis provided a first impression of the nature of the collected data. Histograms, frequency tables, and pie charts were applied as visual aids in the identification of initial trends. From an overall picture of the data, different groups were discriminated based on archaeological status and geography. Kolmogorov-Smirnoff (K-S) tests for normality suggested highly non-parametric distributions for continuous measurements. Furthermore, large differences in measurements between continuous variables (below 200m for altitude vs. several 1,000m for distance to Neolithic monuments) required Z-transformation on all continuous data to normalise scores and reduce the effects of skew and Kurtosis (Field 2009, 153-64; Rose and Altschul 1988, 186).

Binary logistic regression is the most commonly used tool in archaeological predictive modelling and was best suited for non-parametric data with a binary outcome variable. Related to linear regression, binary logistic regression is not a linear function of the input but logarithmic and is expressed as the odds ratio log(p/1-p), where p is the probability that an event occurs and 1-p is the probability that an event does not occur; the resulting value always ranges from 0 to 1 (Graves 2011, 637; Press and Wilson 1978). Chamberlain applied discriminant function analysis in his predictive model for caves in the Yorkshire Dales and Peak District, UK (Holderness *et al.* 2007, 12-3). However, discriminant function requires the predictor variables to be continuous as well as normally distributed (Press and Wilson 1978, 700). Both requirements were not met for the majority of the data used in the Munster Predictive Model.

In a first run, all variables were included in the model to identify the strongest predictors for the model. Because of the small sample size per group (n= 16/17), the model was limited to two predictor variables. Thus, the four variables with the highest impact on the outcome and lowest between-variable dependency were selected for further computation. Different combinations of two independent variables were run to find the best fitting model.

Cross tabulation and correlation analysis were employed to explore the distribution of frequencies and identify possible dependencies between predictor variables that showed the highest correlation with the outcome variable. Dependencies between predictor variables needed to be minimised as they reduce a model’s predictive ability. Cross tabulation was used to perform χ^2 tests to explore associations between categorical data (significant at $p<0.05$) while correlation analysis was used for the same purpose on continuous measurements (significant at $p<0.05$). The aim was to have greatest independence between predictor variables while achieving the highest R^2 and correct predictions within the calibration group.

The final model was applied to Group 3, which added two values to the dataset: the odds ratio and predicted group membership (e.g. Group 1 or Group 0). The group membership was determined by the odds ratio, which ranges from 0 to 1 and at a cut-off point of 0.5. Model results are presented in Chapter 4.5.

3.5 Methodological framework for the North Connaught cognitive-deductive predictive model

The concept of a cognitive-deductive approach uses generalised yet not fully conceptualised or less scientifically quantifiable variables to make its predictions (Kohler 1988, 64). Rather than using clearly defined categories or working with continuous measurements that can be summarised, averaged and given standard deviations, intuitive models rely on inferences that derive from less clearly defined categories such as '*the preferred cave type consisted of a simple long narrow passage*' (Dowd 2008, 311). The terms 'long' and 'narrow' are not directly quantifiable and researchers have to rely on their intuition and knowledge to correctly categorise a cave. This approach is useful when working with rare site types where quantitative statistical analysis would produce unreliable results.

Ultimately, the limitations posed by the nature of the available quantity and geographical separation made the development of a correlative-inductive predictive model unfeasible. The cognitive-deductive approach offered a means to filter out caves that were unlikely to have been used during the Neolithic. Caves that were used for ritual activities other than in a funerary context are few and little understood, which makes find circumstances of artefacts such as those from Brothers' Cave, Co. Waterford difficult to interpret. The artefact assemblage here comprises pottery sherds of Early and Middle Neolithic date, a flint blade, and perforated seashells. While these may represent votive depositions, their association with undated disarticulated human remains (Dowd 2015, 115) could also mean that they are grave goods. An even more complicating factor is that the stratigraphy in caves is typically disturbed by natural agents, which does not allow for reliable contextualisation of finds. These complicating factors add layers of uncertainty to any inferences made about Neolithic cave use and site location choices.

Current knowledge about cave use during the Neolithic is limited to morphology and types of activity. Lack of evidence pertaining to secular activities suggests that the exclusive forms of activity in caves were of a religious nature with a clear emphasis on funerary rites and treatment of the dead (Dowd 2015, 93*ff.*). Thus, selected variables reflected requirements that caves needed to fulfil that would best explain the current evidence. Passage length, height, complexity, orientation, and entrance dimensions are all believed to have been considered to some degree by Neolithic people when selecting a cave for activity. Values for the different variables were summarised into two to three categories. The importance of a category was determined by the amount of Neolithic caves that fell into a particular category. Additionally, each category was weighted based on the assumption that some criteria were seen as more important than others were, as it would be unlikely that only caves were used that met all of the preferred morphological traits.

This analysis resulted in a morphological profile that could make predictions in the form of a likelihood score that states how likely a particular cave is to contain Neolithic archaeology. Applied to the caves from the North Connaught region, likelihood scores were calculated for each of the surveyed caves. In a final step, the model outcomes were discussed within their Neolithic archaeological landscape setting. The theoretical framework was based on the Neolithic landscape analysis of Knocknarea and its two caves that contained human remains of Neolithic date (see Chapter 6), which offered some indications about the spatial relationship between megalithic monuments and caves.

Additional to the cognitive-deductive modelling, some limited correlation analysis was applied to detect any correlation between cave morphology and artefacts that were not associated with funerary activities. The analysis had the potential to contribute some insights into the limited understanding of non-funerary related religious activities in caves during the Neolithic.

A disadvantage of this method compared to correlative-inductive predictive modelling is that it cannot be tested statistically. Instead, a careful review of the evidence and reasoning by peers followed by field visits and excavation is the only way to validate such a model. However, while correlative-inductive models produce tangible statistics in the form of probabilities, p-values, and confidence levels, they rely on assumptions of certain distribution patterns, interpolations, and uncertainty in the input data. Theoretical issues, such as over-simplification of complex human thought processes and determinism that dominates the modelling process has led to much criticism and outright rejection of archaeological predictive modelling as a valid analytical tool. Ultimately both approaches need to be tested in the field to determine their real-world validity.

Chapter 4: A correlative-inductive archaeological predictive model for caves in Munster

This chapter presents the results from the data-driven or correlative-inductive predictive model for four counties in Munster: Clare, Limerick, Waterford, and Cork. The aim was to test if a purely correlative-inductive predictive model, in conjunction with a relatively small number of caves, could be used to predict the presence of Neolithic archaeology in caves of unknown archaeological status. Section 4.1 presents the two calibration sets used to build the model, followed by a brief presentation of the target caves that were evaluated for their archaeological potential. Section 4.2 presents the variables that were tested for their predictive potential. Variables that showed a statistically significant difference were analysed for possible effects of regional different environments on the data. Section 4.3 presents various stages of model development and proposes two slightly different models that produced similar results and presents the caves that are most likely and least likely to have been used during the Neolithic.

Archaeological predictive modelling employs a multitude of theoretical approaches and statistical methods to make predictions about past decision making processes (see Chapter 2 for a more detailed overview). In the strictest of definitions, a correlative-inductive model is solely data-driven, meaning that no assumptions are made about predictor variables. Such assumptions can be: ‘a nearby fresh water source is essential for a settlement, thus distance to water is a good predictor variable’. In practice, a strict correlative-inductive approach is rarely taken and expert knowledge is applied to pre-evaluate a variable for its suitability for inclusion into the model (Verhagen and Whitley 2011, 3-4). Given the relatively small number of known Neolithic caves, and the limited knowledge that was derived from these sites, a purely correlative-inductive approach was taken to explore all available data sets, seeking patterns and correlations that are not obvious from current research and interpretations. Some of the outcomes from this analysis presented unexpected relationships, while others did not support current interpretations.

Contrary to the categorical consideration of all caves for the predictive model, a number of inclusion criteria were applied to caves within the research area for analysis. Those criteria were applied for reasons of data quality, accessibility, and testability (see Chapter 3 for a more detailed description of inclusion criteria). Of the caves 339 recorded for the Munster modelling area, 31 caves were used to build the model and 88 caves were evaluated for their archaeological potential. Those 31 caves consisted of caves that were used during the Neolithic and caves that have not produced evidence for Neolithic activity. The terms 'Neolithic' and 'non-Neolithic' should be understood in the context of this particular predictive model, in which I attempted to simply generate two contrasting sets which both display the highest likelihood of belonging to one or the other group.

4.1 Development of a base model

Correlative-inductive archaeological predictive models can utilise different statistical methods to make inferences about a given dataset as outlined in Chapter 3. Most commonly, archaeological predictive models are based on binary logistic regression and discriminant function, which both can be used when the outcome can only be one of either state; in this case a cave was or was not used during the Neolithic. Binary logistic regression was most suitable for variables that consisted of categorical and continuous data. Unlike linear regression, from which logistic regression is derived, binary logistic regression does not make as many assumptions about the relationship between the input data and outcome variable, such as the assumption of linearity between the two (see Chapter 3 for more detail).

Target caves

There are 339 recorded caves in counties Clare, Cork, Limerick, and Waterford (Drew 2006a) of which only a subset was suitable for inclusion in the predictive model. This was due to limitations in location accuracy, accessibility, and testability of outcomes. It is unlikely that archaeological material survives in hydrological active caves, as these would have been washed out by flooding events (see Chapter 3 for an outline of all inclusion criteria). After excluding all caves that did not meet the inclusion criteria, 84 caves of unknown archaeological status remained to be assessed by the predictive model.

4.2 Defining a calibration set

Binary logistic regression explores the relationship between the binary status of an outcome and how external factors may influence the outcome and to what degree. The purpose of this predictive model was to predict whether a cave was used during the Neolithic and thus the possible outcomes were 'used during the Neolithic' or 'not used during Neolithic' or, in short, 'Neolithic' or 'non-Neolithic'. A calibration set was created for caves that were used during the Neolithic and a roughly equally sized sample (n=16 vs. n=15) for caves that were 'Neolithic' (fig. 4.1). A third group of caves, 'target group' (n=88), of unknown status was evaluated for their Neolithic archaeological potential.

Neolithic caves / Caves used during the Neolithic

The 28 caves in the model area with recorded Neolithic material ranged from sites with single finds of lithics, such as Moneen Cave, Co. Clare (Dowd 2013a, 2015), to complete inhumation burials, such as at Annagh Cave, Co. Limerick (Ó Floinn 1992, 2011). After applying inclusion criteria as described in Chapter 4, 16 caves were included in the 'Neolithic archaeology present' group. Eleven of these Neolithic caves are located in counties Clare (5) and Waterford (6) and make up almost two thirds of the caves in this group. Three caves are located in County Limerick and two in County Cork.

The caves in the 'Neolithic' group (n=16, table 4.1) are frequently found in clusters. The five caves from Clare are part of a complex of caves in the townlands of Edenvale and Newhall, which consists of eight caves that are distributed around Edenvale Lake and Ballybeg Lough. At Lough Gur, Co. Limerick, Grange Hill Cave, and Red Cellar Cave are in close proximity to one another and there are at least two, probably three, further caves in the vicinity (Cleary *et al.* 1995; Coleman 1965, 66; Grogan *et al.* 1987, 352). Connaberry Cave C, Co. Cork is part of a series of small caves that run along the eastern slope of a deep river gorge south of Castletownroche overlooking the Awbeg River.

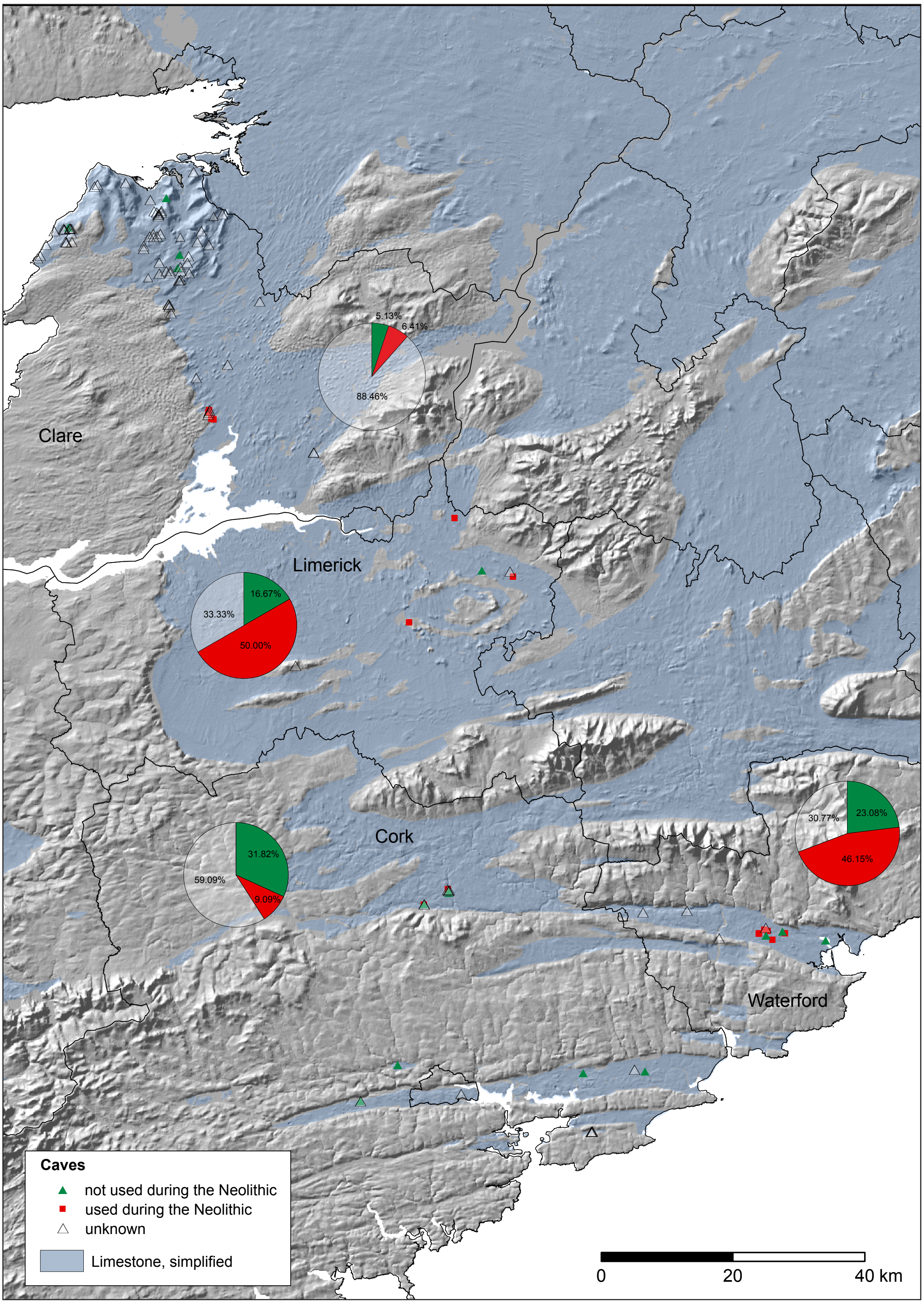


Figure 4.1: Distribution of caves included in the predictive model by group membership. Pie charts show the proportion of group membership by county.

Killavullen Cave 3, Co. Cork is one of several caves that penetrate a small limestone knoll beside the River Blackwater. The five Waterford caves are part of a wider-spaced cluster in the Dungarvan valley. Nine further caves are distributed over an area of 3.7km^2. I suspected that the tight clustering of a large proportion of the caves in this group would introduce bias to the variables, which could have led to false patterns and correlations.

The clustering of the caves is mostly due to the early excavation campaigns that were carried out by the *Committee Appointed to Explore Irish Caves*, and there is a possibility that their distribution pattern is not an accurate representation of the distribution of caves of Neolithic significance. This possibility is supported by finds of Neolithic date in Annagh Cave (Ó Floinn 1992, 2011) and Killuragh Cave (Thomas 1995; Woodman 1996); neither occur as part of a cluster. However, it is also possible that the clustering is part of a real pattern that reflects past site location choices. Clusters of caves may have been preferred over isolated cave sites, a possibility that is supported by the finds in Knocknarea Cave C and Cave K, which lie in close proximity to one another and are part of a larger group (see also Chapter 6 for a more detailed discussion).

It would require a larger number of Neolithic caves to draw a sample from, which would have resolved the problem of false patterns from spatially clustered caves. Attempting to reduce this effect by excluding some of the clustered caves from such a small sample size would have limited the number of variables that could be included in the model without generating a Type 1 error due to an overfitted model (Peduzzi *et al.* 1996; Vittinghoff and McCulloch 2007).

Cave Name	**County**
Alice and Gwendoline Cave	Clare
Barntick Cave	Clare
Bats' Cave	Clare
Elderbush Cave	Clare
The Catacombs	Clare
Connaberry Cave C	Cork
Killavullen Cave 3	Cork
Annagh Cave†	Limerick
Grange Hill Cave	Limerick
Killuragh Cave	Limerick
Ballynamintra Cave	Waterford
Brothers' Cave	Waterford
Carrigmurrish Cave	Waterford
Kilgreany Cave	Waterford
Oonaglour Cave	Waterford
Quinlan's Quarry Cave†	Waterford

†cave destroyed

Table 4.1: Caves used during the Neolithic.

Non-Neolithic caves / Caves 'not used during the Neolithic'

The absence of Neolithic activity from a cave is not easily proven and the old principle that absence of evidence does not imply evidence of absence applies underground as much as it applies above ground. Absence of archaeology from a given location today does not mean that this was always the case and all archaeological predictive models suffer from uncertainties when it comes to populating the non-site group (Kvamme 2006, 20-1; van Leusen *et al.* 2010, 155). Caves are generally excellent for preserving archaeological material over long time spans, but in Ireland, they are often only partially excavated. The stratigraphy in caves is typically disturbed and it further makes confirmation of their archaeological status and an establishment of a clear chronology difficult. Furthermore, some activities may not have left any detectable traces behind (Dowd 2015, 57-8). Another complicating factor is that much of the archaeology recovered during early excavation campaigns was lost before finds could be subjected to modern archaeological analysis, such as radiocarbon dating, to get dates from human remains.

Populating the 'non-Neolithic' group with sites where excavation has not revealed any Neolithic archaeology, or archaeology from other periods, at least reduced the chance that a cave that contained undiscovered Neolithic archaeology was included in that group. The term 'cave not used during the Neolithic' should therefore be taken with caution as this evaluation is based on incomplete data. Using the inclusion criteria as outlined in Chapter 4, 16 caves were included in the 'non-Neolithic' group (table 4.2). The group shows a much wider spaced homogenous distribution than the 'Neolithic present group' (fig. 4.2).

Cave name	County
Ballynameelagh Cave I	Waterford
Foley Cave	Cork
Glencurran Cave	Clare
Killavullen Cave 4	Cork
Knockadoon Cave	Limerick
Knockane Cave	Cork
Main Earth Cave	Cork
Mammoth Cave	Clare
Moneen Cave	Clare
Ovens Cave	Cork
Park North Cave	Cork
Robbers Den	Clare
Shandon Cave	Waterford
Badger Cave	Cork
Uaimh na Mart	Waterford

Table 4.2: Caves not used during the Neolithic.

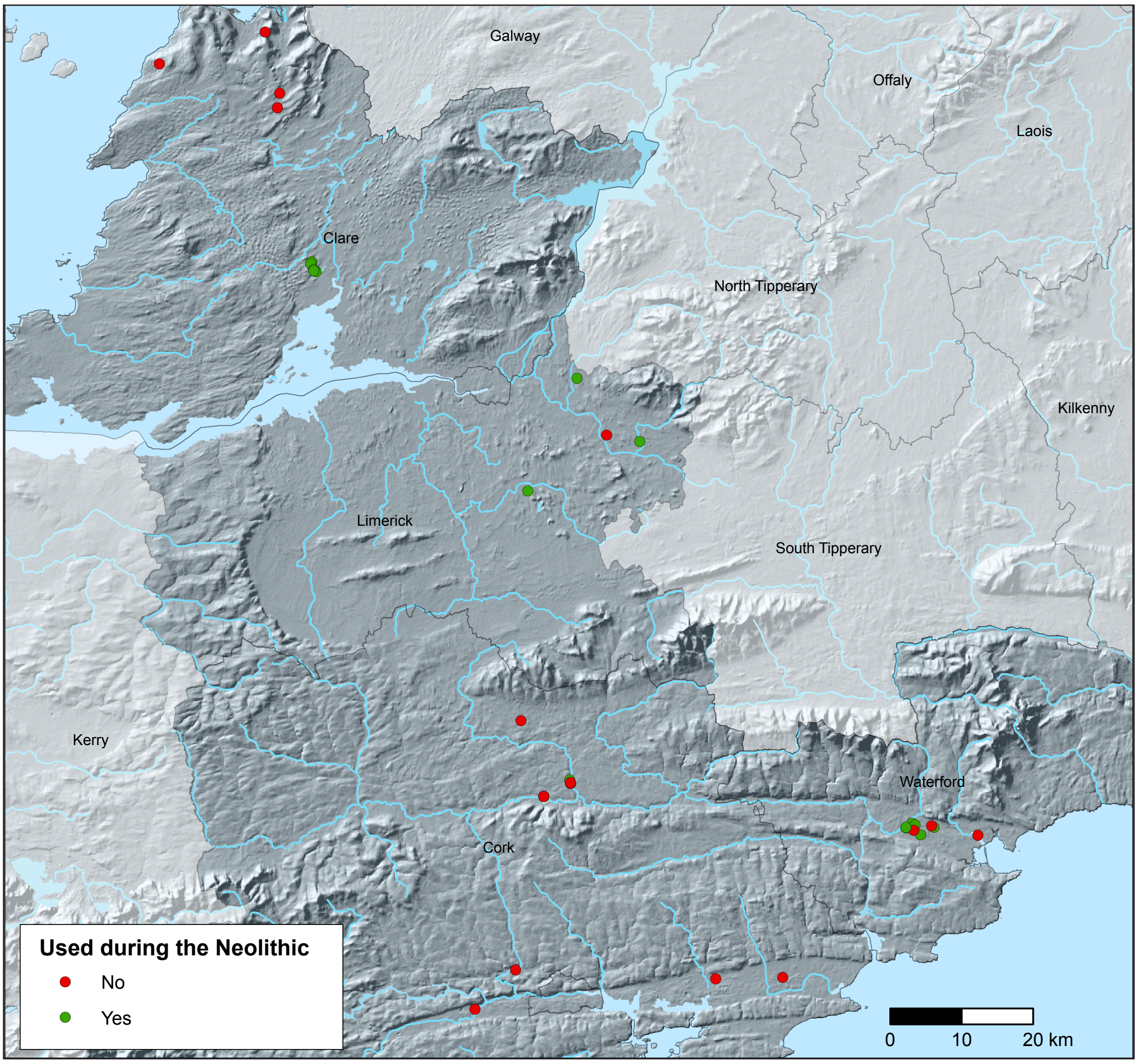


Figure 4.2: Distribution of Munster caves in the calibration set.

4.3 Selecting model variables

The variables used to create this model are, with the exception of one, all environmental and non-archaeological. The use of these variables, as discussed in Chapter 2, is often criticised for being environmentally deterministic, whereas promoters of this approach accuse their opponents of misrepresenting the abilities of predictive models (Gaffney and van Leusen 1995; Kvamme 1990, 271). DEM derived data (elevation, aspect, slope), soil types, geological data *etc.* are readily available from state agencies such as the Irish Environmental Protection Agency, which makes them useful in situations where extensive and costly field surveys are not feasible or where a desk derived predictive model guides the selection of targets for fieldwork. The variables tested for this model and how their values were derived are described in Chapter 3 and the main findings from their evaluation are outlined in the following sub-sections.

Kolmogorov-Smirnov tests were used for continuous measurements and Pearson's chi-square tests for categorical data after finding that almost all variables were non-parametric (table 4.3). The latter was tested using SPSS crosstabs function, which requires a minimum of five events per category, which was not achieved due to the small number of caves in each group. The Likelihood Ratio statistic, which is suitable for small sample sizes, confirmed the chi-square test results.

Tests of Normality[c,d]

		Kolmogorov-Smirnov[a]		
	Neolithic	Statistic	df	Sig.
Nearest Monument type	No	.205	12	.174
	Yes	.534	14	.000
Distance to nearest embanked enclosure	No	.144	12	.200*
	Yes	.333	14	.000
Slope direction 4 categories	No	.291	12	.006
	Yes	.275	14	.005
Below 50m OD	No	.417	12	.000
	Yes	.534	14	.000
Slope direction 4 categories	No	.229	12	.082
	Yes	.191	14	.180
Soil drainage	Yes	.[d]	.[d]	.[d]
	No	.[c]	.[c]	.[c]
Subsoil	No	.247	12	.041
	Yes	.354	14	.000
Topsoil	No	.395	12	.000
	Yes	.382	14	.000
Nearest waterbody type	No	.257	12	.028
	Yes	.273	14	.006
Distance to nearest fresh water source	No	.225	12	.093
	Yes	.207	14	.106
Distance to nearest river	No	.265	12	.019
	Yes	.244	14	.023
Distance to nearest stream	No	.266	12	.019
	Yes	.176	14	.200*
Distance to nearest lake	No	.165	12	.200*
	Yes	.286	14	.003
Hill slope	No	.259	12	.026
	Yes	.145	14	.200*

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

c. Soil drainage is constant when Caves used during Neolithic = No. It has been omitted.

d. Soil drainage is constant when Caves used during Neolithic = Yes. It has been omitted.

Table 4.3: Tests for normality for all tested variables. Only 'slope direction' and 'distance to nearest fresh water' source show a parametric distribution in the 'Neolithic' and 'non-Neolithic' groups.

Outliers masked some important predictor variables, such as elevation, as non-significant. Moneen Cave, located in the 'Neolithic' group, produced proportionally high values in five environmental continuous variables (fig. 4.3). However, as these effects only occurred in continuous variables I decided to exclude it in individual tests to avoid unnecessary lowering of the already low number of caves in the calibration set.

Two of the 14 tested variables (table 4.4) showed significant associations between Neolithic caves and non-Neolithic caves. Caves on east and west facing slopes were more frequently associated with use during the Neolithic, than caves that were not in such locations (χ^2 (DF=1) =5.49; p = 0.019). Neolithic caves were more frequently found to be closer to embanked enclosures than to other Neolithic monuments. There was also a mild correlation between cave use during the Neolithic and altitude. Caves associated with use during the Neolithic were more frequently located below 50m than non-Neolithic caves (χ^2 (DF=1) =2.386; p = 0.122).

Other variables that are commonly associated with the presence of archaeological sites in predictive modelling, such as distance to water, soil data, or slope, did not show any significant between-group differences. Some of the findings were mirrored by Chamberlain's results from the Yorkshire Dales and Peak District (Holderness *et al.* 2007); other results contradicted them. For example, in Chamberlain's work (Holderness *et al.* 2007, 81) a statistically significant relationship between archaeological caves and elevation was established for the Peak District study area, but in the Yorkshire Dales this relationship was not statistically significant. In the southwest of Ireland, the relationship is inversed and caves were more frequently located at altitudes below 50m. A direct comparison between the two model areas should be done with caution; both areas have a different geological history which needs to be taken into account before drawing any conclusions. Chamberlain also built a model that lacked a temporal dimension, i.e. he included all archaeological caves regardless of the period of activity and did not take into account that preferences for cave setting and morphology probably changed over time.

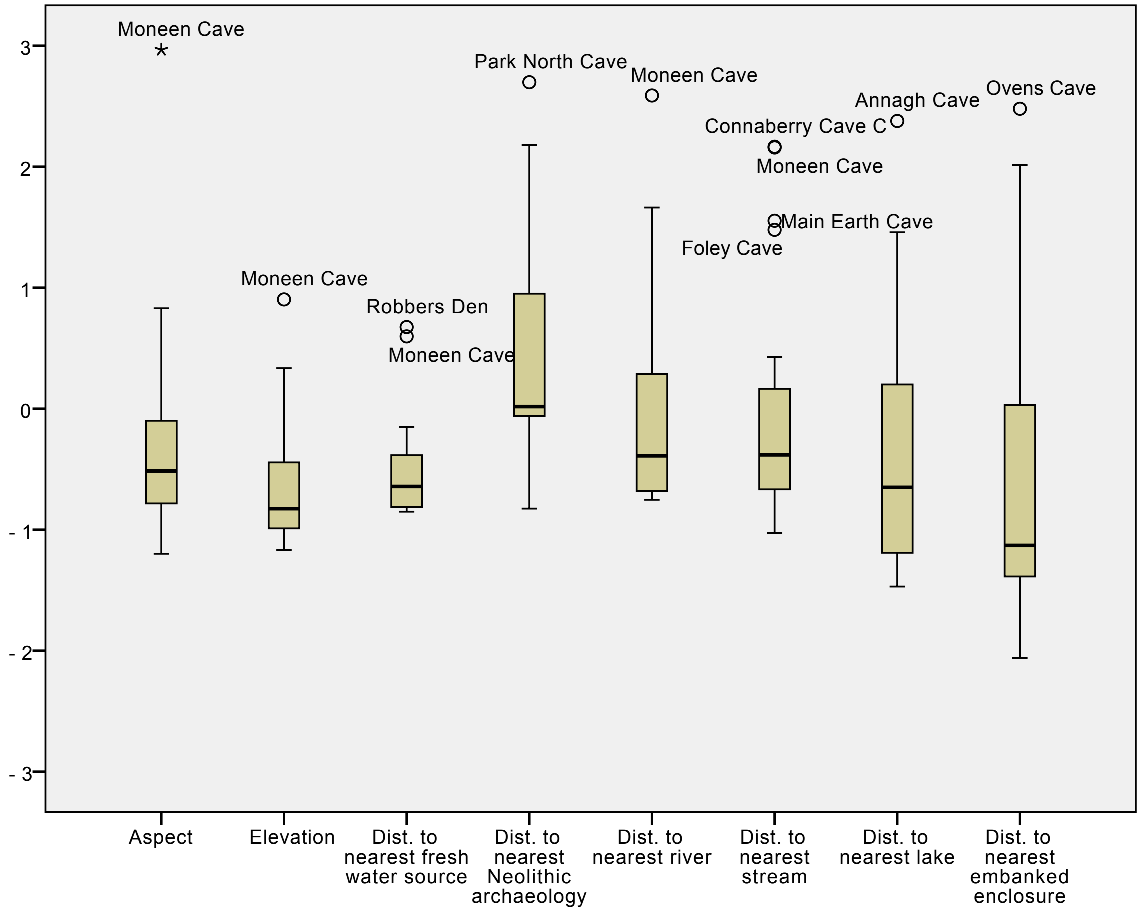


Figure 4.3: Box plots of z-distributions for continuous variables in calibration set (n=31).

Non-parametric tests for model inclusion (significant at p<0.05)				
Variable	**Type**	**Statistic**	**DF**	**Significance**
Nearest monument type	nominal	12.03	3	0.007**
Distance to nearest embanked enclosure	continuous	1.530	-	0.018*
Aspect	nominal	7.047	3	0.070**
Elevation below 50m	binary	2.386	1	0.122**
Elevation	continuous	0.765	-	0.602*
Soil drainage	nominal	0.322	1	0.570**
Subsoil type	nominal	1.893	3	0.595**
Topsoil type	nominal	0.370	3	0.946**
Nearest fresh water class	nominal	1.755	2	0.416**
Distance to nearest fresh water	continuous	0.788	-	0.563*
Distance to nearest river	continuous	0.580	-	0.890*
Distance to nearest stream	continuous	0.765	-	0.602*
Distance to nearest lake	continuous	0.870	-	0.436*
Slope	continuous	0.464	-	0.983*

*Kolmogorov-Smirnov test
**Pearson chi-squared 2-tailed test

Table 4.4: Summary of non-parametric tests assessing between-group differences across potential predictor variables.

How many predictor variables?

The size of the calibration set (n=31) described in section 4.2 determined how many independent variables could be included in the predictive model. A rule of thumb is the maximum number of events (or caves) per variable (MEPV), which allows for a maximum of one predictor variable per 10 events (Peduzzi *et al.* 1996). The smallest group size was n=15 for 'not used during the Neolithic', which would have allowed for the inclusion of one independent variable. However, following Vittinghoff and McCullough (2007), the rule of thumb was relaxed and a second variable was included in the modelling process. The inclusion of further variables would have resulted in a Type 1 error (Peduzzi *et al.* 1996, 1373), which would have compromised the performance of the model.

The following sections introduce the variables that were considered for this predictive model and the outcome of preliminary statistical tests that explored the relationship between predictor variable and outcome variable.

Proximity to Neolithic monuments

Exploring a possible relationship between caves and Neolithic monuments was one of the principal research questions in this doctoral thesis. The RMP listed 36 Neolithic monuments for the Munster model area, comprising passage tombs, court tombs, portal tombs, Linkardstown cists, and embanked enclosures, which occur significantly less frequent in Munster than in the North Connaught where the RMP had listed 202 monuments of the same types (fig. 4.4). As was discussed in Chapter 3, the relative abundance of monuments in the two areas appeared to be significantly different. Yet analysing this variable had the potential to guide the analysis and interpretation of the predictive model in North Connaught, which focussed on the relationship between caves and Neolithic monuments.

Portal tombs were the most frequent monument type in the Munster research area and were the closest monument type for five caves, of which none were in the 'Neolithic cave' category. In contrast, seven embanked enclosures were listed in the Munster research area

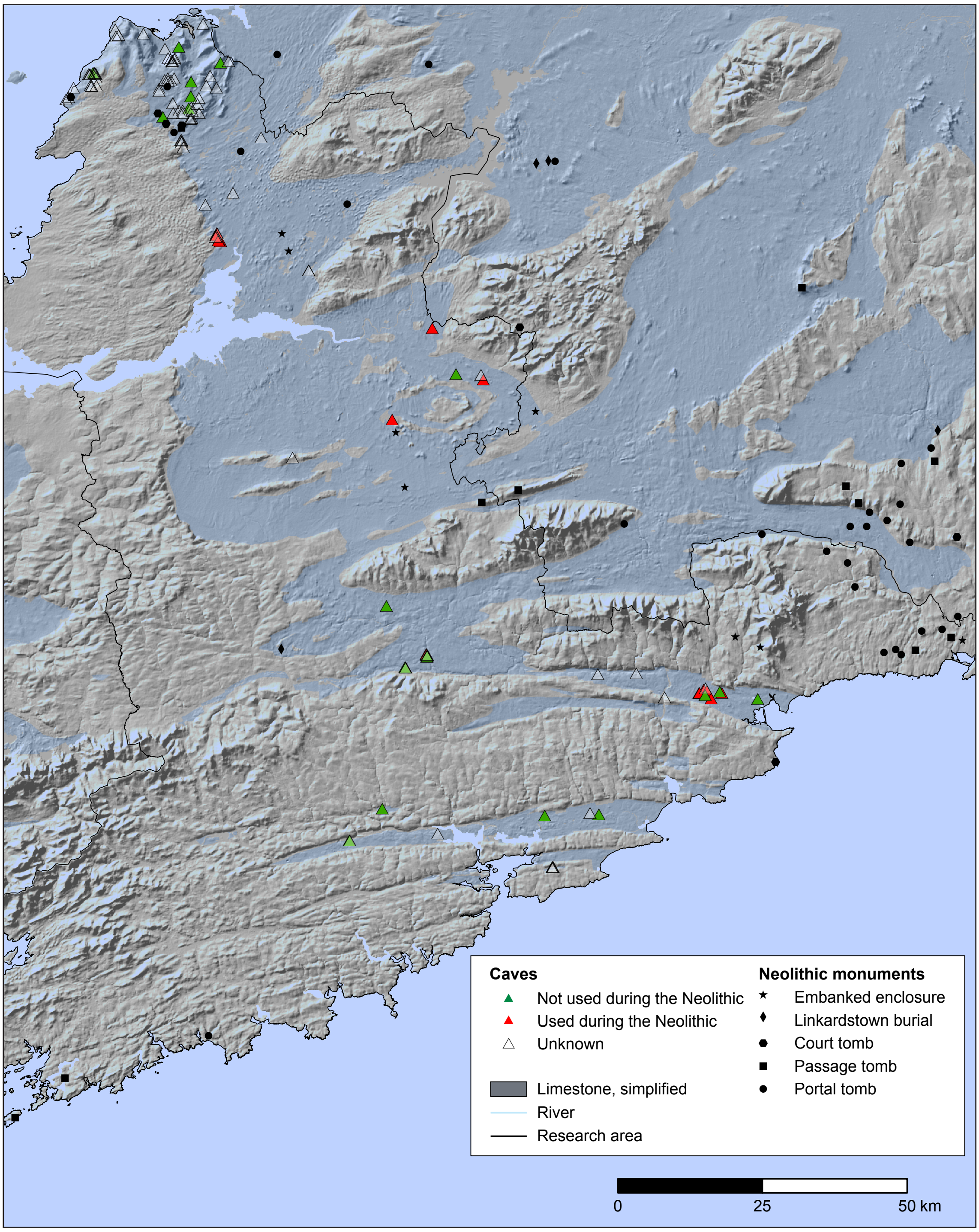


Figure 4.4: Distribution of caves included in the model in their spatial context with Neolithic monuments.

by the RMP, and this monument type appeared in closest proximity to 81% of Neolithic caves and only in 16% of non-Neolithic caves (fig. 4.5). During model building this variable caused a Type 1 error (overfitting) when used in conjunction with a second categorical variable. To resolve this error, I calculated distance values between each cave and the nearest embanked enclosure in ArcGIS and exported the measurements as a continuous variable 'distance to nearest embanked enclosure' into SPSS. The mean

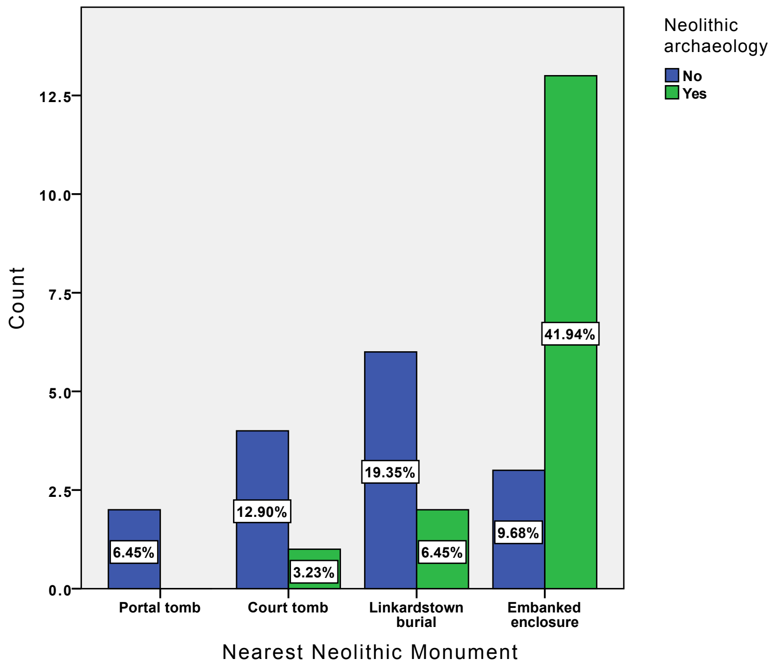


Figure 4.5: Bar chart illustrating the occurrence of nearest monument types between Neolithic caves and non-Neolithic caves.

distance between embanked enclosures and non-Neolithic caves was 30km±16.3 and between embanked enclosures and Neolithic caves 14km±7.3 and a mean difference of 15.4km (t (DF 29) =3.435; p=0.002). This confirmed the indicated association between Neolithic caves and embanked enclosures. Here, including a continuous variable along with a categorical variable instead of two categorical variables resolved the issue of a Type 1 error.

Aspect

Although derived from continuous data, 'Aspect', which describes the cardinal direction the terrain faces, is nominal due to its circular and finite scale (0-360˚) and required re-coding into four dummy variables for north (315°-45°), east (45°-135°), south (135°-225°) and west (225°-315°). Nearly 39% of caves were located on north-facing slopes (fig. 4.6).

After dividing the caves into their Neolithic archaeology present/absent groups a noticeable, yet not statistically significant, trend in the difference between the two groups emerged. Non-Neolithic caves tended to be more frequently located on north-facing slopes, whereas Neolithic caves tended to be located more frequently on either east- or west-facing slopes. The chi-squared test failed to detect a significant difference in aspect between the two calibration sets (χ^2 (DF=3) =7.047, p=0.070). However, the likelihood ratio, which is more reliable for smaller groups, was LR (DF=3) =7.575, p=0.056. While the p value remained above statistical significance, the small sample size and non-parametric data may have obscured true statistical significance.

The bar chart (fig. 4.6) suggested that Neolithic caves are more frequently associated with east-west aspects than non-Neolithic caves. To test if there was a correlation between east or west facing slopes and Neolithic caves the four-value variable was converted into a binary variable east or west aspect present/absent group. The difference between Neolithic and non-Neolithic caves was statistically significant at χ^2 (DF=1) =5.490, p=0.019.

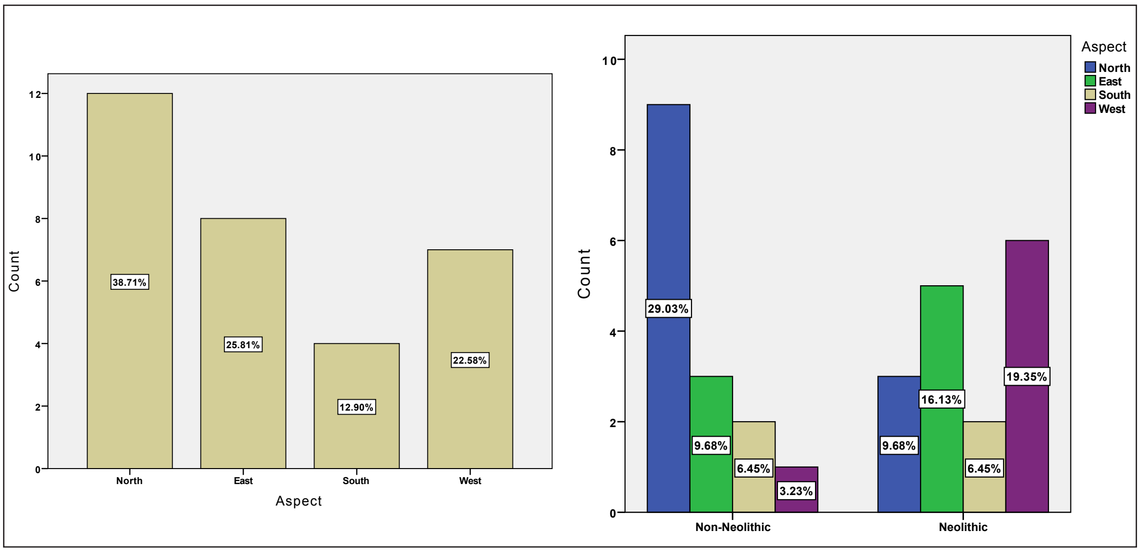


Figure 4.6: Left - aspect of hill slope at caves within calibration group. Right - aspect of hill slopes at caves divided between non-Neolithic and Neolithic caves.

Elevation

Frequently used in archaeological predictive modelling as a good indicator for site presence, the variable 'elevation' produced mixed results for Chamberlain's model (Holderness *et al.* 2007, 83 and 97). In the Munster region, non-Neolithic caves were located at a mean altitude of 48m±40.7, whereas Neolithic caves were at a mean altitude of 34m±20.1. A mean difference of 13m between the two groups was statistically not significant at p=0.602 (K-S test). The high range of values and low number of caves in the calibration groups made a meaningful comparison difficult. Reducing the number of variables by grouping the elevation values into two categories (<50m and >50m), however, gave a clearer picture but returned a similarly non-significant outcome (χ^2 (DF=1) =2.386, p=0.122) (fig. 4.7).

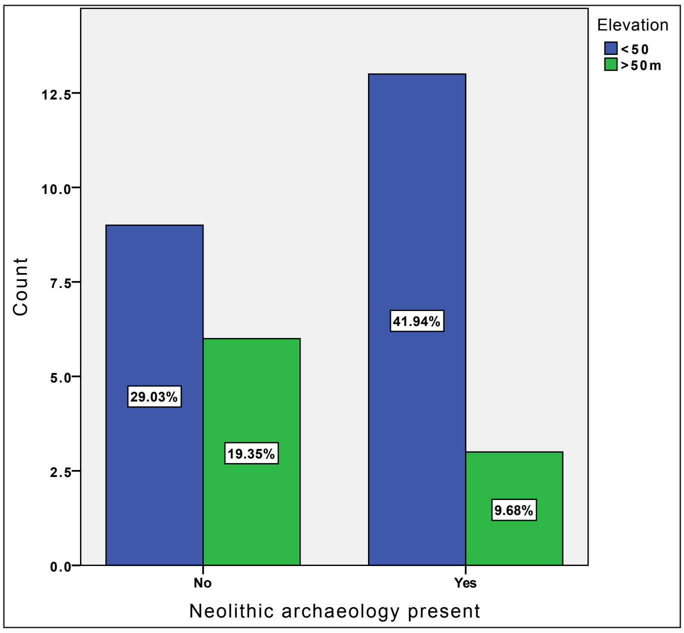


Figure 4.7: Difference in elevation above and below 50m between Neolithic and non-Neolithic caves.

Soil Type

Soil types can be useful in archaeological predictive modelling to predict the presence of settlements and agricultural activity (Ebert and Kohler 1988; Legg and Taylor 2006, 127). Data on different soil types allow for an evaluation of soil acidity, drainage ability, and depth.

Data was not available for five of the caves. Chi-square tests did not detect significant differences between the two calibration groups for topsoil, subsoil, and soil drainage (table 4.4) Areas with thick-bedded limestone bedrock, the dominant host material for solutional caves, are generally well-drained as the permeable limestone quickly drains off surface water. This explains how 92% of all caves included in this study were located in locations with well-drained soils. A similar prevalence of well-drained soils was also observed in 84% of the calibration set (n=26). Karstic rock (KaRck, 50%) and general bedrock (Rck, 19%) were the most common underlying subsoil types in the calibration groups. While soil types and drainage quality may have played a significant role in the selection of sites for settlement, agricultural, or industrial activities, this effect had no detectable impact on Neolithic caves.

Proximity to fresh water

Proximity to fresh water is often used as a predictor variable in archaeological predictive modelling as access to fresh water is vital for farming, domestic, and industrial activities. Andrew Chamberlain found a positive correlation between archaeological caves and distance to water in the Peak District but not in the Yorkshire Dales (Holderness *et al.* 2007, 96-8).

In Munster, the mean distance for non-Neolithic caves was 0.56km±0.64, and for Neolithic caves 0.34km±0.29 (fig. 4.8). This difference was statistically not significant at p=0.563 (K-S test). However, looking at the histogram, there was a tendency for Neolithic caves to be located closer to fresh water sources than caves that were in the 'non-Neolithic' group.

The possibility of a relationship between fresh water and Neolithic caves was further explored by dividing the data set into sub-categories of nearest fresh water class (river, stream, lake) and their individual distances to caves. Further exploration, however, did not detect any significant difference between the two groups (table 4.4).

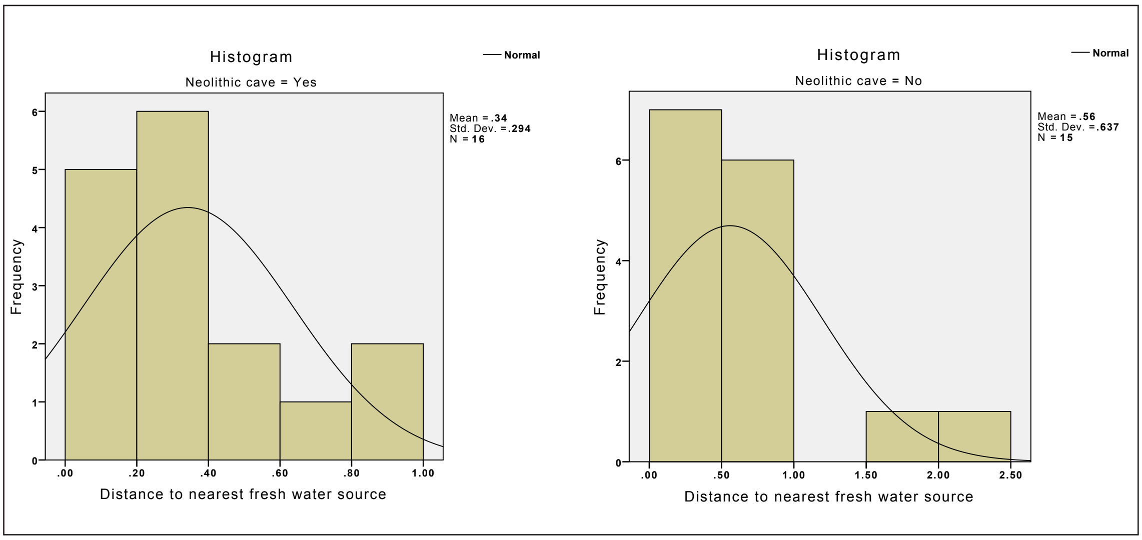


Figure 4.8: Histograms, means and standard deviations for distance to fresh water for Neolithic caves (left) and non-Neolithic caves (right).

Slope

Caves in the model were predominantly located on relatively level terrains of less than 10˚ inclination. In 87% of all investigated caves in the model area (n=119), ground slopes were less than 10˚, and in 56% of cases less than 5˚. The trend was mirrored in the calibration set (n=31) with 97% of caves located on terrain with less than 10˚ slope and 68% less than 5˚. Only Moneen Cave was located in a location with steeper terrain. The outcome of a K-S test did not detect any significant difference between the two groups (p=0.983). Excluding Moneen Cave from the non-Neolithic caves group resulted in an almost equal mean and standard deviation between both groups (fig. 4.9). Slope was, therefore, not a significant predictor.

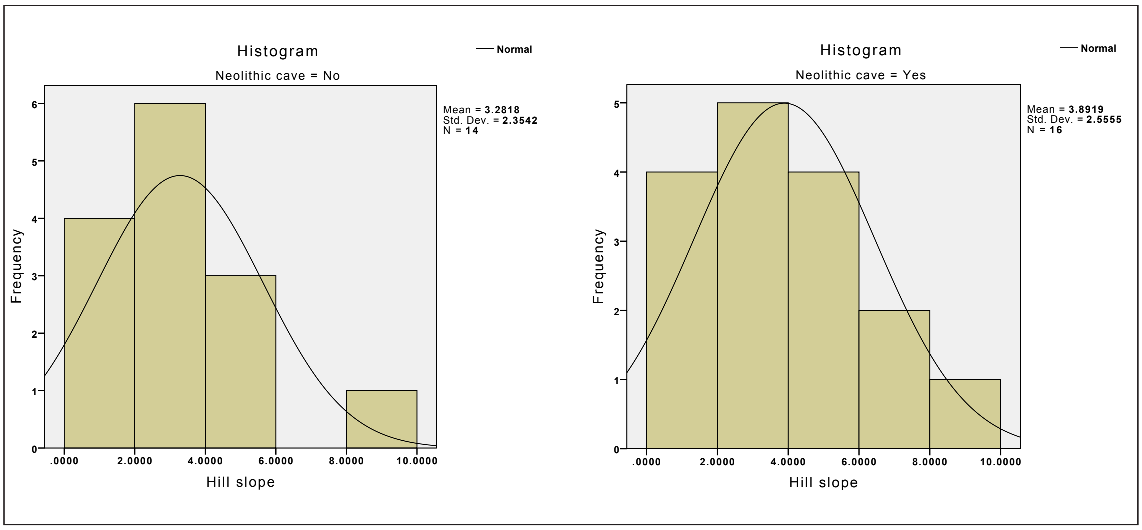


Figure 4.9: Histograms, means and standard deviations for hill slope for non-Neolithic caves (left) and Neolithic caves (right).

4.4 Effects of regional differences on distance to water and DEM derived data

Regional differences due to the location of caves in different landforms may have caused significant differences in elevation, aspect, slope, and distance to water. The caves in Co. Clare are predominantly located in the Burren, a vast limestone plateau that rises 344m above sea level. With the exception of some turloughs and two permanent streams, it is devoid of surface water. Most of the surface water is quickly swallowed by the Burren's extensive subterranean drainage systems (Lynch 2014, 15). Relict caves are commonly found in the higher regions of the Burren. Limestone in counties Waterford and Cork folded along major synclines in the valleys between Devonian sandstone peaks that rise to altitudes of over 500m above sea level. The limestone is covered by a thin layer of glacial till that protects it from erosion, leaving behind an undulating landscape with occasional surface openings into mud-filled relict caves (Coleman 1965; Parkes *et al.* 2013, 28-44).

To test regional differences in different categories, data was divided by county and chi-square tests were applied. However, only counties Clare and Waterford contained a sufficient number of caves for these tests.

Elevation

A slight trend became apparent for caves being located at lower elevations in the southeast and at higher elevations in the east of the model area. Caves in west Limerick are at slightly higher altitudes between 40m and 80m as the terrain rises towards the Slieve Felim Mountains. Caves in the Edenvale-Newhall complex, south of the Burren, are all located below the 50m contour. By county, from the southeast to the southwest there was an overall increase in the median elevation of caves included in the Munster study area (n=119) ranging from 20m in Co. Waterford to 109m in Co. Clare. This trend of increasing elevation, however, is not as strong when looking at caves from the Neolithic group (n=16) where elevation ranged from 19m in Co. Waterford to 59m in Co. Limerick. Caves in Co. Clare belonging to the 'Neolithic' group cluster around 33m. Moneen Cave, Robber's Den and Glencurran Cave, all located in the Burren, are the only caves in the calibration set that are situated above 100m OD and these are not associated with Neolithic activity. However, one third of caves in the Burren that were included in the model are situated below the 100m contour line.

With four recorded court tombs, one passage tomb, three portal tombs, and two possible Neolithic enclosures (Lynch 2014) there seemed to have been a higher Neolithic activity level in the Burren region than in most other parts of the research area, yet Neolithic caves are predominantly found further away from these monuments. If there was a preference in the past to use caves at lower altitudes, that would explain the lack of Neolithic cave use in the Burren.

Aspect

Aspect or slope direction stood out as the second best predictor after proximity to Neolithic monuments. A slight prevalence in east/west aspects for Neolithic caves and north/south aspects for non-Neolithic caves was visible when combining counties. Because of the small data set, dividing by county and into two direction categories (N-S and E-W) showed that there was a slight bias towards east/north aspects in the 'Neolithic' group in all counties versus a more equal distribution in the 'non-Neolithic' group. An exception in both cases was Co. Cork where all but one non-Neolithic caves were on north or south facing slopes (table 4.5). This regional bias did not obscure the overall trend but it may have impacted on the predictive power of this variable.

			Aspect		
Neolithic activity			N-S	E-W	Total
No	County	Clare	2	2	4
		Limerick	1	0	1
		Cork	6	1	7
		Waterford	2	1	3
		Total	**11**	**4**	**15**
Yes	County	Clare	1	4	5
		Limerick	1	2	3
		Cork	2	0	2
		Waterford	1	5	6
		Total	**5**	**11**	**16**

Table 4.5: Occurrences of caves on north-south or east-west facing hill slopes, by county.

Distance to water

The mean distance between fresh water sources and caves differed significantly between the four Munster counties. The largest difference was observed in Co. Clare (n=76) where in 54% of cases the distance between caves and freshwater bodies was over 1km (mean=1.54km±1.385). This trend is not repeated for the other counties where caves tended to be less than 1km from fresh water sources. However, Neolithic caves were all located around or near Edenvale and Bellybeg lakes. The typical karst geology of the area with its highly permeable limestone is responsible for the scarcity of surface water in the

Burren (Lynch 2014, 15), and one would have expected that these regional differences would have distorted the outcomes, yet excluding outliers from that region also did not reveal any significant difference.

Manually measuring the distance between a cave site and a water body manually on a map was necessary because the available EPA data for Irish fresh water bodies is of very low resolution and only roughly follows the actual watercourses. The OSI offers a much more accurate data set but current pricing policy put the cost of the data outside this project's financial scope. The availability of higher accuracy data for water bodies as well as DEM would have enabled me to calculate a Euclidian distance between caves and waterways, taking into consideration local topography.

While there were some significant regional differences in the relationship between caves and distance to freshwater, the majority of these differences were caused by outliers or were not reflected in the calibration set due to the small number of caves in the set (n=31). A larger, more evenly distributed number of Neolithic caves, or at least a set of caves that was not influenced by possible research bias, would have been desirable.

4.5 The final predictive model

Once the variables that displayed the strongest correlation with the presence of Neolithic archaeology in caves were identified, the predictive model itself was created. As outlined in Chapter 3, binary logistic regression was chosen as the most suitable analysis for predictive models that have only two possible outcomes and that have predictor variables with categorical as well as continuous values. The previous analysis of 14 environmental and cultural variables pointed out two variables that showed a significant correlation with the dependent variable 'Neolithic'. The variables were:

1. Distance to embanked enclosure (continuous) [EM_EN] (K-S=0.518, p=0.018)
2. Aspect west (binary) [W-E] (χ^2 (DF=1) =5.49, p=0.019)

In linear modelling, where the outcome variable is continuous, regression analysis determines the influence an increase in the value of a predictor has on the outcome or dependent variable. The relationship is expressed as $Y = \beta_0 + (\beta_1 * X_1) + \ldots + (\beta_i * X_i)$. The outcome Y is a function of one or more variables (X_i) whose influence on the outcome is described by the regression coefficient β_i. β_0 represents the constant or intercept at Y; in logistic regression, it represents the likelihood of an event-taking place if no predictor variable is included. The intercept depends on the ratio between 'yes' and 'no' cases and it is zero if an equal amount of either case is used. This equation is used when the relationship between predictor and outcome is linear, meaning the value of the dependent Y can be directly calculated with the regression equation. However, when the outcome variable is binary - in this case Neolithic activity took place in a specific cave or it did not - the relationship between predictor and outcome is non-linear. Logistic regression attempts to predict the likelihood that an effect took place or not (or whether Neolithic activity took place or not) in a given case (a cave in this instance). Since the effect is categorised into a binary variable, 0 (non-Neolithic) and 1 (Neolithic), the likelihood of an effect occurring lies between 0 and 1. Logistic transformation turns the outcome Y, which in linear regression is an infinite positive or negative number, into a probability value that ranges from 0 to 1. The logistic regression equation incorporates the linear regression equation into the logistic function, which is: $P(Y) = \frac{1}{1 + e^{-(\beta_0 + (\beta_1 * x_1) + \ldots + (\beta_2 * x_2))}}$. As the outcome approaches 0, the likelihood that an event took place diminishes and, conversely, as it approaches 1 the likelihood increases. The cut off point is set at 0.5, which equals a 50% chance of an event ocurring or not.

Running each variable individually through regression analysis in SPSS, 'distance to embanked enclosure' continued to be the best predictor variable (χ^2=11.097; p<0.001). On its own it could explain 40% variability in the outcome (R^2=0.401) and reached a classification accuracy of 77.4%, incorrectly classifying five caves from the 'non-Neolithic' group and two caves from the 'Neolithic' group. Adding this variable to the model improved classification accuracy by 25.8% compared to the empty model, which achieved 51.6% classification accuracy (table 4.5). Variable 'aspect east-west' initially achieved a good classification accuracy of 71% compared to the empty model (R^2=0.223) and the influence of an east or west facing hill slope on the presence of Neolithic archaeology in caves was statistically significant (table 4.6). In combination with EM_EN, however, it failed to improve the overall classification accuracy of the model. At p=0.207 the effect of aspect on the presence of Neolithic archaeology in caves was not significant. However, adding the variable to the model caused a slight improvement in the correct classification of 'Neolithic caves' over the one variable model.

After inserting both variables and with an intercept (β_0) = 1.584, the final regression equation for the model was:

$$P(Y) = \frac{1}{1+e^{-(1.584+(-0.105*x_1)+(1.4*x_2))}}$$

Model	Chi-square	p	Nagelkerke R-square	Classification acuracy	β	Standard error	Confidence interval lower	Confidence interval upper
EM_EN	11.097	0.001	0.401	77.40%	-0.119	0.047	0.81	0.974
W-E	5.671	0.024	0.223	71.00%	1.8	0.795	10.274	28.731

Table 4.6: Summary statistics for initial regression of single independent variables.

The predictive model identified 14 caves (fig. 4.10) that are more likely to have been used during the Neolithic than not. Odds ratios were above 0.8 for six caves:

- Ratty River Cave 1, Cloonass td., Co. Clare (Mullan and Boycott 2004, 147)
- Ratty River Cave 2, Cloonass td., Co. Clare (unpublished)
- Ballynahemery Cave, Ballynahemery td. Co. Waterford (Ryder 1989, 45-6)
- Fox Skull Cave, Edenvale td., Co. Clare (Mullan 2003, 213)
- The Glen One Cave, Edenvale td., Co. Clare (*ibid.*,213)
- The Glen Two Cave, Edenvale td., Co. Clare (*ibid.*,213)

Lower odds ratios between 0.52 and 0.74 were calculated for the remaining eight caves:

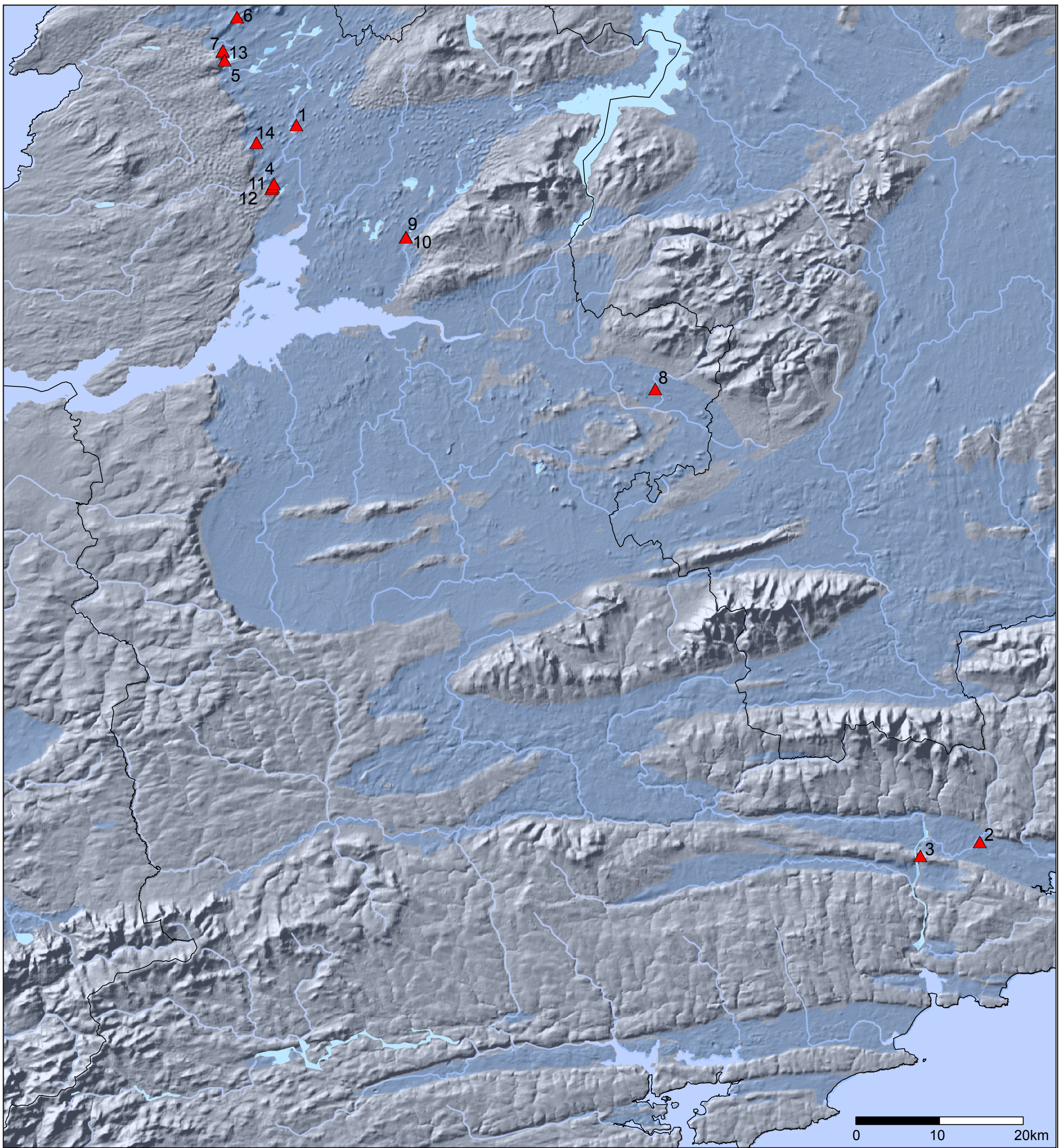
- Dronana Cave, Dronana td., Co. Waterford (Ryder 1989, 45-6)
- Pouleyon, Gortnagade td., Co. Limerick (Thomas 1995, 72)

- Ballyalia, Ballyallia td., Co. Clare (Mullan 2003, 206)
- Lake Caves, Clifden td., Co. Clare (*ibid.*,201)
- Vigo Cave, Nooan td., Co. Clare (*ibid.*,203)
- Nooan Cave, Nooan td., Co. Clare (*ibid.*,202)
- Whelan's Quarry Cave, Ballyneillan td., Co. Clare (Bunce 2007)
- Monocline Hole, Clooncoose td., Co. Clare (Mullan 2003, 195)

Ten of the 14 predicted caves are located in Co. Clare, between the Edenvale-Newhall complex and the south Burren. Three of these, with the exception of the Ratty River Caves, are located within the Edenvale-Newhall complex. Dronana Cave and Ballynahamery Cave are both situated in Co. Waterford, with Ballynahamery Cave located in close proximity to the Dungarvan valley caves. Pouleyon Cave is the only cave predicted for Co. Limerick and it is located near a loosely clustered group of four caves south of Slieve Felim. The spatial proximity of the predicted caves to the calibration set indicates that the samples are not spatially independent, which means that they predict their immediate environment best.

Conclusion

The correlative-inductive predictive model for Munster relied solely on a desk-based approach using variables that were derived from freely available sources. The quality of the model's predictions can only be verified in the field. The small sample size limited the inclusion of more than two variables and an independent test would have been desirable to test the model for performance. While the statistics attest good predictive power and high classification, the model suffered from some regional clustering, low sample size, and uncertainties due to the use of third party data for location and environmental data. However, in this first attempt at predictive model creation for Irish caves, the model identified six caves in counties Clare and Waterford that could be targeted for excavation in future research projects. Additionally, two strong predictors were identified that potentially shed some new light on cave use during the Neolithic: proximity to embanked



	Cave Name	Odds Ratio		Cave Name	Odds Ratio
1	BALLYALLIA CAVE	0.607964	8	POULEYON	0.70285
2	BALLYNAHEMERY CAVE	0.835801	9	RATTY RIVER CAVE (1)	0.900686
3	DRONANA CAVE	0.734058	10	RATTY RIVER CAVE (2)	0.900552
4	FOX SKULL CAVE	0.824195	11	THE GLEN ONE CAVE	0.822341
5	LAKE CAVES	0.588195	12	THE GLEN TWO CAVE	0.819609
6	MONOCLINE HOLE (1)	0.518259	13	VIGO CAVE	0.566823
7	NOOAN CAVE	0.564513	14	WHELAN'S QUARRY CAVE	0.524987

Figure 4.10: Location map of predicted caves used during the Neolithic and predicted probability.

enclosures and slope aspect. The former is less easy to interpret. Embanked enclosures are mostly attributed to the Late Neolithic while Neolithic cave use is a phenomenon that occurred around the mid fourth millennium BCE. The large distance between caves and embanked enclosures also brings into question the validity of this variable as a suitable predictor. Slope aspect indicates that caves located on west or east facing slopes were preferred for ritual activities during the Neolithic.

The results should be seen as a proof of concept and ‘work in progress’. The highly probable caves also fit into the previously suggested morphological framework for cave use during the Neolithic. They are short simple passages with small entrances, but the lack of detailed descriptions of these caves do not allow for further interpretation (Dowd 2008, 2015). However, the true reliability of the predictive model and value of its predictions can only be assessed by a more detailed investigation of the caves that are more likely to have been used during the Neolithic.

There is a distinct regional difference between the distribution of caves and Neolithic monuments. Clare, and the Burren, show a high density of caves and monuments, predominantly court tombs and portal tombs. However, none of the caves in the Burren produced any signs of Neolithic use to date. The nearest Neolithic caves are located in the Edenvale-Newhall complex some 30km south of the Burren. Here, the nearest Neolithic monuments are embanked enclosures which are located some 11km to the east, separated by the River Fergus and River Rine. In Limerick, the closest proximity between a cave and a Neolithic monument is Grange Hill Cave and an embanked enclosure in Grange townland, some 2km south of the cave. Along the southeast coast of Waterford and Cork, the caves in the Dungarvan valley are closest to two embanked enclosures, which are located 11km north of the valley. The nearest Neolithic monuments in south Cork are some 30km away.

The application of a solely data driven archaeological predictive model for caves has proven to be impractical. The strongest predictor variable was one that, on an interpretive level, does not make much sense. Chronologically, embanked enclosures are associated with the Late Neolithic and Early Bronze Age, although future investigation may close that chronological gap. The spatial gap between these two monument types, however, is not that easily closed. Other variables that should have shown, at least on a cognitive-deductive level, a better correlation with caves suffered from a small sample size and their influence was not detected by correlative-inductive methods. A cognitive-deductive predictive model, based on Bayesian or Dempster Shafer theory, would have allowed for insertion of variables and adjustment of their coefficients based on best knowledge and intuition. This would have probably led to a more meaningful and interpretable predictive model.

Chapter 5: A cognitive-deductive archaeological predictive model for caves in North Connaught

The previous chapter demonstrated how limited correlative-inductive predictive models are in the light of small non-parametric data sets that display a high level of variation. In most instances, no statistically significant correlations could be detected between the presence of Neolithic archaeology in caves and the used environmental variables. Whether the absence is real or caused by inadequate data and underpopulated calibration sets could not be addressed without more data.

Cognitive-deductive predictive models take a less rigid approach in comparison to correlative-inductive models since their theoretical framework is more open to intuition and expert input (Verhagen 2007, 76). Intuitive models make more use of expert knowledge but usually lack a clear definition of its individual components (Altschul 1988, 64). For example, if one was to make a statement like, “caves used for excarnation were usually long passages with low entrances”, a general idea about the shape of a cave is conveyed yet it appeals to one’s subjective definition of ‘long’ and ‘low’. A 40m long cave may seem impressive to someone who has never stepped into a cave, while an experienced caver would frequently enter caves that are several kilometres long. However, looking at a subset of caves, such as the caves that are subject to this chapter, a 40m cave would qualify as a long cave. Thus, apart from one’s subjective definition, attention also has to be given to the context in which classifications are used.

This chapter presents the development of an intuitive model that combines intuition and expert knowledge in an informal Bayesian theoretical framework. It reviews morphological data from caves that produced Neolithic remains and assigns clearly defined categories of cave morphology based on distribution of occurrences within these categories. Predictions are based on likelihood ratios and do not display absolute probabilities. The results from this predictive model are then assessed and interpreted in the context of each cave’s landscape setting.

5.1 Cognitive-deductive methods: Bayesian inference, Dempster Shafer Theory and intuitive modelling

Bayesian inference is based on the concept of making a prediction about the likelihood that an event takes place given that another correlated event occurs. It is more flexible than regression models as it works from prior knowledge about an event and incorporates levels of uncertainty and ignorance when making predictions, as well as allowing for an easy incorporation of new data into the model as it becomes available (Millard 2005, 169-70). To develop a formal areal model, such as in a GIS, basic requirements are similar to inductive-correlative models: a training set with 'site' and 'non-site' data is used to identify patterns and make predictions for entire landscapes (Finke *et al.* 2008). However, it still relies on a calibration set of data for 'sites' and 'non-sites' to derive its inferences, rendering it unsuitable if a contrasting calibration or training set of 'non-sites' is not available.

Dempster Shafer theory (DST), a simplified extension of Bayes theorem (Dempster 1968; Shafer 1976), was developed to draw inferences from small and incomplete data sets, especially where calibration data is not available. It factors in expert knowledge, uncertainty, and degrees of ignorance towards what is known (observed patterns) and what is not known (lack of patterns) about observations, which makes it less stringent than empirical statistics where data have to meet specific assumptions for different analyses to work reliably. It uses plausibility and belief to assess the evidence, which is comparable to probability and confidence intervals in empirical statistics. It further calculates belief intervals to quantify uncertainty and combines subsets of evidence to come to the most plausible outcome. Verhagen *et al.* (2008) provide an overview of DST and its application in archaeology, which is not as widespread as empirical methods. DST is perceived as more honest as it shows when evidence is contradictory or insufficient to make a clear prediction of whether an event took place at a given site or not (*ibid.*, 574).

Using existing excavation report data for an area in Melbourne, Australia, Canning (2003) developed a predictive model from incomplete data of unknown quality using

DST. His predictive model, such as all predictive models in a CRM context, aimed at the identification of potential pre-contact Aboriginal sites to support planning and land development. Similarly to other APMs discussed in this thesis and as much as any other APM, Canning's predictive model works within its own theoretical framework but owes validation in the real-world. Despite the availability of a large database of archaeological records and surveys for his area, Canning decided against the use of quantitative analytical methods, which depend on a high level of data integrity to calculate reliable probabilities (*ibid.*, 270). Because of the nature of DST and its incorporation of uncertainty and ignorance about input data, its predictions are not as straight forward as quantitative-probabilistic models, such as those using logistic regression. Instead, it provides likelihood values that indicate which loci are more likely to contain archaeology than others within a research area. In that, it reflects on the uncertain nature of archaeology and the generally fragmented state of the archaeological record causing interpretations to be formulated with great care.

At the time of data analysis for this project, ArcGIS did not support DST which was only available through the open source application GRASS GIS and the commercial IDRISI but the tool is predominantly aimed at landscape assessments that make predictions based on inter-site relationships. To test if these tools could be applied to spatially completely separated research areas, time and labour intensive conversion of data layers from ArcGIS into compatible formats would have been necessary. Given the limited time frame of this research, this was not feasible.

Instead, a cognitive-deductive approach was chosen and developed to compare spatially separated data sets and incorporated in their individual Neolithic landscapes. The approach utilised current knowledge about cave morphological traits, such as cave length, height, and orientation, that are believed to have been significant to Neolithic people when they chose caves for ritual activity, predominantly those involving funerary rituals (see Chapter 6; Dowd 2015, 121-4). The frequency with which specific attributes occurred was used to evaluate the likelihood of the presence of Neolithic remains in tested caves.

5.2 Selecting model variables

Reconstructing Neolithic cave morphology

In speleology, cave morphology is categorised based on hydrological, chemical, geological, and geomorphological processes that influenced the shape and complexity of caves (Palmer 2007). These classifications were only of limited use in the context of this study since most caves can fall into multiple categories at once depending on their developmental history. For example, a rift or fissure cave is formed by tectonic forces where a joint or fault is driven apart. However, it can become hydrologically active if it attracts surface water or intersects with an existing water bearing cave. The resulting solution processes continue to enlarge the fissure to form vadose or phreatic passages. Is a cave like this a tectonic or a solutional cave? In particular larger and/or complex cave systems consist of sections with different developmental histories that make clear categorisations difficult. For the purpose of this study, categories were developed based on traits that attempted to reflect past preferences for specific morphological traits that made it suitable for religious and funerary activities.

Morphological traits that were likely to have been of importance in the use of caves for funerary activity are, based on evidence from 17 Irish Neolithic caves and finds of human remains therein, passage length, cave entrance size, complexity, orientation, and number of openings (Dowd 2004, 2008, 2015) (table 5.1). Although the majority of antiquarian publications of cave excavations lacked pre-excavation surveys which made it difficult to estimate a cave's precise dimensions and appearance during the Neolithic, some general observations could still be made from the available data.

Antiquarian excavation campaigns significantly altered the appearance of caves when excavators dug deep into Pleistocene deposits or removed large obstacles. For example, at least one metre of deposits was removed from Plunkett Cave, Co. Sligo between the entrance and the 'Water Gallery'. The original floor level is still visible as a raised floor in a small recess where the passage turns southeast (fig. 5.1).

Cave Name	County	Entrance dimensions	Complexity	Passage height	Number of openings	Orientation	Adjusted Length Category
Alice and Gwendoline Cave	Clare	large	low	low	3	east	short
Annagh Cave†	Limerick	small	low	low	1	northeast	short
Ballynamintra Cave	Waterford	medium	low	low	1	northeast	short
Barntick Cave	Clare	small	low	low	1	northeast	short
Bats' Cave	Clare	medium	low	medium	1	east	medium
Brothers' Cave	Waterford	-	high	-	-	northeast	long
Carrigmurrish Cave	Waterford	large	high	medium	2	-	long
Connaberry Cave C	Cork	small	low	low	2	north	short
Elderbush Cave	Clare	medium	medium	medium	1	east	medium
Kilgreany Cave	Waterford	-	low	medium	1	west	medium
Killavullen Cave 3	Cork	large	low	-	1	northeast	short
Killuragh Cave	Limerick	small	low	low	2	northeast	short
Knocknarea Cave C	Sligo	small	low	medium	1	north	short
Knocknarea Cave K	Sligo	small	low	low	2	north	short
Oonaglour Cave	Waterford	large	low	-	1	south	long
Quinlans Quarry Cave†	Waterford	-	-	-	-	-	-
The Catacombs	Clare	small	medium	medium	2	east	medium

†cave destroyed

Table 5.1: Morphological characteristics of caves used during the Neolithic. Each trait was divided into three categories.

Figure 5.1: Original floor level left in situ *in a small recess in Plunkett Cave, Keash.*

At Kilgreany Cave, Co. Waterford the original cave has been subject to significant modifications and today only two of at least three chambers as well as possible side passages and recesses survive. Tratman (1929) and Movius *et al.* (1935) removed a depth of at least 3.5m of material from the cave during their excavation campaigns. Dowd (2002) reconstructed the stratigraphy of the cave and, judging from the surviving section drawings (fig. 5.2) of the original excavations, the Neolithic floor level was around 1.5m - 2m below the ceiling with the passage sloping downwards from the entrance (fig. 5.3). Only two small areas of the original Neolithic floor level survived protected by calcite deposits. An intentional

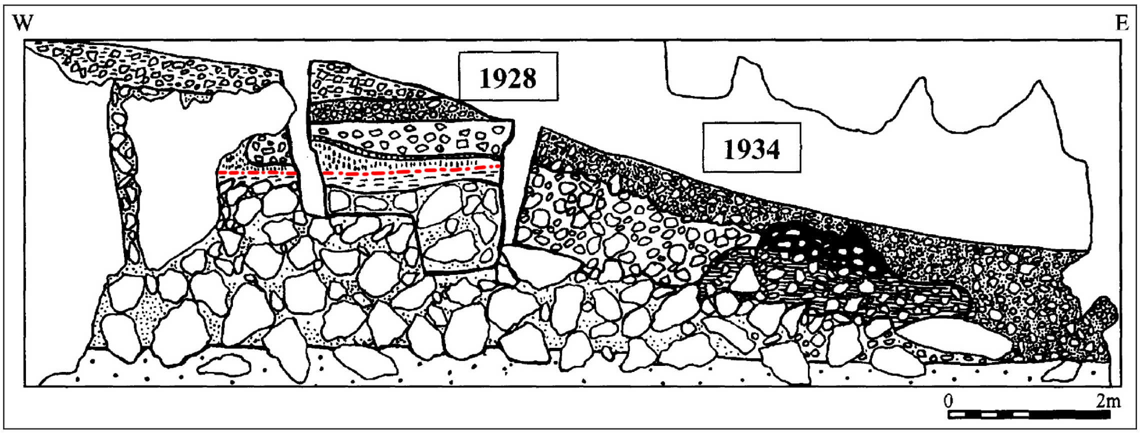


Figure 5.2: Two superimposed antiquarian section drawings from Kilgreany Cave. Probable Neolithic layer indicated in red (after Dowd 2002, 80).

Figure 5.3: Kilgreany Cave during excavation (A; Tratman 1929) and today (B). Encircled in photograph B are the faint remains of the letters 'B' to the left and 'C' to the right that are clearly visible in photograph A.

removal of the deposits is plausible but natural agents, such as a rising water table, are also a possibility; the cave is subject to frequent flooding (Ryder 2009, 77-8). Bedrock remnants recorded by Movius indicate that a significant section of the cave was quarried away during the 19th century and the original cave entrance could have projected out as much as 6m from the current entrance (Tratman 1929, 112). Tratman further speculates that the original entrance may have faced north (the report states east but was rotated by 90°). The cave's width may not have been very different from today; it has a very irregular yet low arched ceiling. Estimation the Neolithic floor level cannot be estimated with any level of certainty as all cave walls are highly irregular with many overhangs, projections, and recesses. The second entrance of Kilgreany Cave opens into a small quarry which is of recent date. The precise extent of the destroyed section is not known but a small passage in the south wall of the quarry faces the quarry entrance of the cave, and it is likely that the two were originally connected. During the excavation, the connection to the rear chamber was also widened and this section may not have been accessible in antiquity.

Another influencing factor on the Kilgreany floor level is the amount of material that accumulated since the Neolithic. Although not active anymore, relict caves tend to accumulate material over time from flooding as well as human activity. Caves near water, on low ground, or below ground level and with sloping entrances, can accumulate significant amounts of soil and debris while caves in cliff faces or in karst landscapes may have a relatively stable floor level as not much material gets washed in. Kilgreany Cave is a good example of how difficult it can be to reconstruct the original Neolithic stratigraphy and floor levels even where detailed excavation plans exist (Dowd 2002; Movius *et al.* 1935; Tratman 1929). A more recent survey of the cave by Ryder (1989, 42) has such a different floor plan, that it is almost impossible to superimpose it onto the antiquarian plans (fig. 5.4). Furthermore, the antiquarian excavations show that the Neolithic levels survived only in two small locations. To accurately reconstruct the cave's floor plan and overall appearance during the Neolithic would require a highly detailed survey of the cave, which could only be achieved with 3D imaging technology.

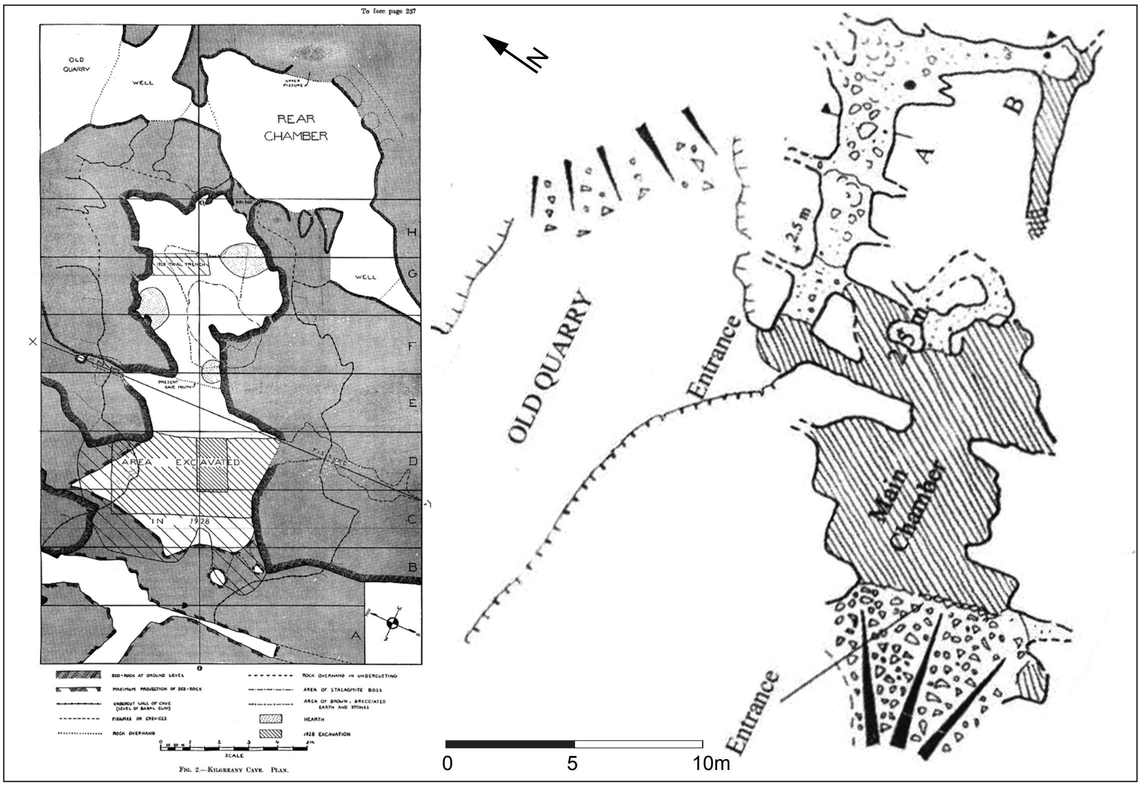


Figure 5.4: Two floor plans of Kilgreany Cave by Movius et al. (1935, left) and Ryder (1989, right) illustrate how two different surveyors capture the morphology of the same cave.

Caves of archaeological significance that were discovered recently and remained intact prior to archaeological investigation are extremely rare. Human bones from Knocknarea Cave K were found exposed on the cave's loose gravel and silt floor by this author, which suggests that little material has accumulated since the Neolithic. The entrance, however, is filled with dark, organically rich soil that formed a steep and muddy, albeit short, slope elevating the bottom of the entrance aperture one metre above the passage floor. But what did the cave look like when it was used during the Neolithic?

With unanswered questions about the extent a cave's interior changed since the Neolithic, I attempted to categorise passage heights in the broadest terms possible whilst still being able to make inferences about possible preferences for this trait. The categories 'low', 'medium', and 'high' are based on restrictions in moving through a passage if a passage decreases in height. Passages with a ceiling height of less than 1.4m require a person to move through on hands and feet. If the passage is taller, moving in a crouched position is possible. Considering that Neolithic people were likely smaller than modern populations

(Hatton 2013; Piontek and Vančata 2012; Power 1993; Vančata and Charátóva 2001), a passage height from 1.7m would have allowed for movement in an upright position. Recent analysis done on human remains from the Carrowkeel passage tomb complex supports these estimates (Geber *et al.* 2016).

Bones of Neolithic date from Irish caves show no traces of interference by animals, such as gnaw marks (Dowd 2008, 309; 2015, 95; Dowd *et al.* 2006, 17). This strongly suggests that caves were blocked for a prolonged period of time, at least for the duration of the decomposition of bodies in cases where fleshed remains rather than dry disarticulated bones were deposited (Dowd *et al.* 2006, 17). From a practical point of view, a cave entrance would have to be small enough to be blocked by a wall, a slab, or other means that would ensure scavengers could not enter the cave for several months or more. It also would also have been important to make sure that scavengers could not access a cave from an alternative opening.

Evidence for the practice of blocking caves to separate corpses from the outside world comes from Annagh Cave, Co. Limerick where a single *in situ* slab covered the entrance of the cave and was only displaced during modern quarrying. This cave is morphologically unique amongst Irish Neolithic caves as it consists of a single small chamber that was accessed via a small opening in its roof. The blocking of its entrance was so effective that the cave remained undisturbed since the Middle Neolithic until its re-discovery 1992 (Ó Floinn 1992, 20; 2011, 18).

In non-funerary contexts, physical sealing of a cave may not have been imperative to rituals. Votive deposition of objects and bones in a cave possibly did not require physical blocking. For example, the 2.7m high and 6m deep Grange Hill Cave contained a hoard of polished stone axes. No detailed record of the find circumstances survive but it is possible that the axes were individual offerings deposited in and around the cave over time (Dowd 2004, 469-70). In cases where caves were used for token depositions, symbolically blocking an entrance with a ritual deposition may have been seen as sufficient protection. A dog skeleton found buried near the cave entrance to Killuragh

Cave may have had such a function (Dowd 2008, 309). Intentional blocking of caves has also been observed frequently during my fieldwork, although unlikely the result of Neolithic funerary activities. Farmers and landowners frequently block cave entrances to prevent their livestock from entering and getting injured.

Other caves have produced evidence of excarnation yet their morphology would have made it difficult to physically seal them. Alice and Gwendoline Cave is a short but complex cave with three entrances, some with a wide mouth, and several connecting passages. If the cave were to be physically sealed for a funerary ritual, blocking of all three passages would have been necessary. Although lacking radiocarbon dates, Dowd (2008, 309) interprets the human bone assemblage from Alice and Gwendoline, which predominantly consisted of small skeletal elements, as the result of excarnation rituals. The cave would have been a poor choice from a practical point of view, because there were other, more suitable caves in the vicinity that could have been sealed with less effort. However, without a confirmed Neolithic date the age of the bones remains uncertain. Similarly, if there was a wish or requirement to visit a deceased individual, for example to monitor the progress of decomposition (Dowd 2015, 106), then unblocking and re-sealing a cave with a large entrance would have been a cumbersome task. Following these observations, the factor 'Entrance dimensions' was used to discriminate between caves that would be blocked easily, blocked with difficulty or those that were either too large to be blocked, or where such a task would have required a significant amount of effort.

Passage length has also been proposed as a significant factor for Neolithic people when they selected caves for ritual activities (Dowd 2008, 311). Anthropogenic and natural agents have significantly altered the appearance of some of the Irish caves since their use during the Neolithic, which would have had an impact on passage complexity. Many passages that are accessible today may have been blocked in antiquity. Ballynamintra Cave, for example, features several lower levels but only the upper level seems to have been accessible in prehistory and the opening in the floor that leads to the lower levels seems to have been choked with mud and debris in the Neolithic. Many antiquarian records state that passages were filled almost to the roof with sediments, such as Brothers' Cave, the Catacombs, Alice and Gwendoline, and Elderbush Cave, which may have reduced their complexity to some degree. This is partially supported by the distribution of archaeological finds throughout these caves, which were often limited to entrance areas. The Catacombs feature a network of interconnected passages with at least two access points, yet potentially Neolithic material was found within the first 10m of the central entrance passage and adjoining galleries. However, the archaeological material had likely been displaced by animal burrows, subsequent occupation, and other human activity (Dowd 2004, 45, 426), which could mean that other parts were either not accessible or deliberately avoided during the Neolithic. In other cases, such as Elderbush Cave, natural agents, such as burrowing animals or flooding events, may have caused displacement of bones and objects from their original location of deposition. Similarly, Alice and Gwendoline was also dug prior to antiquarian excavations (Scharff *et al.* 1906, 5-6), which not only probably disturbed original occupation levels but also displaced archaeological material.

The uncertainty pertaining to cave morphology, particularly for caves that were excavated by antiquarians, has made it necessary to group values into discrete categories rather than using measured length. In the process, I tried to factor in that Neolithic floors in excavated caves were significantly higher in antiquity, which made some cave sections inaccessible. These factors are accounted for in the 'adjusted length' category (table 5.1).

Transforming morphological data into assessable formats

The small number of Neolithic caves and a large variation within the data - for example cave length varied between 6m and 160m - made categorisation of the data a more feasible approach than working with continuous measurements as it exposed patterns more easily. Entrance dimensions were also based on estimates, considering that with higher floor levels the entrances to the caves were also likely to be lower. The graph in figure 5.5 illustrates the frequency distribution of key morphological traits of caves that were used during the Neolithic. Over two thirds of caves that were used during the

Neolithic measured 30m or less in length and had a simple layout with a single passage or chamber with short or no projecting galleries.

Correlation analysis was used to test variables for dependencies of the input variables. It showed correlations between passage length, complexity, and number of openings ($p<0.05$), which is less of a surprise as a more complex network of passages naturally increases overall passage length. This, in return, often leads to several openings where the hosting limestone has eroded thereby exposing cave passages. There were no statistically significant correlations between cave morphology and the presence of artefacts of Neolithic date sometimes found in caves (stone axes, lithics and pottery).

After adjusting the data for changes in floor levels and alteration due to quarrying since the Neolithic, patterns in cave morphology began to emerge. The distribution further shows, based on current knowledge, that at least half of the caves used during the Neolithic consisted of short low passages or chambers of low complexity (fig. 5.5). Only three caves are likely to have been accessible for more than 60m during the Neolithic, one had more than two openings, and only four had entrance dimensions that would have been difficult to block. The confirmed Neolithic material from three of the latter four caves - Alice and Gwendoline, Oonaglour Cave, and Carrigmurrish Cave (with the exception of Killavullen Cave 3) - is indicative of votive deposition rather than excarnation or burial rituals, although the unknown date and the make-up of the bone assemblage from Alice and Gwendoline renders its classification inconclusive.

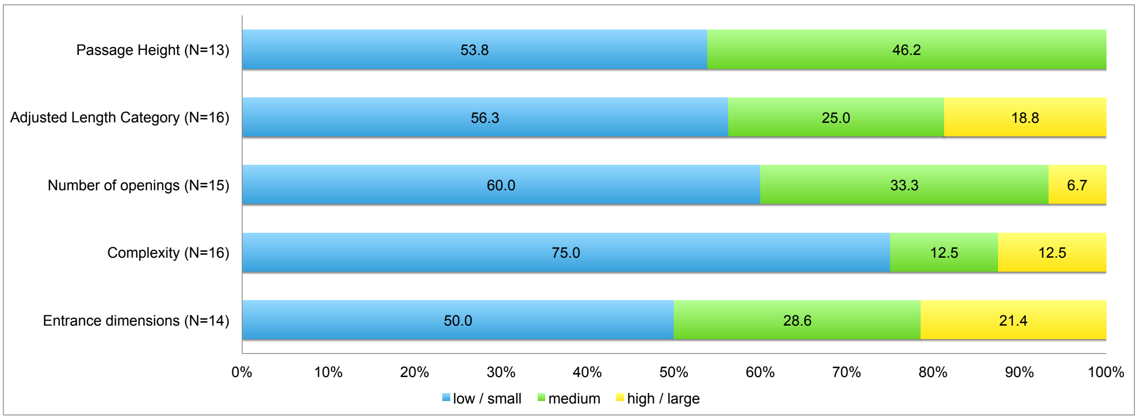


Figure 5.5: Distribution of morphological traits of caves used during the Neolithic.

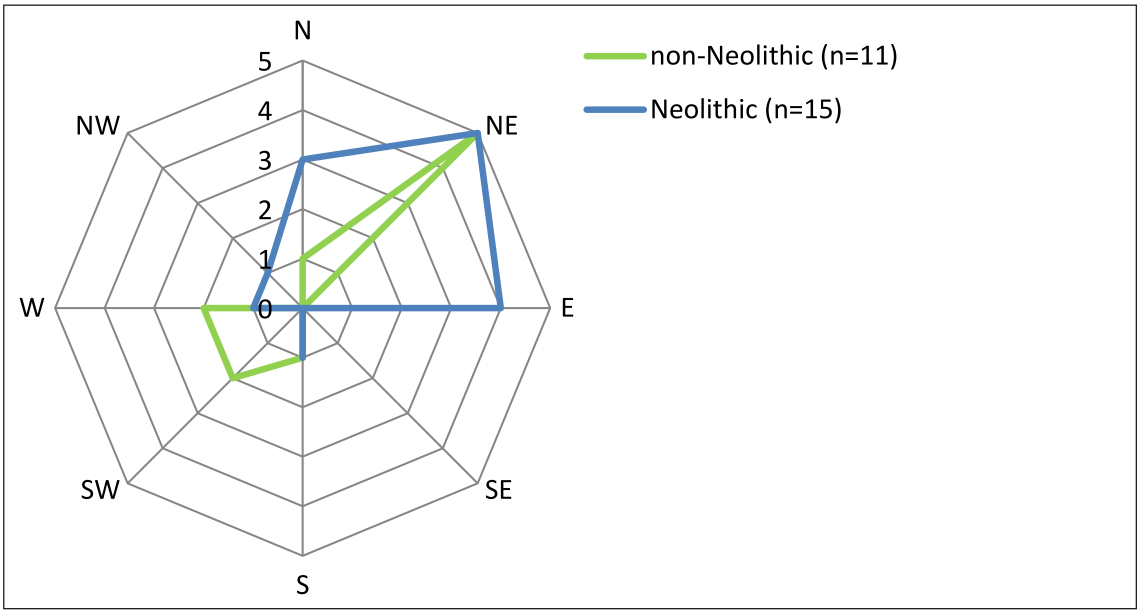


Figure 5.6: Radar chart showing distribution of cave entrance orientation of caves used during the Neolithic versus caves not used during the Neolithic.

Orientation could be established for 15 of the 18 Munster caves included in this study. Twelve of these caves faced in north to east directions (fig. 5.6), which implies that caves facing away from the sun may have been preferred for religious/funerary activities in the Neolithic. This also suggests that it is more likely to find evidence for Neolithic activity in caves that are oriented north to east. An alternative explanation may found in bedrock morphology in the area. Caves generally form along joints and fissures in the thickly bedded limestone or along bedding-plane partings. The former types of caves form a geometric network of straight passages that are connected by perpendicular galleries, whereas the latter form more organic and random networks. The orientation of the joint lines for Dungarvan and much of Clare partially corroborate with the observed orientations in that they follow these joints and fissures (Bunce 2015, pers. comm.; Barry 2015 pers. comm.). However, limestone fractures at right angles which causes caves to develop along two general axes, thus facing four general directions (Palmer 2007, 237-8). Assuming that cave entrance orientation is equally distributed along these two axes, we are left with a clear bias towards north to east orientations for Neolithic caves.

Orientation of caves used during the Neolithic was also strongly correlated with the presence of Neolithic artefacts (table 5.2). East-west oriented caves were more frequently associated with the presence of Neolithic artefacts than those that were not (fig. 5.7).

Correlations between cave orientation and artefacts

Statistics		Artefact	Lithic	Axe	Pottery
Kendall's tau_b		0.68	0.287	0.267	0.218
	Sig. (2-tailed)	**0.006**	0.241	0.276	0.374
Spearman's rho		0.742	0.313	0.291	0.237
	Sig. (2-tailed)	**0.002**	0.256	0.292	0.394

Table 5.2: Correlation analysis between orientation and presence of artefacts in general and different artefact types. Significant correlations ($p < 0.05$) are printed in bold.

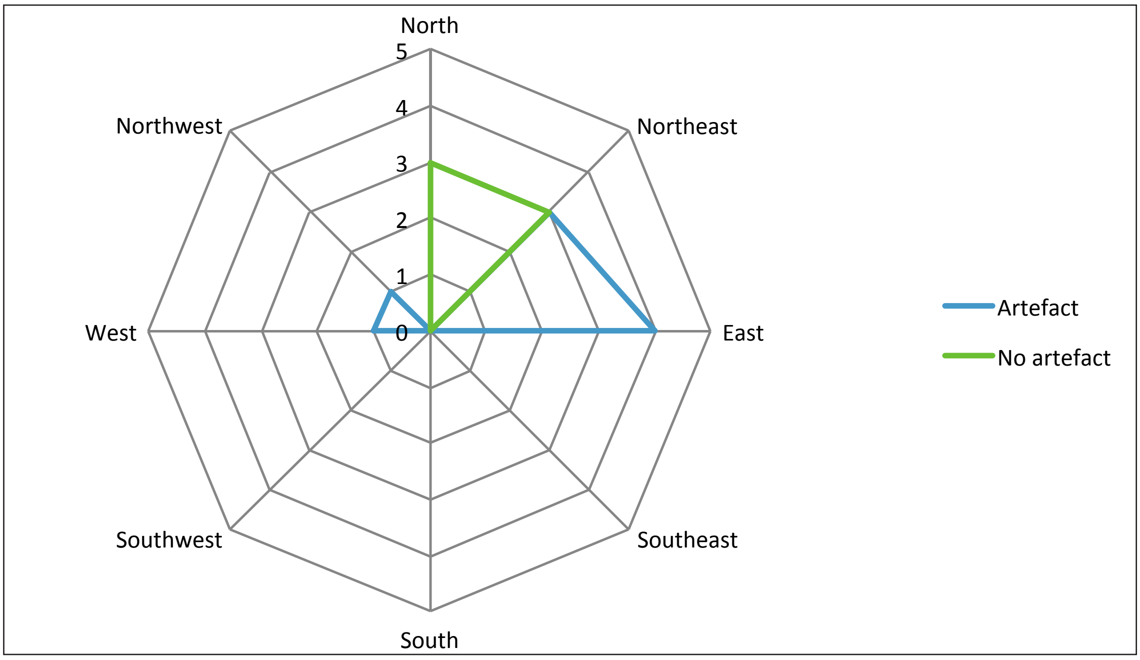


Figure 5.7: Distribution of cave entrance orientation in caves used during the Neolithic divided into artefacts present / absent sub-groups.

Environment

With the exception of Connaberry Cave C and Red Cellar Cave, all caves used during the Neolithic in Munster are associated with small knolls and outcrops and are not associated with uphill landscapes. This, however, is not a pattern that indicates Neolithic preferences for these locations but rather is based on two external factors: geology and antiquarian choices. As discussed in Chapter 4, the limestone in Munster is predominantly low lying and only the Burren features caves in significant numbers that are located in upland areas. Research bias can be named as another influencing factor that reflects the preference of antiquarians to excavate caves that occur in clusters and in easily accessible loci, so that they could easily move from one cave to the next.

The topography of the limestone regions in Munster and North Connaught are inherently different, which made the use of variables derived from DEMs and those influenced by geology, such as distance to water, unfeasible. Moreover, those variables were explored in depth in Chapter 4 and no significant relationships between these and the presence of Neolithic archaeology in caves could be detected.

Overview of the predictor variables and the final predictive model

While uncertainties surrounding the data from caves used during the Neolithic and the lack of a calibration data set did not allow for a quantitative statistical model, some deductions could be made that were used to create a cognitive-deductive model. This aided the identification of caves that were more likely to have been used during the Neolithic than others. Furthermore, a correlation between the presence of Neolithic artefacts and an east-west orientation was detected using correlative-inductive methods. This was a significant finding in itself but more than one factor was needed to create a convincing predictive model for caves used in a non-funerary related ritual context. Lacking these factors, precedence was given to predicting the presence of excarnation rituals in caves. Six variables were identified based on current knowledge about funerary activity in Irish caves:

1. A small entrance
2. Low complexity
3. A single access point
4. Less than 20m passage length
5. Low ceiling
6. North to east orientation

While the morphological variables confirmed Dowd's observations about preferred cave morphology (2008), the dominance of north to east facing caves was a newly discovered correlation. However, because cave orientation is likely influenced by bedrock geology (see this chapter, p. 138), this variable could only be a strong predictor in its local geographical context, but at the same time should not be dismissed entirely as an indicator. To use these variables in the predictive model in the North Connaught research area, local factors, such as topography and passage length needed to be taken into account and adjusted for accordingly. For this purpose, an intuitive weighting system was applied to the individual variables giving the most important variables a higher weight while decreasing the weight of those which were either of less importance or not directly applicable to the North Connaught research area. A weighting factor > 1 inflated the coefficient of a variable while a factor < 1 deflated it.

The aim was to develop an equation that could combine a complex of observations regarding cave morphology and output a value that could indicate which cave most closely matched the patterns observed in Neolithic caves. Each variable was already divided into three different categories that represented the amount of caves that displayed this particular type of morphological trait. The principle was that if more caves fell into a particular category, that category was given more importance in the prediction. The percentages for each category were transformed into scores or coefficients by dividing them by 100. For example, 53.8% of caves fell into the category 'small' in the variable 'passage height', which resulted in a score of 0.53 for that variable. To weight the scores for significance, each score was multiplied by a weighting factor based on the relative significance of each variable. Orientation was given a coefficient of 0.5, as it was one of the strongest but the least reliable predictor in this context. The variable 'Entrance dimensions' was given the highest weighting factor of two, to account for its seemingly essential importance in Neolithic funerary activity. The resulting equation resembles that of a simple regression equation:

$$l_y \frac{(a_{na}w_1 + b_{nb}w_2 .. + i_{ni}w_i)}{i}$$

Where l_y is the likelihood of a cave being used during the Neolithic, i_{ni} the score for a category within variable ($_{ni}$) and w_i the weight assigned to each variable.

The likelihood score ranged from 0.109 to 0.768, meaning that the highest scoring cave could be seven times as likely to contain Neolithic archaeology than the lowest scoring one.

The final equation was:

$$l_y = \frac{(Entrancedimensions_{ni}2 + Numberopenings_{ni}1.8 + Complexity_{ni}1.6 + Length_{ni}1.4 + Height_{ni}1.2 + Orientation_{ni}0.5)}{6}$$

The equation was translated into an Excel formula that queried data from multiple tables to calculate the likelihood value:

=SUM(((VLOOKUP(I2,Orientation!B:E,4,FALSE)*0.5)+(VLOOKUP(D2,'Sheet 4 - Table 1-1'!C:H,4,FALSE)*1.6)+(VLOOKUP(E2,'Sheet 4 - Table 1-1'!C:H,2,FALSE)*2)+(VLOOKUP(F2,'Sheet 4 - Table 1-1'!C:H,6,FALSE)*1.2)+(VLOOKUP(G2,'Sheet 4 - Table 1-1'!C:H,4,FALSE)*1.8)+(VLOOKUP(H2,'Sheet 4 - Table 1-1'!C:H,5,FALSE)*1.4)*1)/600)

To answer questions about the relationship between caves and Neolithic monuments, a different approach needed to be taken since there was no quantifiable data available from Munster, as was also discussed in Chapter 4.

5.3 Applying the findings to the North Connaught research areas

The North Connaught research region consisted of eight small areas that were selected in which all horizontal relict caves that were accessible without climbing equipment were recorded and surveyed (see Chapter 3). The eight research areas were analysed individually by considering the calculated likelihood scores (lhs) in context with their landscape setting. The discovery of 13 human bones during fieldwork in Knocknarea Cave K led to the development of a more in-depth analysis and re-interpretation of the Knocknarea research area. The results are presented in Chapter 6. Knocknarea is the only research area in the North Connaught region that features Neolithic cave use and much of its interpretation has influenced analysis and interpretations of the remaining research areas (see Chapter 6).

Applying the model to North Connaught caves

Data conversion for the North Connaught region followed the same rules as the Munster region with the exception of the category 'passage length'. Its classification parameters were slightly adjusted from the Munster model to *under 3m* (Category 0), *3m to 21m* (category 1), *21m to 50m* (category 2), and *over 50m* (category 3) to account for local length variation. The orientation categories were converted to categorical values each representing 45° sections of the compass (1=N: 337.5°-22.5°; 2=NE: 22.6°-67.5° *etc.*).

Over 80% of the caves included in the analysis of the North Connaught region were under 21m long. The most extensive caves were the Keash Caves with up to five entrances per system. These caves also had the largest entrances and passages. The majority of caves, however, were simple passages with only one entrance and a slight tendency to high passages (fig. 5.8).

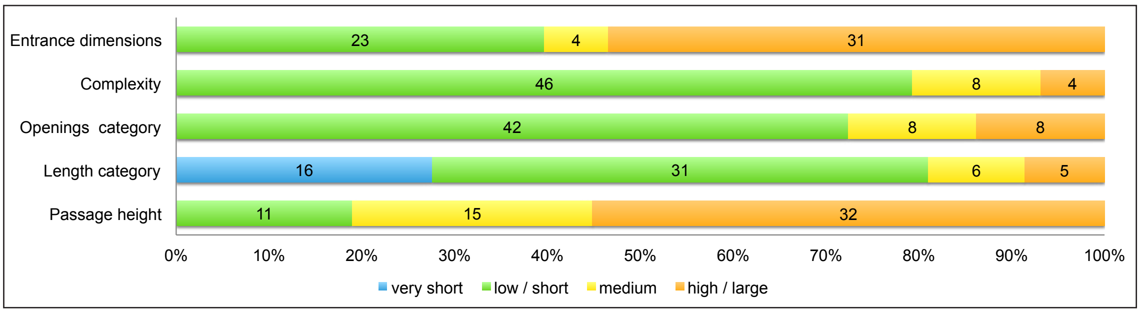


Figure 5.8: Distribution of morphological traits of caves in the North Connaught research area.

Fifty-three per cent of caves in the North Connaught research areas were oriented in a north to south direction, whereas 80% of the Munster caves were in a north to east direction. None of the caves were oriented towards the southeast in either region. As discussed previously, cave orientation is very dependent on underlying bedrock geology, and particularly where caves are clustered together, caves tend to be oriented either in the same direction or at right angles to each other. For example, all the caves on Knocknarea and the Keash Caves were oriented in that fashion (fig. 5.9).

The caves with the highest likelihood scores for containing Neolithic archaeology were caves with small entrances. All but one of those cave were in either the Bricklieves or

Cave name	Orientation (°)	Length (m)	Complexity	Entrance size cat.	Passage height cat.	Openings category	Length category	Orientation category	Likelihood score
Knocknarea Cave R	340	20	1	1	1	1	1	1	**0.762**
Treanscrabagh Cave	334	17	1	1	1	1	1	8	**0.751**
Knocknarea Cave A	347	14	1	1	2	1	1	1	**0.747**
Knocknarea Cave B	345	13	1	1	2	1	1	1	**0.747**
Knocknarea Cave C	350	14	1	1	2	1	1	1	**0.747**
Deerpark Cave 1	356	0	1	1	2	1	1	1	**0.747**
Keash Cave F1	0	0	1	2	1	1	1	6	0.674
Knocknarea Cave F	347	11	1	1	3	1	1	1	0.655
Knocknarea Cave G	345	15	1	1	3	1	1	1	0.655
Parallel Cave	340	13	1	3	2	1	1	5	0.641
Carricknahorna Cave	210	10	1	3	2	1	1	6	0.635
Knocknarea Cave N	231	9	1	3	2	1	1	6	0.635
Fermoyle Cave 1	245	8	1	3	2	1	1	6	0.635
Sramore Fox Hole	8	3	1	1	1	1	0	1	0.631
Sheemore Cave 3	355	3	1	1	1	1	0	1	0.631
Knocknarea Cave V	166	2	1	1	1	1	0	5	0.620
Calcite Cavern	258	5	1	1	1	1	0	7	0.620
Knocknarea Cave D	343	4	1	1	2	1	0	1	0.616
Leean Cave 3	210	4	1	1	1	1	0	6	0.614
Knocknarea Cave K	350	26	1	1	1	2	2	1	0.609
Tully Cave 3	300	20	2	1	1	2	1	8	0.600
Legendary Tunnel	105	30	1	1	3	1	2	2	0.593
Knocknarea Cave J	350	20	1	1	3	2	1	1	0.575
Muckelty Hill Cave 6	159	0	1	1	3	1	2	5	0.571
School Cave	63	5	1	3	3	1	1	2	0.570
Curraghan Cave	270	10	2	3	2	1	1	7	0.569
Fawnarry Cave	105	8	1	3	3	1	1	3	0.565
Culleenduff Cave 2	164	6	1	1	3	2	1	5	0.563
Gully Cave C	339	5	1	3	3	1	1	1	0.559
Sheemore Cave 2	354	8	1	3	3	1	1	1	0.559
Sheemore Cave 1	354	13	1	3	3	1	1	1	0.559
Doons Cave 4	180	16	1	3	3	1	1	5	0.548
Doons Cave 1	170	17	1	3	3	1	1	5	0.548
Cross Cave	213	18	1	3	3	1	1	6	0.543
Keash Cave J1	0	0	1	1	1	2	0	7	0.540
Muckelty Hill Cave 1	70	2	1	3	2	1	0	3	0.526
Culleenduff Cave 3	172	3	1	1	3	1	0	5	0.512
Poulagaddy	0	20	1	1	3	1	0	8	0.512
Doons Cave 2	174	7	1	3	2	1	0	5	0.509
Muckelty Hill Cave 4	170	3	1	3	2	1	0	5	0.509
Leean Cave 1	241	4	2	2	2	2	1	6	0.508
Chapel Cave	98	20	2	3	3	1	1	3	0.494
Knocknarea Cave H	350	24	1	3	3	1	2	1	0.486
Keash Cave G	232	26	1	3	3	1	2	6	0.470
Fork Rift Cave	259	16	1	3	3	1	3	7	0.461
Keash Cave O1	0	0	1	2	3	1	0	7	0.441
Knocknarea Cave I	348	4	1	3	3	1	0	1	0.428
Leean Cave 2	15	13	2	3	2	3	1	1	0.421
Ravens Wing Cave	360	40	2	3	3	1	2	1	0.415
Annexe Cave	276	3	1	2	3	3	1	7	0.412
Knocknarea Cave O	337	6	1	3	3	2	0	1	0.348
Culleenduff Cave 1	166	3	1	3	3	2	0	5	0.337
Knocknarea Cave E	347	19	2	3	3	3	1	1	0.328
Keash Cave O	281	96	2	3	3	3	1	7	0.317
Keash Cave L - N	279	145	3	3	3	3	3	7	0.159
Keash Cave B - F	275	186	3	3	3	3	3	7	0.159
Keash Cave P - R	294	94	3	3	3	3	3	8	0.159
Keash Cave H - K	232	98	3	3	3	3	3	6	0.153

Table 5.3: Summary of results from the North Connaught research areas.

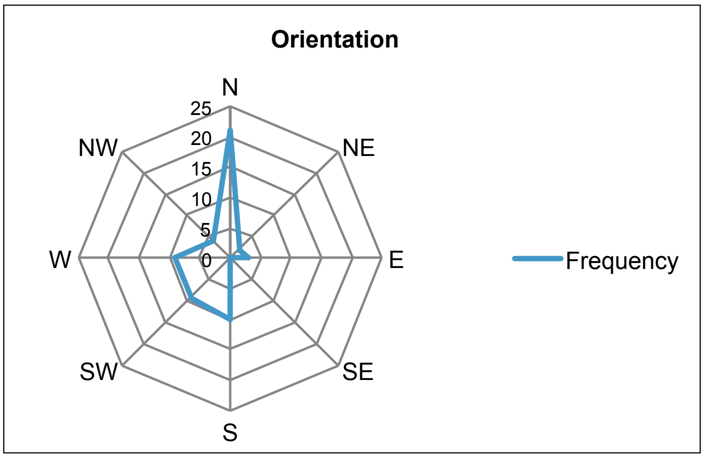


Figure 5.9: Distribution of entrance orientation in caves in the North Connaught research area.

the Knocknarea research areas. Both areas also had the highest concentration of Neolithic monuments (table 5.3). The only exception was Deerpark Cave which is in an area that contains one Neolithic monument.

5.4 Knocknarea

A detailed analysis of the two caves on Knocknarea that produced human bones of Neolithic date, along with an introduction to the area's topography and archaeology, is given in Chapter 6. This section will focus on the analysis of the remaining caves of unknown archaeological potential.

Caves on Knocknarea

Of the 27 visited caves sites on Knocknarea, 18 were included in the analysis (fig. 5.10). The remaining caves were either too small (2m or less deep, 0.4m or less wide) to be considered suitable for funerary rituals, as was the case for Caves M, P, U, V, and W, or their location required climbing equipment for access, as was the case with Caves L, P, and Q. Two caves on the east slopes of Knocknarea could not be reached due to their location in difficult terrain and because of health and safety concerns.

The morphological homogeneity of the Knocknarea caves is striking, which also resembles the proposed morphology preferred for funerary activities during the Neolithic. This was particularly apparent in caves that were located in close proximity to one another. Caves A, B, C, D, F, G, H, J, K, and R all consist of straight, relatively short, and narrow passages with no major galleries branching off. The only exceptions are Knocknarea Caves E and I. Cave E (fig. 5.11) consists of three parallel passages that are inter-connected by a cross

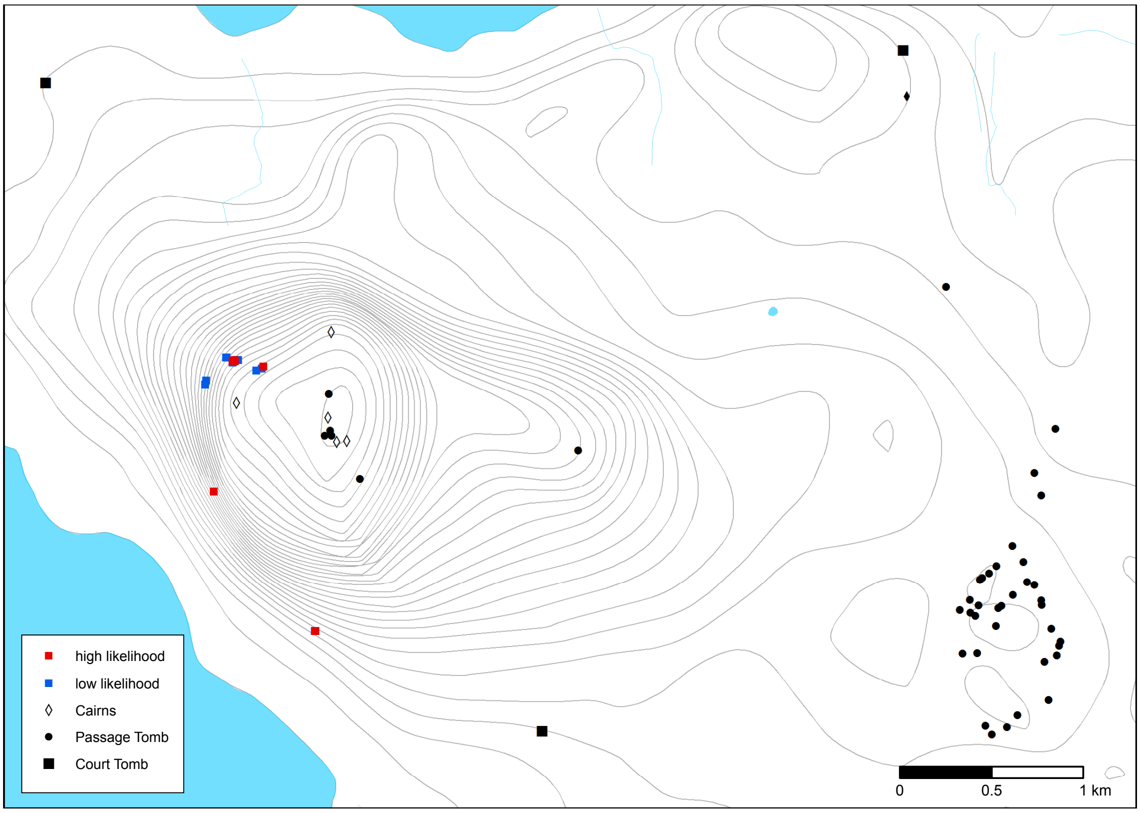


Figure 5.10: Model outcomes for the Knocknarea research area.

passage at the rear. Cave I is a heavily eroded passage remnant that consists of a large almost square opening that extends for 4m into the cliff (fig. 5.12). Twelve caves have openings small enough to be easily blocked and, apart from five, all caves are oriented in a northerly direction. Differences within morphological categories is more pronounced in passage length, which ranges from 3m to 26m (fig. 5.13), and passage height, which ranges from 0.5m to 7m (fig. 5.14).

Six caves produced similar likelihood scores of 0.67 to 0.78 (table 5.4). One is Knocknarea Cave K (see Chapter 6) ranking 10th in the group, despite being

Figure 5.11: Entrance Knocknarea Cave E.

used as an excarnation site during the Neolithic. The most likely explanation is the presence of a second cave, Knocknarea Cave J, which connects to Knocknarea Cave K. This connection is probably responsible for the low score. This should be interpreted as an outlier.

Figure 5.12: Knocknarea Cave I.

Knocknarea Cave R was predicted to be the most likely cave in the research area to have been used during the Neolithic. Located some 200m east of Cave K, Cave R is slightly lower and shorter than Knocknarea Cave K and does not feature a second entrance. A similarly small entrance leads down a muddy slope onto a silt and rock covered floor. However, the sediment is very thin and bedrock is exposed throughout the cave.

The caves that penetrate the same grassy cliff as Cave C are all very similar in length and shape to Caves K and C and, with the exception of Caves D and E, all scored high on the likelihood scale. Cave D is an underdeveloped narrow fissure that rapidly tapers from

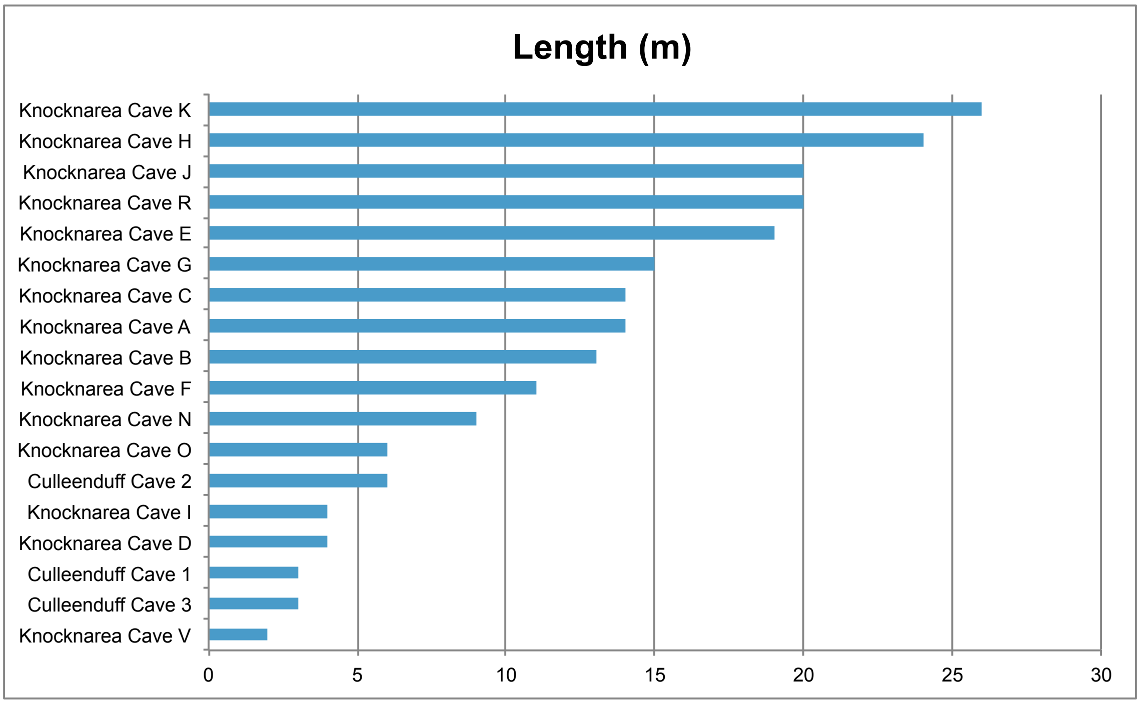


Figure 5.13: Distribution of length values of Knocknarea caves.

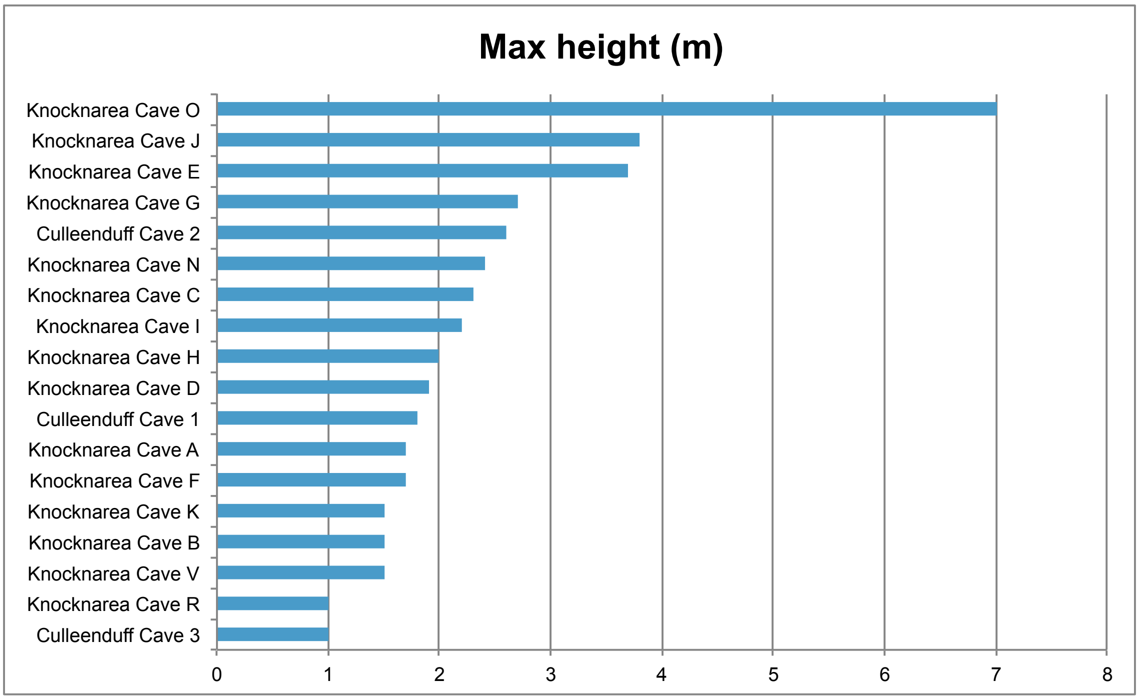


Figure 5.14: Distribution of passage height values of Knocknarea caves.

Cave name	Complexity	Entrance dimension cat.	Passage height cat.	Openings category	Length category	Orientation category	Likelihood score
Knocknarea Cave R	1	1	1	1	1	1	**0.762**
Knocknarea Cave A	1	1	2	1	1	1	**0.747**
Knocknarea Cave B	1	1	2	1	1	1	**0.747**
Knocknarea Cave C	1	1	2	1	1	1	**0.747**
Knocknarea Cave F	1	1	3	1	1	1	**0.655**
Knocknarea Cave G	1	1	3	1	1	1	**0.655**
Knocknarea Cave N	1	3	2	1	1	6	0.635
Knocknarea Cave V	1	1	1	1	0	5	0.620
Knocknarea Cave D	1	1	2	1	0	1	0.616
Knocknarea Cave K	1	1	1	2	2	1	0.609
Knocknarea Cave J	1	1	3	2	1	1	0.575
Culleenduff Cave 2	1	1	3	2	1	5	0.563
Culleenduff Cave 3	1	1	3	1	0	5	0.512
Knocknarea Cave H	1	3	3	1	2	1	0.486
Knocknarea Cave I	1	3	3	1	0	1	0.428
Knocknarea Cave O	1	3	3	2	0	1	0.348
Culleenduff Cave 1	1	3	3	2	0	5	0.337
Knocknarea Cave E	2	3	3	3	1	1	0.328

Table 5.4: Results from Knocknarea research area.

0.7m in width near the entrance to 0.3m and would have been unsuitable for funerary rituals. Cave E would have also been less suitable because of its higher complexity and high ceiling, which both would have required more effort to block than other caves in the vicinity. Caves A, B, and F are all of similar length (11m - 14m), width (0.9m - 1.1m), and height (1.5m - 1.7m). Entrance dimensions show higher variations in height (0.7m - 1.5m) and width (0.6m - 1.1m). However, the entrance dimension may have changed since the

Neolithic due to possible fluctuations in soil accumulation and erosion at the entrances.

Sedimentation in the Culleenduff Caves, three tectonic caves that formed along fault lines in a small rocky outcrop at the foot of Knocknarea, is extremely thin and, apart from their low likelihood scores, the presence of surviving archaeological material is unlikely.

Knocknarea Caves N, O, and V are the only accessible caves with a potential to be used for funerary activity along the western cliff but fall short on one or more morphological traits to gain higher scores. Cave N, a 9m long straight passage, is the seventh highest scoring cave but has a too high entrance to be blocked up efficiently. Cave O is a 7m tall fissure with a projecting "window" and small entrance chamber that would have been suitable to accommodate activities. Cave V, the southernmost cave in this series, features a small flat terrace, while all the others open onto a steep scree-slope that is covered only partially with a thin layer of soil and vegetation. At the entrance, two courses of stones look as if they were placed deliberately to create a small retaining wall. It is not substantial enough to sustain a wall high enough to seal the 1.5m high entrance and it may be connected to later activity.

The presence of human remains in two of the twelve densely clustered Knocknarea caves makes these viable targets for further investigation. Six caves share morphological traits with those that were used during the Neolithic and, thus they are the most likely in the group to produce human remains. While Knocknarea Cave R scores highest in the likelihood analysis, its thin layer of sediments may not offer much archaeological potential. Caves A, B, F, and G warrant closest attention, not least because of their close proximity to Caves K and C.

5.5 The Bricklieves

The largest research area and the richest in Neolithic archaeology are the Bricklieves Mountains, a large limestone outcrop bordered by Lough Arrow to the east and an undulating drumlin landscape to the west. The thick limestone deposits are intersected by deep steep sided valleys into which several caves open (see Appendix 1.5 for detailed topographical and geological description).

Archaeological background

The Bricklieves and Keshcorran were a focus of Neolithic activities, as reflected in the presence of at least 23 passage tombs, two court tombs and one wedge tomb (Hensey *et al.* 2014, 8), commonly known as the Carrowkeel-Keshcorran passage tomb complex. Hensey *et al.* (2014) argue that this area should be seen as part of a larger complex that also incorporates two large cairns (possibly passage tombs), five court tombs, three wedge tombs, two portal tombs and four unclassified tombs in the Moytirra uplands east of Lough Arrow. Additionally, two court tombs, one portal tomb, one passage tomb, and an unclassified megalithic tomb are distributed within the low lands between these two upland regions. Only one of the three tombs outside the Carrowkeel-Keshcorran complex, Ardloy, is a confirmed passage tomb. Heapstown cairn, which also features passage tomb art on one of its kerb stones (Hensey and Robin 2011), is likely to contain a passage or chamber (Hensey *et al.* 2014, 11). An antiquarian excavation of Suigh Lughaidh did not reveal any internal structure (*ibid.* 10; Wood-Martin 1884, 462).

Since Macalister's excavation of eight tombs at Carrowkeel (Macalister *et al.* 1912), only limited investigations (Bergh 1986, 2006; Buckley and Mount 1994; Rynne 1969) and landscape assessments have taken place there (Bergh 1995; Hensey *et al.* 2014; Mount 1996). A number of targeted landscape studies have produced new and possibly new prehistoric monuments such as the large enclosure surrounding Cairn R and two cists on Keshcorran (Kytmannow 2005) as well as the addition of 105 hut sites (Bergh 2006) at Mullaghfarna townland to the previously 82 hut sites recorded by Macalister (1912) and Grogan (1996). Neolithic and Bronze Age dates have been obtained from some of the Mullaghfarna sites with current evidence leaning more towards a peak of use during the Neolithic (Hensey *et al.* 2014, 15).

Much of the uplands in the Carrowkeel-Keshcorran complex were probably covered in forests that required organically rich soils to grow on, with blanket bog developing at a later stage (Mount 1996, 3). This means that Neolithic people built their monuments in a very different environment, when much of the underlying limestone was covered. Furthermore, the original forests that would have grown in the low lands and valleys in and around the hills and ridges were replaced by settlements and farmsteads during the Neolithic, which are now likely preserved beneath blanket bog (*ibid.* 9).

Stolze *et al.* (2013) obtained pollen cores from Loughmeenaghan, Lough Availe, and Templevanny Lough which are all located within the Carrowkeel catchment. Their cores indicate the introduction of cereal cultivation sometime after the Early Neolithic and a decline from the end of the Middle Neolithic. Those events coincide with the Early Neolithic Elm decline and woodland recovery along with climatic deterioration during the Late Neolithic (Hensey *et al.* 2014, 14). Radiocarbon dates obtained from the Carrowkeel-Keshcorran complex indicate an increase in activity around 3200 to 2900 Cal. BCE (Hensey *et al.* 2014, 16). The dates from the passage tombs coincide with those from Knocknarea Cave K (Dowd and Kahlert 2014). The juvenile from Knocknarea Cave K (4499± 58 BP) and Carrowkeel Cairn G (4342± 28 BP) are of similar date. Both dates fall into the peak of activity in caves during the Neolithic. Furthermore, recent analysis carried out on human bones from some of the Carrowkeel tombs revealed cut marks typical of defleshing (Hensey *et al.* 2014, 22), which indicates that excarnation rituals were practiced within the complex.

Caves in the Bricklieves

Of 36 caves recorded in this region, five were subsequently excluded from the study as their dimensions did not qualify them as true caves. These sites were kept as entries 17, 81, 83, 86, and 90 in Appendix 1 but are not further discussed. The Keash Caves, which are commonly named separately by their entrance, were considered as groups based on internal connections. This left 25 caves to be analysed (fig. 5.15). After calculating and weighting all variables, five caves produced likelihood scores of over 0.6 (table 5.5).

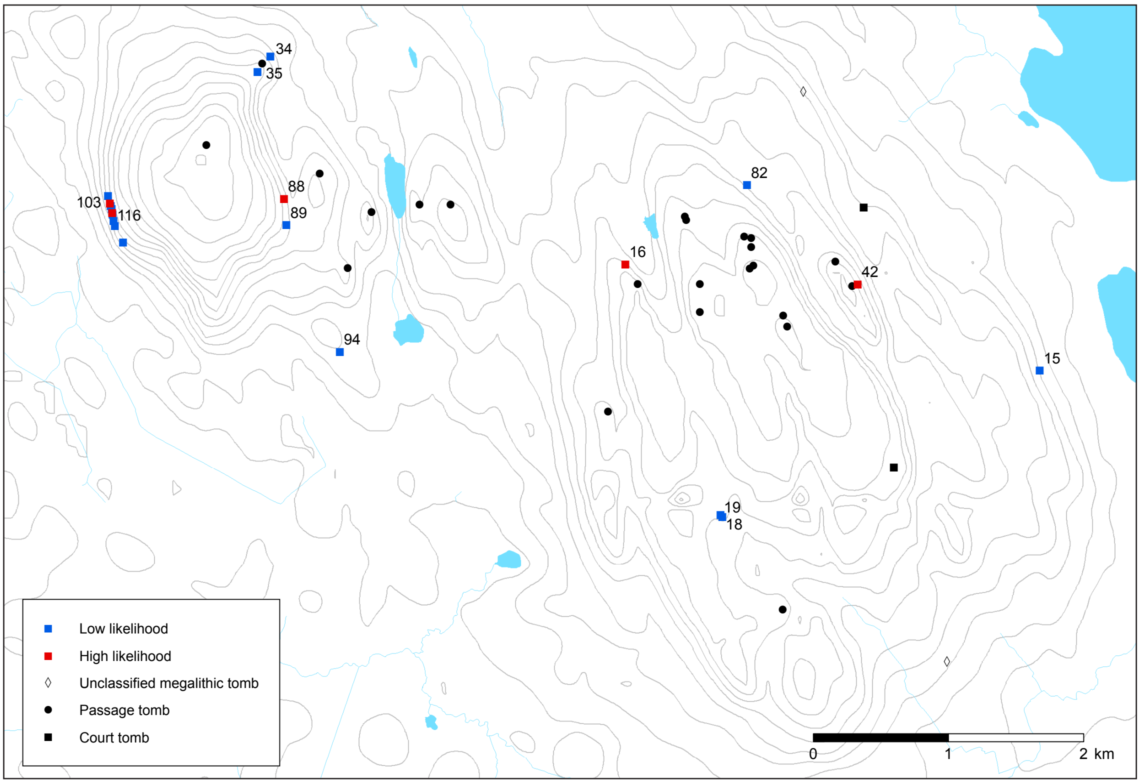


Figure 5.15: Overview of Bricklieves research area and results from analysis.

The highest scoring cave was Treanscrabbagh Cave (lhs = 0.751, ID 16). Its location is probably the most intriguing, as it penetrates a low limestone shelf some 160m northwest of passage tomb Cairn B and *"the physical proximity between monument and cave would not have been lost to Neolithic people"* (Dowd 2015, 111). The passage tomb sits above the cave on a narrow ridge (fig. 5.16) and has an undifferentiated north-facing chamber. It has been described by Macalister as "*the largest and best-formed of the entire series, with the exception of E"* (Macalister *et al.* 1912, 321). Its commanding location at just over 300m OD allows for unrestricted views across the landscape to the north, including the Cúil Irra peninsula.

Treanscrabbagh Cave's morphology is similar to Knocknarea Cave K, with a tight squeeze that leads into a narrow and short passage, albeit tighter than Knocknarea Cave K. The passage is extremely low and crawling is the only means to move through it. However, the floor is likely to have been lower during the Neolithic which would have allowed more space for activity. The floor of the entrance area is filled with loose stones that could have been the result of natural processes but intentional blocking by humans is also a possibility.

Cave name	ID	Complexity	Entrance dimensions	Passage height	Openings category	Length category	Orientation category	Likelihood score
Treanscrabagh Cave	16	1	1	1	1	1	8	**0.751**
Keash Cave F1	103	1	2	1	1	1	6	**0.674**
Parallel Cave	42	1	3	2	1	1	5	**0.641**
Carricknahorna Cave	18	1	3	2	1	1	6	**0.635**
Calcite Cavern	88	1	1	1	1	0	7	**0.62**
Legendary Tunnel	89	1	1	3	1	2	2	**0.593**
School Cave	34	1	3	3	1	1	2	0.57
Gully Cave C	94	1	3	3	1	1	1	0.559
Cross Cave	19	1	3	3	1	1	6	0.543
Keash Cave J1	116	1	1	1	2	0	7	0.54
Poulagaddy	35	1	1	3	1	0	8	0.512
Chapel Cave	15	2	3	3	1	1	3	0.494
Keash Cave G	104	1	3	3	1	2	6	0.47
Fork Rift Cave	82	1	3	3	1	3	7	0.461
Keash Cave O1	117	1	2	3	1	0	7	0.441
Keash Cave O	111	2	3	3	3	1	7	0.317
Keash Cave L - N	108	3	3	3	3	3	7	0.159
Keash Cave P - R	112	3	3	3	3	3	8	0.159
Keash Cave B - F	98	3	3	3	3	3	7	0.159
Keash Cave H - K	105	3	3	3	3	3	6	0.153

Table 5.5: Morphological classes and likelihood scores for the Bricklieves research area.

Figure 5.16: Treanscrabbagh Cave (location indicated), penetrating the lower cliff with Cairn B dominating the view from the north.

Oriented due north, Treanscrabbagh Cave overlooks the Cúil Irra peninsula to the north and Doonbredia and Keshcorran immediately west, where cairns Q, R, S, V, and W are visible. Its location marks the western extent of the main Carrowkeel complex and from this point of view, the cave would have been in a more liminal location, albeit spatially not as clearly separated as Knocknarea Cave K would have been from the monuments on top of Knocknarea.

Parallel Cave (lhs=0.641, ID42) penetrates one of the upper limestone cliffs below and *c.* 100m west of Cairn P, a low grass-covered chamberless cairn (Hensey *et al.* 2014, 30; Macalister *et al.* 1912, 330) that sits on the top of Mullaghfarna (fig. 5.17). Cave and cairn are separated by a succession of vertical cliffs and access is only possible via the Mullaghfarna hut site complex (fig. 5.18). Being in a secluded location outside the view of the passage tomb complex and facing Lough Arrow, the cave bears some resemblance to the Neolithic caves on Knocknarea both in its location as well as in morphological terms. Although the cave features a large entrance, rock tumble and a large slab just inside the main entrance significantly reduce the passage's dimension. Past the rock tumble, a

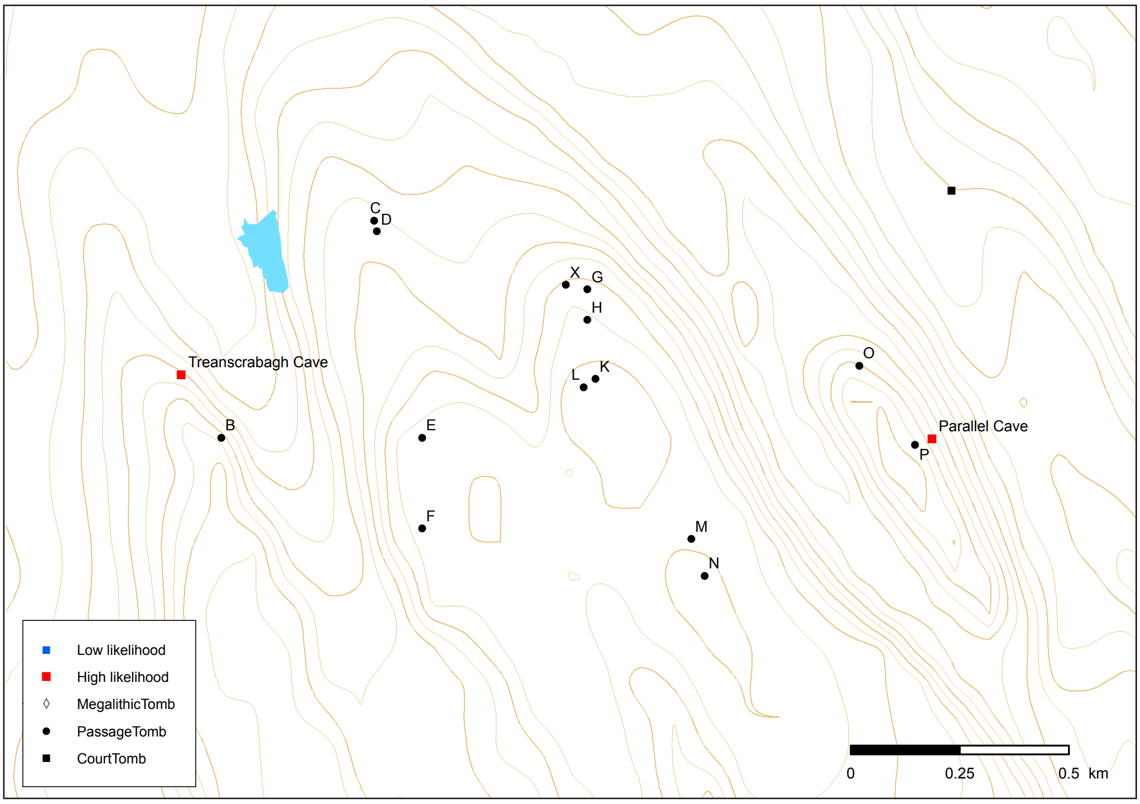


Figure 5.17: Treanscrabbagh Cave and Parallel Cave in relation to their setting within the northern part of the Bricklieves research area.

Figure 5.18: Mullaghfarna hut site complex, looking northwest from below the summit.

4m long passage would have been suitable for funerary rituals. However, the entire floor is covered with large slabs that collapsed from the roof and larger stones (fig. 5.19).

Calcite Cavern (lhs=0.620, ID 88) is located on the western slope of Keshcorran Hill, which hosts a number of Neolithic and possible Neolithic monuments including passage tomb Cairn Q, stone cists, and a large enclosure (Kytmannow 2005). The cave is a small chamber that can be accessed via a low but wide opening. With a length of 5m and a ceiling height only allowing for access on hands and knees, it does not fall within the morphological parameters observed in Neolithic caves. Furthermore, the cave's central location within the Carrowkeel/Keshcorran complex - five cairns are visible from the cave (fig. 5.20) - does not invoke the same notion of liminality and seclusion as can be observed at Knocknarea. Morphologically and spatially, Calcite Cavern would have been a less suitable cave for funerary activity.

The Legendary Tunnel (lhs=0.593, ID 89) penetrates the same cliff face as Calcite Cavern, which lies 300m to the south. While they share the same setting, they are morphologically different. The cave entrance sits at the western end of a small depression leading into a steeply sloping long and narrow rift passage. The depression is filled with trees and shrubs that conceal the entrance to a degree that it is barely visible to the uninitiated

Figure 5.19: Inner passage of Parallel Cave.

Figure 5.20: View from Calcite Cavern onto Carrowkeel.

(fig. 5.21). Although the entrance measures only 1m by 1m, the steeply sloping passage would have posed some difficulty for it to be blocked. The cave is by far the most richly decorated cave within the complex in terms of speleothems (fig. 5.22), only rivalled by Plunkett Cave on Keashcorran. Knocknarea Cave K is also the most richly decorated cave on Knocknarea Mountain. Calcite has shown to have been of significance in the

Figure 5.21: Well concealed entrance to the Legendary Tunnel.

Figure 5.22: Small chamber with pool at the bottom of the Legendary Tunnel.

Figure 5.23: The Keash Caves.

placement of human remains in some instances where bones were deliberately placed on calcite floors or pockets of white calcite deposits (Coleman 1947, 72; Dowd 2015, 113). Its concealed entrance and the speleothems in Legendary Tunnel may have been of significance to people who frequented the monuments on top of Keshcorran (fig. 5.17).

The Keash Caves (fig. 5.23) are located on the west flank of Keshcorran at the westernmost extent of the Carrowkeel-Keshcorran passage tomb complex. The caves have been subject to several excavation campaigns in the early 20th century (Bayley Butler *et al.* 1930; Gwynn *et al.* 1940; Scharff 1895, 1902; Scharff *et al.* 1903a; Scharff *et al.* 1903b) but, apart from a polished stone axe found in Plunkett Cave, no evidence for Neolithic activity has been found to date (Dowd 2013b, 76). The principal caves have large entrances and interconnected passages that make them visible from a considerable distance - a trait that was not observed in other Irish Neolithic caves. There are, however, a number of small caves that generally do not receive much attention, one of which is the high scoring Keash Cave F1 (lhs=0.674). It consists of a small northern passage and a more substantial southern passage (fig. 5.24). While the mouth of the latter is just over 2m wide and nearly 3m tall, a ledge further inside reduces the passage dimensions to a size that would have allowed for funerary activities and the passage to be sealed. However, a small test trench was probably dug by one of the earlier antiquarian investigators (see Appendix 1, 144 *ff.*), which showed that sediments along the passage are extremely thin.

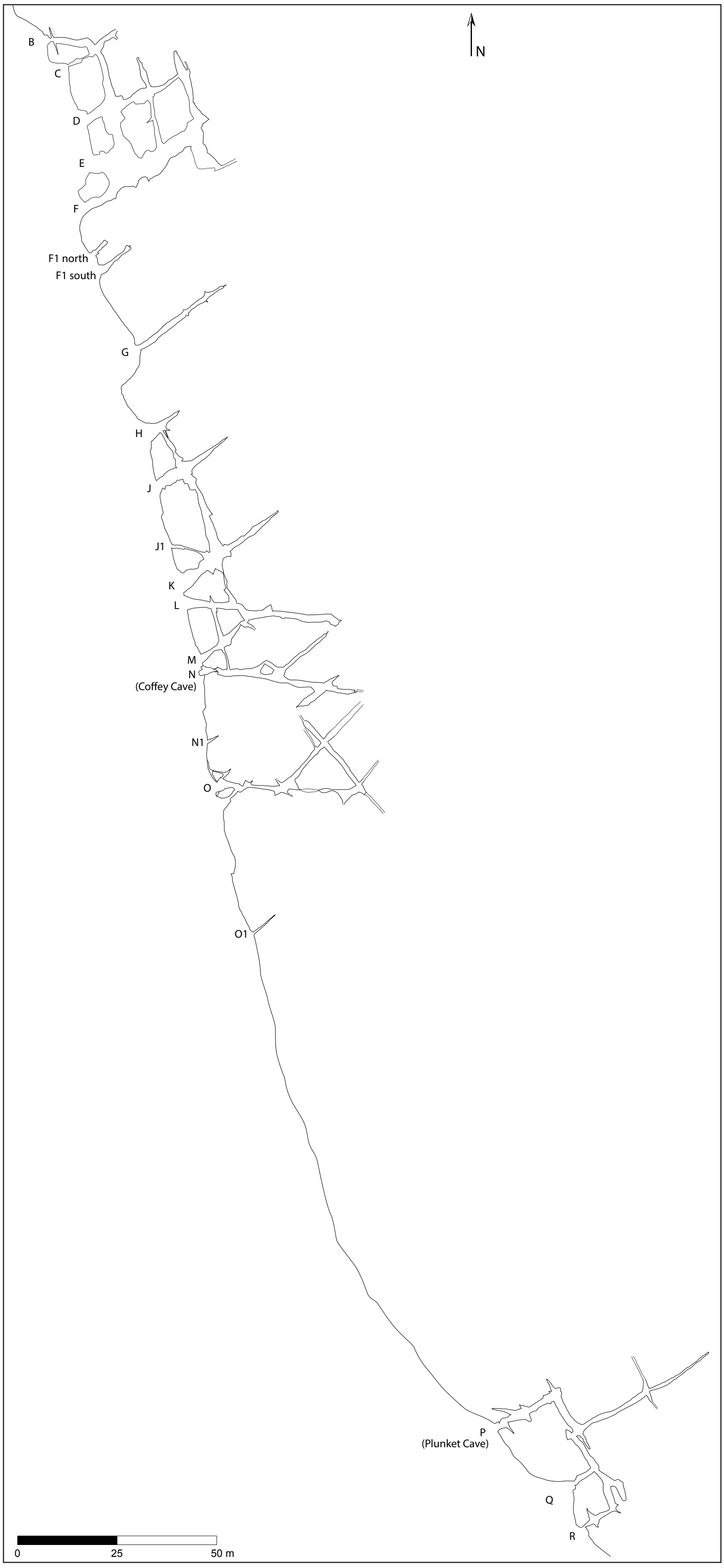


Figure 5.24: Plan view of the Keash Caves.

Carricknahorna Cave (lhs=0.635) and Cross Cave (lhs=0.543) are both located in close proximity to one another and feature a narrow passage that would have been just about spacious enough to accommodate a body (see Appendix 1 for a detailed description of the caves). Accessing the caves requires a scramble up a near vertical ledge that would make blocking the high entrances challenging. Both caves fall into the same morphological categories but Carricknahorna Cave's lower passage gave it a better likelihood score than Cross Cave. Considering the very different topography of the Bricklieves and Knocknarea, two commonalities exist between these two caves and Knocknarea Caves K and C:

1. The caves are all situated in liminal locations, away from the religious focal points (passage tombs). If a spatial separation between a ritual site and megalithic tombs were desired, Carricknahorna Cave would have been an optimal choice.

2. The caves are all in discrete locations and could be easily missed if one is not aware of their presence. If the area was wooded during the Neolithic, it would have been even more difficult to spot the cave.

Moore (2004, 24) mentions that a natural rock formation near Carricknahorna Cave is called the Stirring Rock and is "*a focal point for gathering on Bilberry Sunday*" (fig. 5.25). The large glacial erratic once rested on a natural pedestal that could be rocked with relative ease. While it might have been a simple curiosity, it is plausible that this rock was of some significance to people during the Neolithic, added ritualistic significance to the cave. The cave's short lengths and high entrances (fig. 5.26) would have made them less suitable for burial activities but they could have served as sites for token or votive deposition.

Morphological traits of the remaining caves in the Carrowkeel area were categorised by the North Connaught Model as less likely to have been used for funerary activities. This includes most of the Keash Caves, School Cave, Fork Rift Cave, Chapel Cave, and Poulagaddy Cave. Six of the 20 caves in the Bricklieves had similar morphological traits

Figure 5.25: The Stirring Rock (right), near Carricknahorna Cave, marked red, which penetrates the cliff to the right.

to Munster caves that were used for Neolithic funerary activities. These caves are more likely to produce human remains than others, but that does not rule out that the remaining caves were not visited by Neolithic people. Caves such as Treanscrabbagh Cave, Parallel Cave, and Poulagaddy were found in close proximity to passage tombs and while it is unlikely that their presence influenced the placement of the passage tombs, they probably assumed some significance to the people who frequented the tombs.

Figure 5.26: Entrance to Carricknahorna Cave, looking out.

Using Knocknarea as a template (see Chapter 6), caves located away from tombs may have been more desirable for funerary activities, which make Keash Cave F1 and Carricknahorna Cave the most likely candidates. Both caves are spatially separated from the complex and face away from the tombs. Like Knocknarea Cave C and Knocknarea Cave K, their liminal location and orientation away from the major concentration of megalithic tombs may have been of religious significance. The liminality of the two caves is further enhanced by their setting in the south of the complex, almost in a juxtaposed location to the Cúil Irra peninsula and its rich Neolithic ritual landscape, which seemed to have been a focal point for most of the passage tombs, at least within the Carrowkeel complex (Bergh 1995).

5.6 Sheemore

Sheemore Hill is a small rounded limestone outcrop 3km east of Leitrim Village. The surrounding landscape is dominated by rolling drumlins and undulating areas with thin soil covers, described by Cooney (Cooney 1979, 76) as rocklands. While drumlins characteristically consist of poorly drained glacial till or boulder clay (Mitchell and Ryan 2001, 45-6) between which blanket bog and lakes often develop, rocklands usually feature an often thin but well-drained arable soil cover that may have been sought after by early farmers (Cooney 1979, 81). Sheemore and the elevated landscape immediately to its west consist of such rockland whereas the wider landscape is dominated by more poorly drained drumlins (see Appendix 1.2 for more detail).

Archaeological background

The immediate landscape around Sheemore Hill is devoid of megalithic tombs but the hill's summit is crowned by three passage tombs (fig. 5.27). The next closest megalithic monument is a passage tomb in the townland of Barroe, 2.5km to the northwest. Two of the tombs contain visible chambers that face in a southwest direction. The third, that probably also contains a passage tomb (Condit and Gibbons 1989, 8), remains unopened. The passage tombs are enclosed by a hilltop enclosure and a later enclosure which is also associated with a hut site. The temporal relationship between enclosures and monuments is not known (Moore 2003). Megalithic monuments in south Leitrim are commonly found on lower grounds and are associated with the fertile lower rocklands rather than upland and drumlin landscapes (Cooney 1979, 81).

Caves

At least seven caves were reported along the eastern cliffs of Sheemore (Coleman 1965, 57; Gilhoys 1987, 9) of which three were located in the field and surveyed (fig. 5.27). All three caves are in close proximity to one another along the steep terraced cliffs on the northwest side if the hill.

Figure 5.27: Location of Sheemore caves in relation to passage tombs.

Sheemore Cave 3 (fig. 5.28) is the most likely cave to have been used during the Neolithic (table 5.6). The 3.6m long cave is filled almost to the roof with sediments, leaving only a 0.5m gap. The sharply sloping ground revealed that the sediment layer inside the cave is at least 0.5m deep and it is possible that an excavation is likely to expose a more extensive chamber or passage.

Cave name	Complexity	Entrance dimensions	Passage height	Openings category	Length category	Orientation category	Likelihood score
Sheemore Cave 3	1	1	1	1	0	1	**0.631**
Sheemore Cave 2	1	3	3	1	1	1	**0.559**
Sheemore Cave 1	1	3	3	1	1	1	**0.559**

Table 5.6: Results from Sheemore research region.

Figure 5.28: Sheemore Cave 3 entrance. The drop to the left of the entrance shows the depth of soil accumulation.

Sheemore Caves 1 and 2 (fig. 5.29 and 30) only scored slightly lower in the likelihood analysis but their high entrances makes them less likely to have attracted any form of funerary activity. Blocking either of the caves effectively would have been nearly impossible. Their location at the foot of the hill near a small lake may have been attractive for other ritual activities.

Figure 5.29: Sheemore Cave 1.

Southwest of Sheemore Hill are a few pockets of rockland that Cooney (1979, 85) identified as the dominant land type on which megalithic tombs were built in this area. An approximate orientation towards the southwest, and therefore these particular landforms, could be established for two of the passage tombs on Sheemore. Similar to the hypothesis of the possible function of passage tombs as territorial markers (Parker

Figure 5.30: Sheemore Cave 2.

Pearson 2003, 132-41; Renfrew 1973, 1976; Thomas 2000b, 654), facing these pockets of land (fig. 5.31) may have been related to a claim of ownership of this land.

The Sheemore research area did not produce any caves that were morphologically similar to the Munster Neolithic caves (see Section 2, this chapter). Sheemore Cave 3 offered the highest likelihood of having been used for funerary practices during the Neolithic. The dense vegetation that grew along the cliff face made spotting and accessing caves a difficult task and despite best efforts, many of the caves Gilhoys (1987) and Coleman (1965) mentioned were missed. Although not found in the field, Gilhoys' brief description of the four further caves suggests that they were located along the same cliff. Entrance

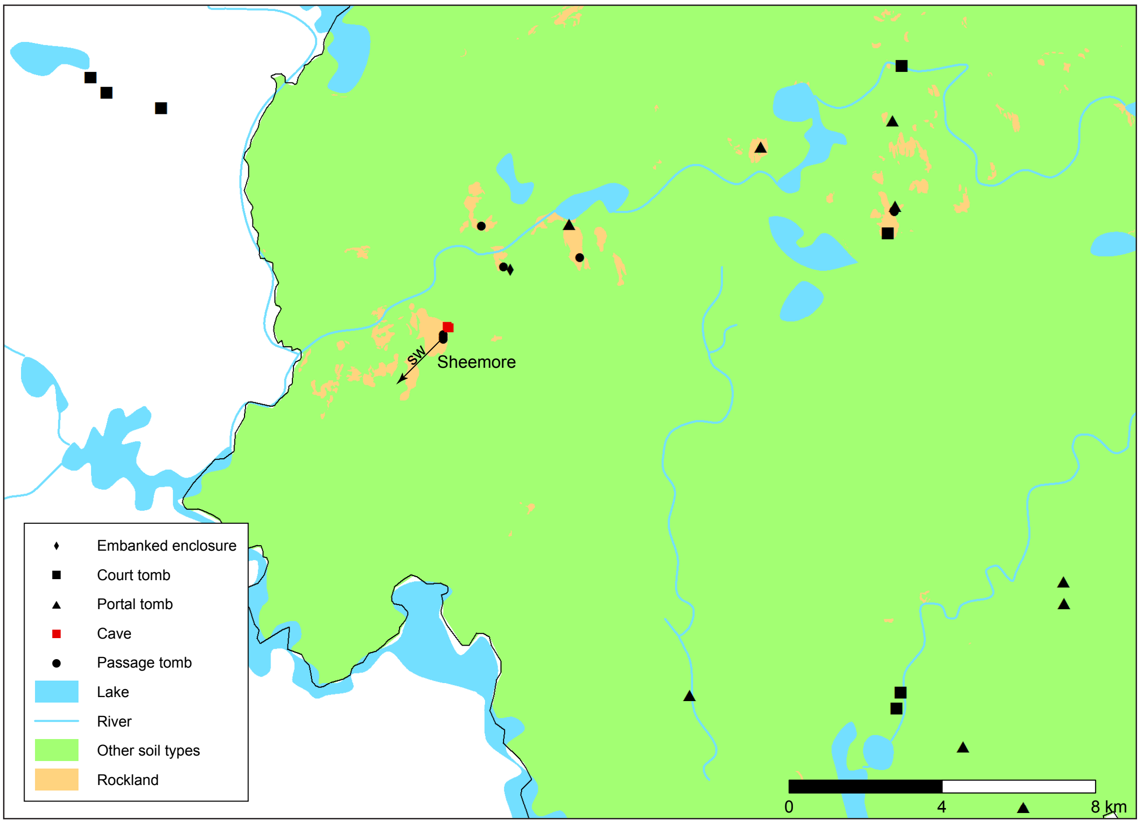


Figure 5.31: Soil map of Leitrim, showing areas of rockland and orientation of Sheemore passage tomb towards a nearby concentration.

heights were described to range from 2m to 4m and passage lengths seem to be decreasing proportionally with entrance height. It does not seem likely that any of the caves he described would have been suitable funerary sites.

5.7 Deerpark

The Deerpark research area lies *c.* 1.5km north of Lough Gill and consists of a central prominent limestone outcrop with steep cliffs at its northern sides and gentle slopes to the south. The area is framed by two lakes to the west and east with Keelogyboy Mountain rising to the north. At the southern edge of the research area is Tully townland, which is separated by a deep and wide gorge from Deerpark Hill. The hill at Tully has similar geomorphological traits as Deerpark with a steep cliff face to the north and a gentle slope to the south. To the north lies a third, albeit considerably smaller, limestone outcrop in Formoyle townland which is masked by a formerly cultivated forest.

Archaeological background

The archaeology of the area is dominated by Early Medieval and Medieval sites with only one site, the court tomb at Magheraghanrush/ Deerpark, that can be positively attributed to the Neolithic. A wedge tomb and two barrows are of possible Late Neolithic or Bronze Age date. Appendix 1.6 provides an overview of all sites within the research area.

The court tomb is located on the highest elevation of Magheraghanrush/ Deerpark with commanding views across the entire Cúil Irra peninsula. The tomb is described by de Valera (1959, 88), Ó Nualláin (1989, 32), and Wood-Martin (1888a, 137-8). Several antiquarian excavation campaigns produced unburnt human bones representing at least three individuals, including one juvenile, animal bones, and flint artefacts (Ó Nualláin 1989, 33).

Caves

Three caves were studied in the townlands of Formoyle, Magheraghanrush/ Deerpark, and Tully (fig. 5.32). Coleman (1965, 56) mentions a second cave in Magheraghanrush but it it could not be located during fieldwork.

Figure 5.32: Surveyed caves in Deerpark research area and court tomb.

Analysis shows that Deerpark Cave is the most likely candidate to have been used during the Neolithic (table 5.7). Its morphology most closely resembles that of Neolithic caves used for funerary rituals: a long and narrow passage with an easily blocked entrance (fig. 5.33). The cave is oriented due north, facing the cliff edge and Keelogyboy Mountain and facing away from the court tomb, which is located *c.* 100m to the southeast.

Cave name	Complexity	Entrance dimensions cat.	Passage height cat.	Openings category	Length category	Orientation category	Likelihood score
Deerpark Cave 1	1	1	2	1	1	1	**0.747**
Fermoyle Cave 1	1	3	2	1	1	6	0.635
Tully Cave 3	2	1	1	2	1	8	0.600

Table 5.7: Results from Deerpark research area.

Figure 5.33: Deerpark Cave 1, view into the passage.

Fermoyle Cave, located some 500m northeast of Deerpark Cave, features a 5m wide and 1.5m high entrance that gives access to an 8m long passage. Its rear is filled almost to the roof with soil and debris (fig. 5.34), which probably was washed in through a sinkhole that opens to the surface above (see Appendix 1 for detail). Openings in cave ceilings also exist in Ballynamintra Cave and Alice & Gwendoline Cave does not seem to have influenced cave use. However, the quite substantial entrance would have made the cave less likely as a place for funerary activity.

Figure 5.34: Entrance to Fermoyle Cave.

Tully Cave is located near the top of a flat-topped limestone ridge. It penetrates the north-facing cliff of the ridge where it turns slightly west into an elongated recess. The small entrance, *c.* 1m wide and high, leads into a small ante-chamber from which a small 'door way' provides access into a low but wide main passage (fig. 5.35). It extends for at least 10m before terminating in a mud choke. Removing this choke would probably extend the length of the cave by several metres. This cave would not be considered as one typically used for funerary rituals, yet its unique entrance outside of which is an almost level platform, might have attracted some form of activity during the Neolithic. Neolithic caves such as Barntick Cave and Elderbush Cave also feature platforms outside their entrances, which would have allowed larger groups to gather at the cave entrances. Deerpark court tomb lies only a short distance from Tully Cave, and the people who built and used the court tomb may have been aware of the cave's presence.

Figure 5.35: Tully Cave. A - entrance. B - main passage.

5.8 Leean

The Leean research area consists of several extensive limestone hills and plateaus that gently slope from the highest elevations around Leean Mountain south towards Lough Gill. The upland areas are intersected by a network of valleys. A few small streams run from the southern valleys and drain into Doon Lough to the south. The well-drained soil in the uplands in the east is thin with bedrock being frequently exposed. Patches of raised bog that are locally exploited are present in the valleys between the upland areas. Blanket bog covers much of the uplands and valleys in the western part of the area, mixed with patches of forestry.

Archaeological background

The Leean research area has not received much attention in terms of archaeological research. The SMR lists 108 monuments for the area. The landscape was first used during the Neolithic but saw its peak during the Bronze Age and was resettled from the Early Medieval after a downturn during the Iron Age (Clarke and Kytmannow 2004; Kytmannow *et al.* 2009a; Kytmannow *et al.* 2009b; Kytmannow *et al.* 2010; Kytmannow *et al.* 2008).

Only one Neolithic monument, a court tomb is located in this research area. The SMR lists four additional megalithic monuments: a Bronze Age wedge tomb and three unclassified megalithic tombs of probably later prehistoric date (online ASI/SMR, accessed 6/2015).

Caves

Caves occur in many of the steep hillsides and cliffs in the research area. Those include countless depressions and sinks on hilltops such as Cahermore (fig. 5.36), whereas horizontal caves were not as frequently found. At least 18 horizontal caves were reported by several researchers (Coleman 1965, Gilhoys, unpublished). Eleven of the 18 visited caves were surveyed, which can be summarised into four smaller concentrations: the Doons, Leean, Curraghan, and Sramore (fig. 5.37). The remaining seven caves could either not be accessed safely, such as Cahermore Cave or Curraghan Cave B, or they were too small or filled with sediments, such as Curraghan Cave D or Doons Cave 5 (see also Appendix 1.1).

Sramore Foxhole scored the highest likelihood value in this group (lhs=0.631, table 5.8), although its length of just 3m would have been outside the range that is commonly observed for Irish Neolithic caves. A similar problem can be observed for Leean Cave 3, which scored second highest in the group (lhs=0.614). This cave consists of a small passage that is accessible for only 4m.

Cave name	Complexity	Entrance dimensions cat.	Passage height cat.	Openings category	Length category	Orientation category	Likelihood score
Sramore Fox Hole	1	1	1	1	0	1	**0.631**
Leean Cave 3	1	1	1	1	0	6	**0.614**
Curraghan Cave	2	3	2	1	1	7	0.569
Fawnarry Cave	1	3	3	1	1	3	0.565
Doons Cave 4	1	3	3	1	1	5	0.548
Doons Cave 1	1	3	3	1	1	5	0.548
Doons Cave 2	1	3	2	1	0	5	0.509
Leean Cave 1	2	2	2	2	1	6	0.508
Leean Cave 2	2	3	2	3	1	1	0.421
Ravens Wing Cave	2	3	3	1	2	1	0.415
Annexe Cave	1	2	3	3	1	7	0.412

Table 5.8: Results from Leean research area.

Morphologically, all but the above mentioned two caves showed very few similarities with the morphology of caves used during the Neolithic. Entrance and passage heights were the main factors that made the majority of caves less likely candidates for funerary rituals. For example, the Doons caves are all fissure formed passages and, like the rift caves on Knocknarea and Sheemore, are short, narrow yet high, which would have made blocking very laborious. Ravens Wing or Sramore Cave, the most complex cave in the series and previously believed to have contained human remains of Mesolithic date (Dowd 2015, 85-6), featured two side passages. As their passages were significantly lower and narrower than the main passage, they could have been seen as caves within a cave and they could have been easily blocked off from the main passage.

The only tangible reference to the Neolithic in the form of a monument is the court tomb on the southern slope of Leean. The site sits on a slightly elevated location overlooking much of the surrounding bog covered plains towards Lough Gill. Curraghan Cave A is visible some 650m to the east and it is the only cave directly visible from the court tomb. While the cave would not have been suitable for funerary rituals, its visibility from the court tomb would not have been lost to the local Neolithic population. Doons Hill and its five caves lay 1.7km to the west and the Leean cluster is located 1.3km to the north, separated by Leean Mountain. Another court tomb is located in Conray townland, 1.3km northeast of the caves in the Glencar Valley.

None of the surveyed caves in the research area showed good Neolithic archaeological potential based on their morphological traits. Curraghan Cave may have been of some

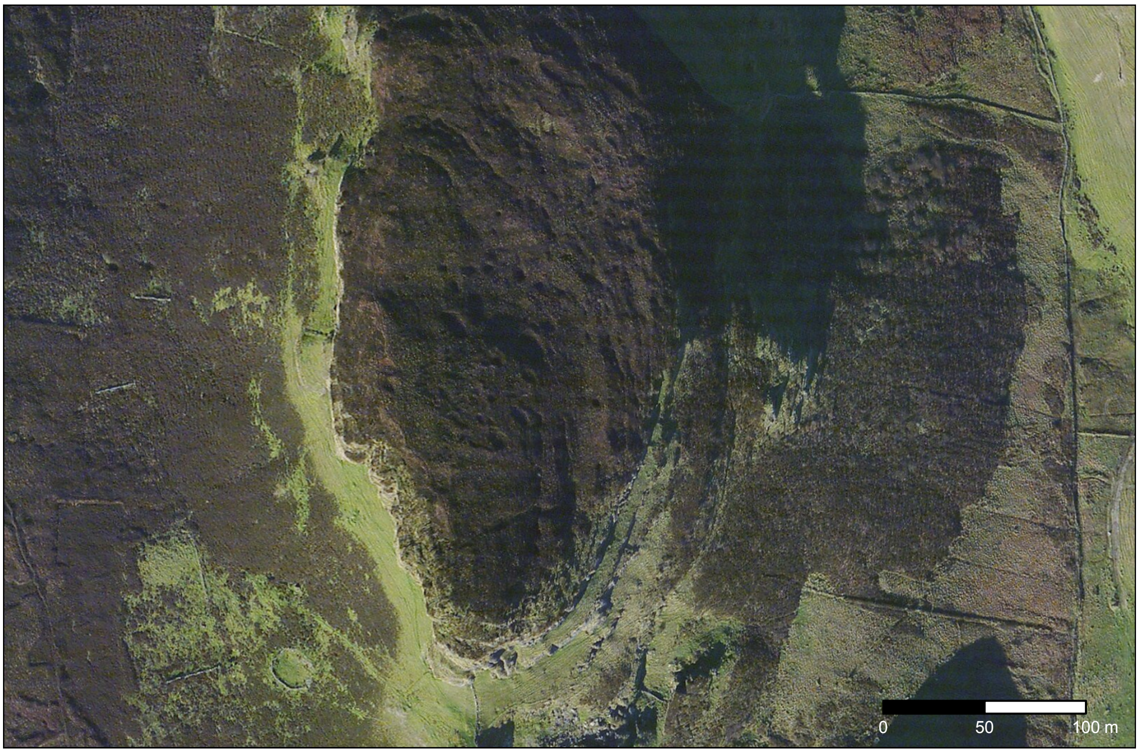


Figure 5.36: Cahermore, several dolines and sinkholes cover the mountain top.

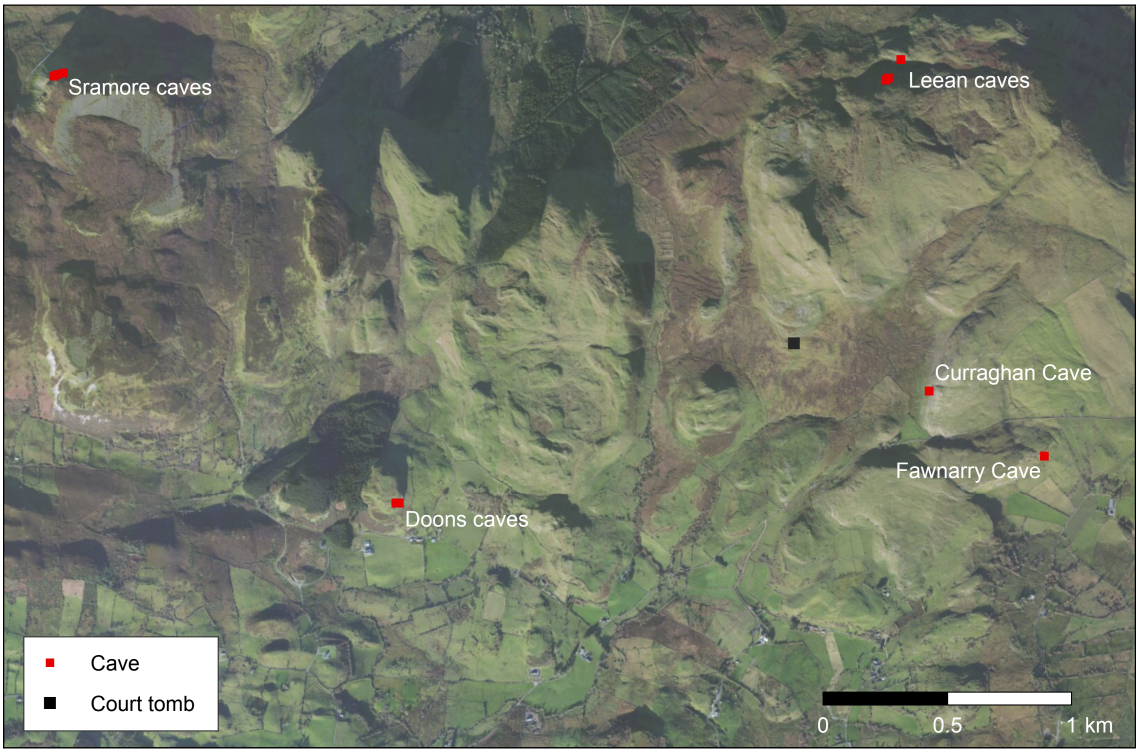


Figure 5.37: Surveyed caves and Neolithic monuments within the research area.

interest for ritual activity due to its proximity to the court tomb. Pollen analysis from the area indicate Neolithic activity (Kytmannow *et al. 2009*, 7), albeit most likely later in date, which offers a possibility that some of the caves were known and used. However, there was not enough data from caves of Neolithic date to support this suggestion.

5.9 Muckelty

The Muckelty research area encompassed the 217m high Muckelty Hill and its immediate vicinity. The carboniferous limestone hill is part of the Ox Mountains/Sliabh Gamph region and stands in a juxtaposition to Knocknashee which rises 4.3km north of it. The hill is slightly oval roughly oriented north to south (see Appendix 1 for detail).

Archaeological background

The archaeological landscape at Muckelty Hill and its wider vicinity is dominated by later prehistoric, Early Medieval, Medieval, and post-Medieval archaeology, with the majority of sites being ringforts/cashels. The flat top of a small hillock at the foot of Muckelty Hill is enclosed by a possible Iron Age or Late Bronze Age hilltop enclosure (Condit and Gibbons 1991, 9). Some 1.3km southwest of Muckelty lies Knocknashee, another hilltop enclosure that encloses a possible Neolithic or Bronze Age settlement of at least 30 hut sites (Bergh 2015). The hilltop enclosure surrounds two passage tombs and the complex resembles Mullaghfarna in the Carrowkeel passage tomb complex as well as Turlough Hill, the Burren, Co. Clare (Bergh 2015, 24; Egan *et al.* 2005, 1). The top of Muckelty Hill is occupied by a ring barrow and an unopened cairn. The nearest Neolithic monument is the court tomb at Clonaraher, located some 3.5km north of Muckelty Hill.

Caves

Six caves are dotted along the south facing slopes of Muckelty Hill (fig. 5.38). However, three are filled almost to the ceiling with debris and can not be entered without digging. Cave 6 consists of one short passage near the top of the hill which turned out to be the

Figure 5.38: Overview of surveyed Muckelty Hill caves. No Neolithic monuments are recorded in this area.

Cave name	Complexity	Entrance dimensions cat.	Passage height cat.	Openings category	Length category	Orientation category	Likelihood score
Muckelty Hill Cave 6	1	1	3	1	2	5	**0.571**
Muckelty Hill Cave 1	1	3	2	1	0	3	**0.526**
Muckelty Hill Cave 4	1	3	2	1	0	5	**0.509**

Table 5.9: Results for Muckelty Hill research area.

most likely cave to contain Neolithic material (table 5.9). It can be accessed via a small entrance that leads into a short passage (see Appendix 1.3 for more detail). Despite its larger interior, the cave would have been suitable as a funerary site (fig. 5.39).

Figure 5.39: Muckelty Hill Cave 6.

Muckelty Hill Caves 1 (fig. 5.40) and 4 (fig. 5.41) produced only a slightly lower likelihood score than Muckelty Hill Cave 6 but their large entrances and short passages would have made them unsuitable for funerary activity.

Muckelty Hill features no known sites of Neolithic date. The immediate surrounding landscape does not feature any Neolithic sites or monuments but a wealth of later prehistoric and historic archaeological sites. However, the two court tombs and the large hilltop enclosure/ Neolithic settlements on Knocknashee indicate the presence of Neolithic activity in the area. The two hills stand out in an otherwise undulating landscape.

Figure 5.40: Muckelty Hill Cave 1.

Figure 5.41: Muckelty Hill Cave 4.

Both hills provide superior views towards the north and east with the Cúil Irra peninsula and Carrowkeel-Keshcorran clearly visible. Separated by 4km of relatively level terrain with no water bodies in between, movement between the two locations would have been relatively easy. It is thus plausible that Muckelty Hill was also frequented by Neolithic people. Knocknashee itself does not have any known caves and those at Muckelty would have been the only caves in the vicinity.

Concluding remarks

Six of the 58 analysed caves, namely Knocknarea Caves A, B, C, R; Treanscrabbagh Cave, and Deerpark Cave 1, scored a likelihood value of > 0.74 after morphological

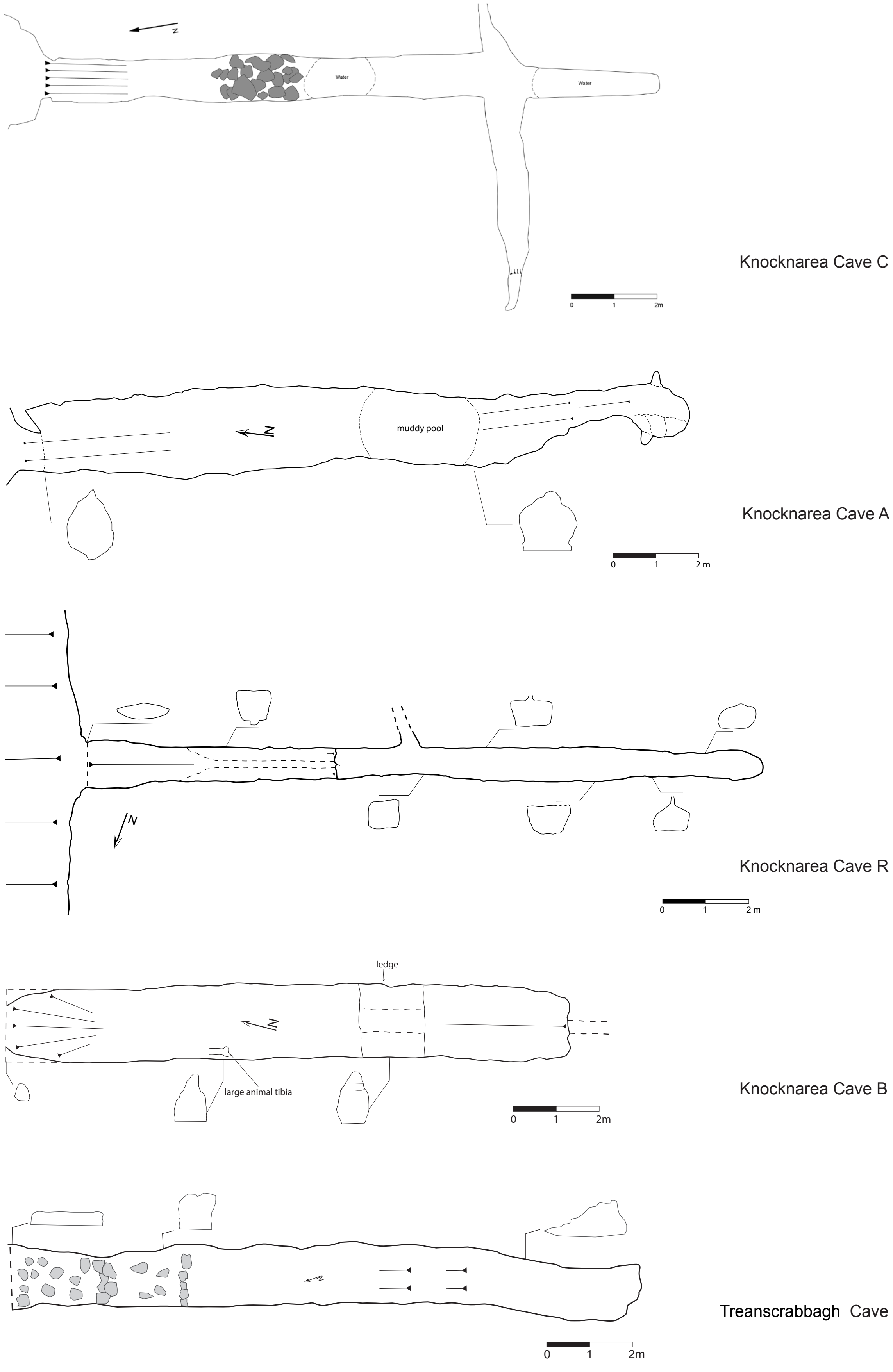


Figure 5.42: Caves in North Connaught most likely to have been used during the Neolithic.

analysis. The caves are single, mostly straight passages with small entrances that would have made them suitable for funerary rituals and that could be blocked easily (fig. 5.42). The research areas Sheemore, Leean, and Muckelty did not produce any scores that indicated a likely presence of funerary activities. Most caves fell short on either entrance dimensions or passage length, with the latter being generally too short. The only exception was Sheemore Cave 3 where the passage was filled with deposits that could have blocked access to deeper parts of the cave. The predictions made by this model need to be considered in the context of the input data that is currently available, which is dominated by caves used for funerary activity, particularly excarnation. Thus, the resulting bias was unintentional, albeit unavoidable. That is not to say that caves were not used for other activities, however, evidence for these is too scarce to make any meaningful inferences.

Landscape analysis put the results from the morphological analysis into context with the caves' local Neolithic landscape setting. The assumption here was that the presence of Neolithic monuments indicated a higher possibility of funerary activities in caves. Lack of Neolithic monuments, especially passage tombs and court tombs in the Munster research area, did not provide any supporting evidence for this assumption but rather indicated the opposite: Neolithic activity occurred in caves where contemporaneous monuments were absent. A strong indication of an intimate relationship between caves and Neolithic monuments came from Knocknarea Caves C and K where their location and the presence of human remains within them complemented a picture of a highly organised ritual landscape. A number of caves within the Knocknarea research area, as well as Treanscrabbagh Cave and Deerpark Cave, all morphologically suitable for excarnation rituals, were also located in close proximity to passage tombs or court tombs.

Chapter 6: Integrating caves into the Neolithic ritual landscape of Knocknarea Mountain, Co. Sligo

The following case study will present the development of a hypothesis that seeks to integrate the natural and the built ceremonial landscape of Knocknarea, Co. Sligo and is a direct consequence of this study. The spatial organisation of religious and mortuary structures in accordance to natural topography and beliefs is a recurring theme in archaeology (Bergh 2002; Bradley 2000; O'Brien 2002; Oubina *et al.* 1998; Parker Pearson 2003, 124-32). In a similar fashion, Knocknarea's spatial organisation suggests a deliberate division into a realm dedicated to the living and a realm dedicated to the dead - shaped by the mountain's topography. I argue that in this dichotomised landscape, caves played an important role in multi-stage funerary rituals as places where the deceased were transformed from decaying corpses into living ancestors. Their presence among the ancestors was represented by their clean and purified bones (Douglas 1966, 24; Parker Pearson 2003).

6.1 Approaching a monumental mountain: the setting and archaeology of Knocknarea

Topography

Knocknarea Mountain is a 330m high outcrop composed of Calp and Upper limestone, intersected by bands of chert (Symes 1880, 11). The mountain sits in a commanding location in the otherwise undulating landscape of the Cúil Irra peninsula in the west of County Sligo. The peninsula is framed by the Garavogue River and Lough Gill to the north and east, and the Ox Mountains and Slieve Deane to the south and southeast. Its prominent location makes Knocknarea an easily distinguishable landmark that is visible from considerable distances. It is also visible from other research areas subject to this thesis, such as Carrowkeel, Keshcorran, Muckelty Hill, as well as Sheemore.

To the north, west and south, the summit of Knocknarea is defined by steep slopes and vertical cliffs that rise up to 60m severely restricting access to the mountain. The more gentle slopes to the east provide an easier access route, where the modern-day access route is located. In 2015, a new track was opened to provide access to Knocknarea from the north, ascending 300m over a distance of 2.4km with over 500 steps climbing the mountain's steep slopes (fig. 6.1).

Figure 6.1: Neolithic sites and monuments of the Cúil Irra peninsula (after RMP) and caves on Knocknarea mountain.

Figure 6.2: Knocknarea from the northwest.

Passing the mountain via the Culleenamore along its northern face, between its steep and uninviting cliffs and the encroaching shoreline, leaves the traveller with a sensation of isolation and liminality (fig. 6.2). Northwest and north of the mountain, the terrain opens into a landscape composed mainly of dunes and a small stretch of arable land. The side of the mountain facing this part of the peninsula is less intimidating, yet Knocknarea still towers high above the lowlands, cutting off all views to the east.

Twenty-nine caves are dotted along Knocknarea's west and north slopes and cliffs: 15 are tightly clustered together, yet discretely tucked away in the terraced cliffs northwest of the Míosgan Méadhbh passage tomb (Dowd 2008). These 15 caves occur as groups in three overlying low terraces. The groups comprise the most complex caves featuring side recesses, interconnecting cross passages, and speleothems (see Appendix 1 for detail). However, most of the cave entrances are small and overgrown which makes them almost invisible to the unitiated visitor (fig. 6.3). Eight caves, mostly short and narrow fissures, are dotted along the western cliffs. Three small tectonic caves are located in a small limestone knoll at the southern foot of the mountain and a further three caves penetrate its northeastern cliffs.

Figure 6.3: Modern trackway on the western flank of Knocknarea. The overgrown cliff in the background hosts seven caves.

Archaeological background

The Cúil Irra peninsula has been continuously populated throughout prehistory - to a lesser degree during the Mesolithic - and intensively farmed into historic times. Such activity has probably obscured or destroyed a significant proportion of Neolithic archaeological remains making it difficult to make any inferences about population density during that time. A few important sites, however, have survived. Bergh (1985), for example, identified a possible Neolithic enclosure south of Knocknarea in Primrosegrange townland that may have been a settlement site. During the construction of the N4 bypass a possibly temporary rectangular settlement platform, an Early Neolithic causewayed enclosure and several Neolithic field walls were discovered (Danaher 2007, 10-1). Other signs of Neolithic activity, particularly domestic activity, come from pollen diagrams from Cúil Irra, Union Wood Lake, and the nearby Carrowkeel region. They indicate an early date of farming activity in the form of coppicing, fire grazing, and small scale farming during the Neolithic (Burenhult 1984, 42-3; Dodson and Bradshaw 1987; Hensey *et al.* 2014; O'Connell *et al.* 2013; O'Connell and Molloy 2001; Stolze *et al.* 2013). The most tangible evidence of the population that once inhabited the Cúil Irra peninsula comes in the form of 80 surviving, albeit often heavily disturbed, megalithic tombs, among which are almost one third of all Irish passage tombs. The tombs contained the surviving remains of 100-150 individuals who once inhabited this region (Bergh 2002a, 144-5; 2002b, 66; Hensey 2015, 22-3; Herity 1974, 1987) (fig. 6.1).

Evidence for Neolithic activity on the peninsula is concentrated in two areas: Knocknarea and the Carrowmore complex, which is located 4km east of Knocknarea. Three court tombs in the townlands of Killaspugbrone, Cummeen, and Primrosegrange as well as four passage tombs, two located in the townlands of Carns, and two further are located in Barnasrahy, and Abbeyquarter North are the only known Neolithic monuments outside these two areas. A collection of lithics of possible Neolithic date appears to derive from *c*. 1.2km east of the Killaspugbrone court tomb in Larass or Strandhill townland (Dowd 2012).

Above its 250m contour, Knocknarea is occupied by a multitude of huts, banks, and megalithic monuments (Bergh 2000, 17) (fig. 6.4). The mountain's highest elevation is crowned by Míosgan Méadhbh, a large flat-topped cairn, almost certainly a passage tomb (Herity 1974, 262). Surrounding Míosgan Méadhbh are two cairns and five passage tombs (fig. 6.5), with an additional tomb located on a ridge east of the hill. The passage tombs were built on the highest elevation and aligned so that they formed a megalithic skyline that was most visible from the east, yet is completely obscured from view from the north and northeast (Bergh 1995, 135; 2002a). Two further cairns of unknown date and classification are located *c.* 500m north and south of Míosgan Méadhbh (fig. 6.6).

A system of banks runs along the east face of Knocknarea over a distance of some 2km and 30m - 50m below its summit. The banks are unlikely to have been defensive structures which suggests that their function was more symbolic, defining the ritual space as well as restricting access (Bergh 2002a, 149-50). Access to the summit is believed to have been guided by an opening in the bank where two sections run parallel for *c.* 200m (Bergh 1995, 58-9) (fig. 6.7). The banks were constructed in two phases and the latter is associated with lithic scatters, consisting mostly of hollow scrapers and debitage.

Two concentrations of 21 hut sites are located 20m - 30m below the summit, clustered south and north of the banks' termini (fig. 6.8). They were built near the banks and out of sight from the monuments above and Bergh notes that they were not consistently built on the most suitable terrain. Along with the hut sites, a number of small platforms which produced chert scrapers and debitage can be assumed to be associated with the huts (Bergh 2009, 107-11). The hut sites and their immediate environs are scattered with lithics, similar to those found associated with the later construction phase of the bank, indicating that bank and huts are contemporaneous (*ibid.*).

Lithic scatters, consisting mostly of chert cores and debitage, were also found spread across the top and northern flank of the eastern ridge and have most likely been quarried in this area. The number of lithics and their wide distribution indicates a long tradition of procuring raw material and knapping on Knocknarea (*ibid.*).

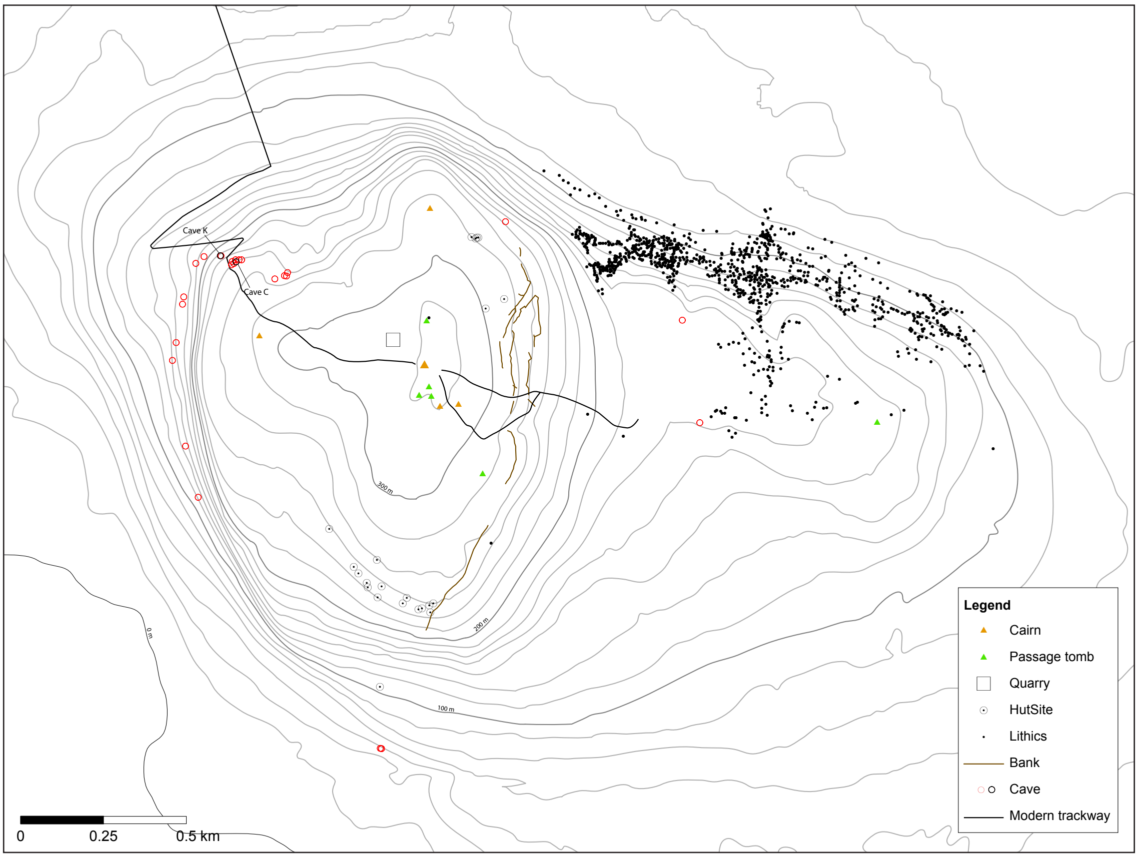


Figure 6.4: Caves, modern trackways, and Neolithic and possible Neolithic sites and monuments on Knocknarea (monuments after RMP, banks and lithic scatter after Bergh 1995, 2009).

Figure 6.5: Míosgan Méadhbh with northern satellite passage tomb in the foreground.

Figure 6.6: Double banked section of eastern enclosing wall system.

Figure 6.7: Hut sites near the southern terminus of the bank.

Neolithic caves on Knocknarea

Knocknarea features the only two caves in the northern half of Ireland that have produced Neolithic archaeology. In 2001 a human occipital bone fragment was discovered in Knocknarea Cave C and dated to 4740±50BP (3640-3370 Cal. BCE) (Dowd 2008, 55). During fieldwork in 2013, two human phalanges were discovered by the author in

Figure 6.8: Southern terminus of bank running down a steep slope.

Knocknarea Cave K, *c.* 50m west of Knocknarea Cave C. The cave consists of a single straight passage that extends for 26m in a roughly southern direction. The cave is accessible via a small and well concealed entrance as well as through a short aperture that connects to Knocknarea Cave J some 16m inside Knocknarea Cave K (fig. 6.9). The phalanges were found lying on the cave floor *c.* 5m inside the cave amongst scatters of animal bones. A rescue excavation was commissioned by the National Monuments Service that saw the recovery of a total of 220 animal bones and 13 human bones and bone fragments (fig. 6.10); all occurred as surface finds scattered along the cave passage (fig. 6.11). The human remains represent one, possibly two adults aged 30-39 years and a juvenile aged 4-6 years (table 6.1). Because the assemblage is small and consists of only small skeletal elements, apart from a Schmorls node on an adult lumbar vertebra that suggests intensive physical activity, osteological analysis revealed little information about the individuals (Dowd and Kahlert 2014).

AMS dating of three samples, one from the juvenile and two from the adult bone material, returned Middle Neolithic dates similar to that on the bone from Knocknarea Cave C (table 6.2). The slight difference in the dates on the two adult bone samples from Knocknarea

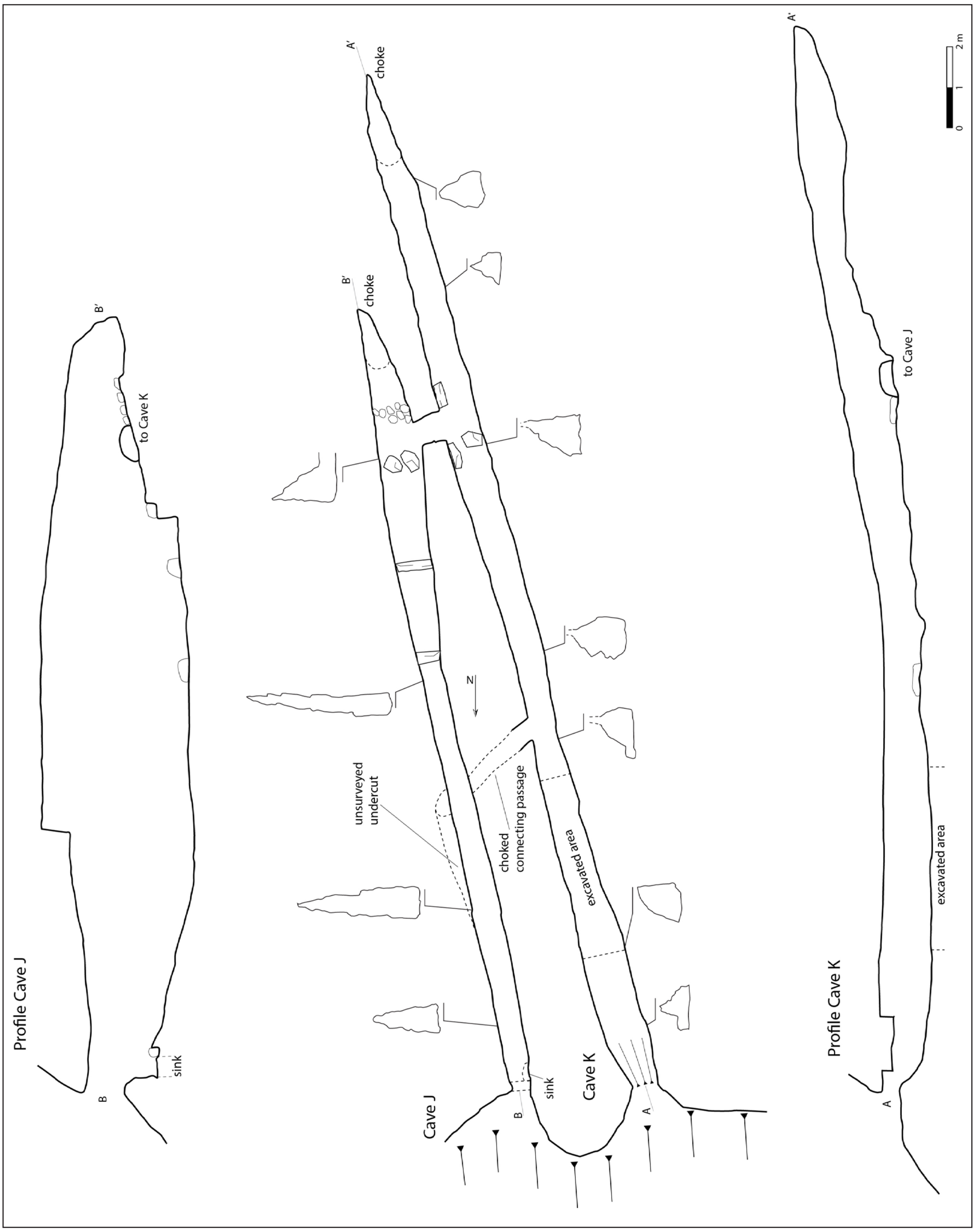


Figure 6.9: Plan of Knocknarea caves J and K.

Cave K (4734±39BP and 4656±37BP) suggests that two adults may have been interred at different times. The date on the juvenile clearly indicates a later phase of activity in the cave at the beginning of the third century BCE.

The presence of small skeletal elements, such as phalanges, and a distinct absence of any larger bones, such as skull and long bones, indicates that the bodies were excarnated as

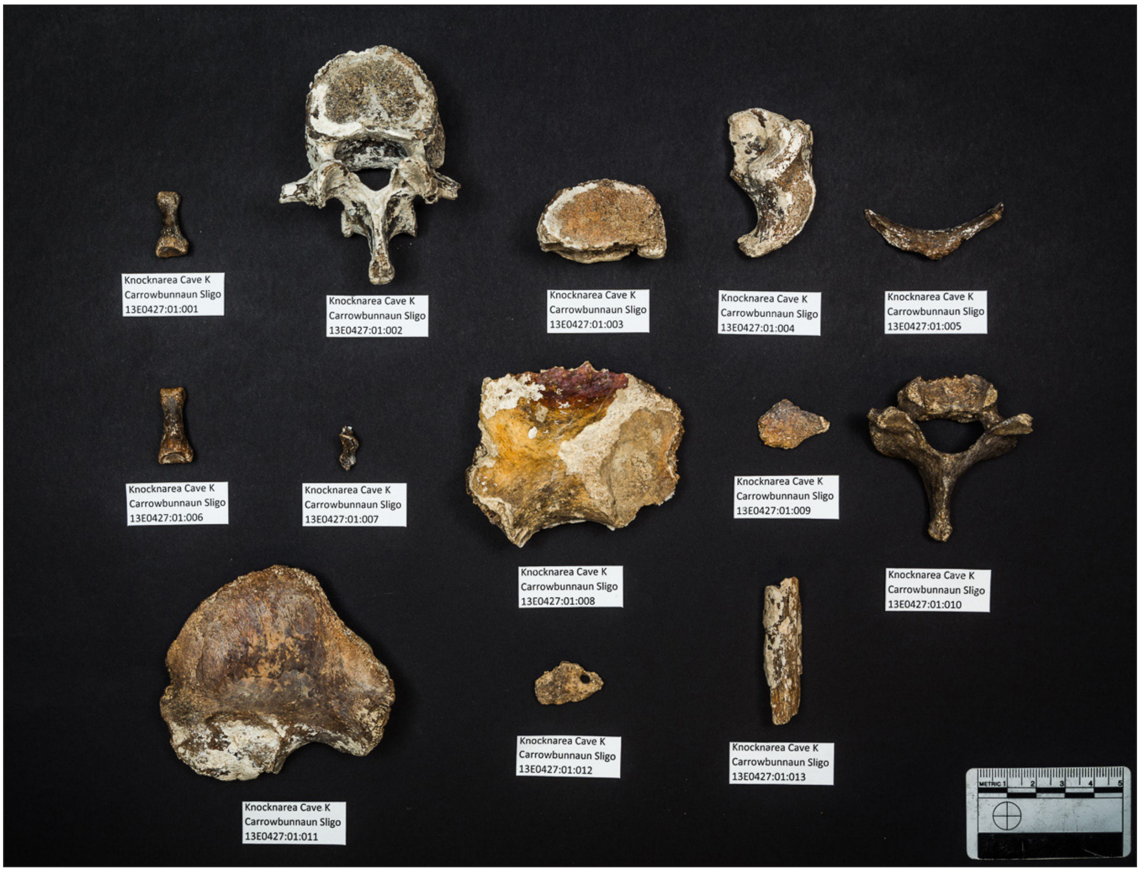


Figure 6.10: Human bone assemblage from Knocknarea Cave K.

part of a multi-stage funerary rite (Dowd and Kahlert 2014, 17). Following excarnation, all large bones and most of the smaller ones would have been removed from the cave to be used in further funerary rites, leaving behind only smaller fragments and bones that were overlooked. Similar assemblages were recorded in Kilgreany Cave, Ballynamintra Cave, and Killuragh Cave, which also have been associated with token deposition. The presence of small skeletal elements paired with a distinct absence of any long bones and skulls is typical for excarnation practices (Dowd 2008, 306-9; 2015, 104-5). It is unlikely that the bone assemblage represents inhumations or token deposition. Token deposition involved the placement of large skeletal elements inside the cave, with few to no small bones and fragments like the ones found in Knocknarea Cave K. Indeed, the bone assemblage from Knocknarea Cave K represents what would have been left behind after bones suitable for secondary burial were removed. Remains from inhumation burials are not limited to large skeletal elements but rather comprise small and large bones representative of an entire body (Dowd 2015, 64-5).

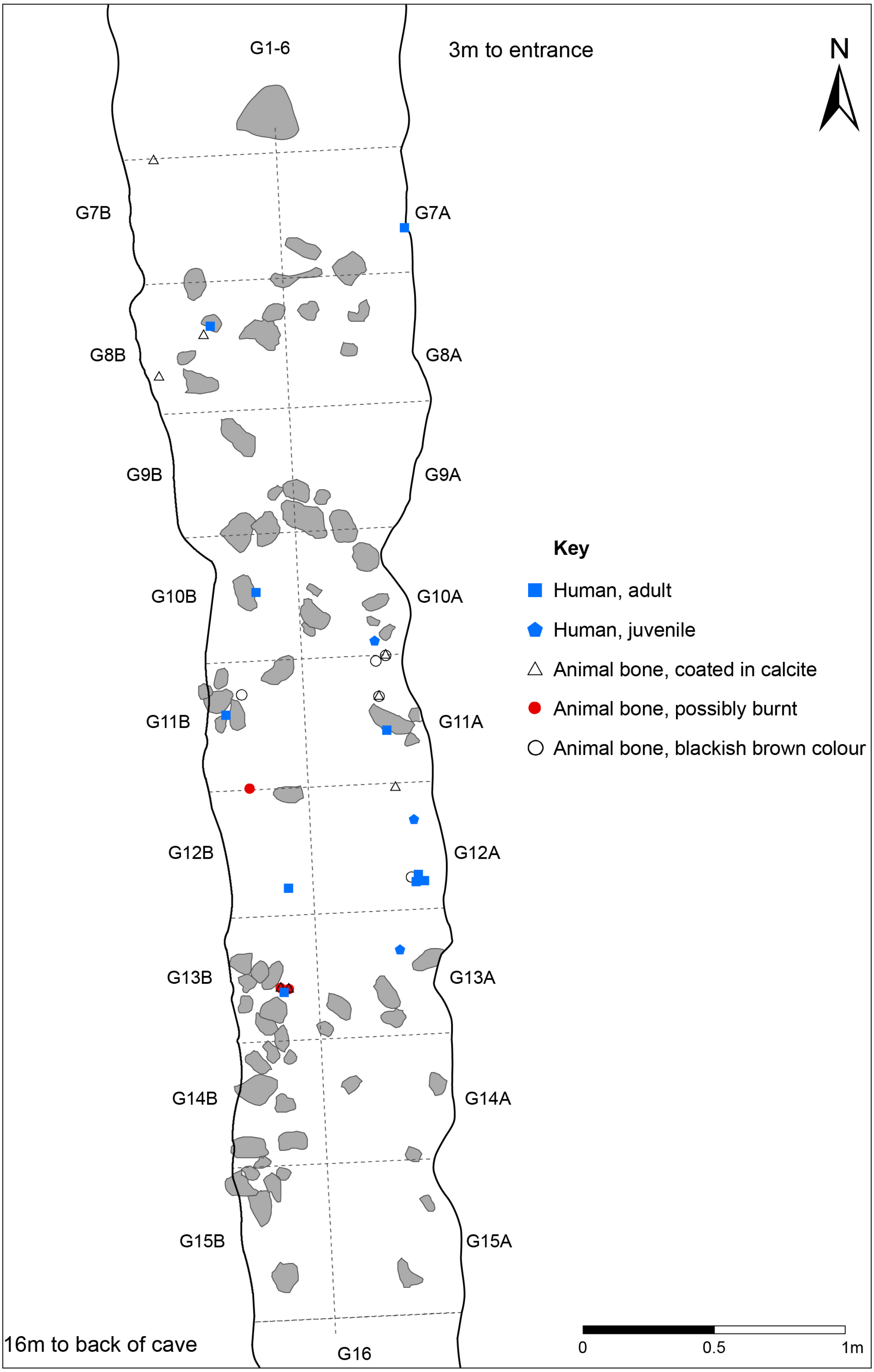


Figure 6.11: Distribution of human bones and potentially archaeological animal bones in Knocknarea Cave K.

Excavation code	Site grid	Description	Completeness (approx.)	Side
13E0427:01:001	10B	Adult proximal foot phalanx	100%	N/A
13E0427:01:002	7A2	Adult lumbar vertebra (LV1/LV2)	100%	N/A
13E0427:01:003	8B3	Adult vertebra	50%	N/A
13E0427:01:004	10A8	Juvenile ischium	90%	Left
13E0427:01:005	11A2	Adult rib	25%	Right
13E0427:01:006	11B3	Adult proximal foot phalanx	100%	N/A
13E0427:01:007	12A3	Juvenile vertebra	5%	N/A
13E0427:01:008	12A4	Adult ilium	25%	Right
13E0427:01:009	12A4	Adult cervical vertebra (CV7)	90%	N/A
13E0427:01:010	12A6	Adult cranial fragment	<5%	N/A
13E0427:01:011	12B6	Adult cranial fragment	<5%	N/A
13E0427:01:012	13A3	Juvenile ilium	100%	Left
13E0427:01:013	13B3	Adult ulna	10%	Right

Table 6.1: Human bones from Knocknarea Cave K (after McKenzie, in: Dowd and Kahlert 2014, 12).

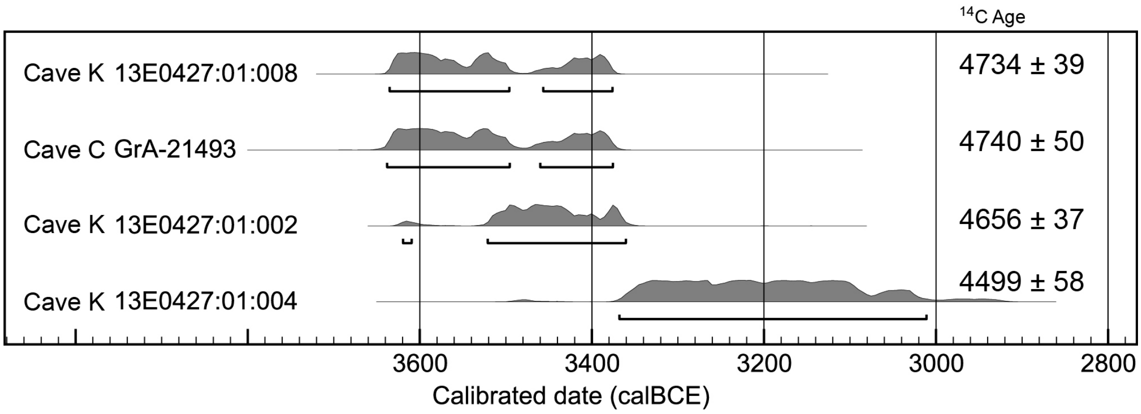


Table 6.2: AMS dates for human remains found in Knocknarea caves K and C (after Dowd and Kahlert 2014).

The majority of the 220 animal bones are of recent date and are not related to human activity. Nine bones, including cattle and sheep, were discoloured and encrusted in calcite which suggested potential archaeological significance. However, a radiocarbon date obtained for a juvenile bovine pelvis placed it in the Iron Age .

Knocknarea Cave K has added a new dimension to the archaeology on Knocknarea by widening the horizon past the monumental and towards the natural. It demonstrates that the mountain was not merely an iconic background against which rituals were carried out but that the people actively engaged with it when they inserted their dead directly into fabric of the mountain. In doing so, ritual activities, in particular funerary rites, were not constrained to the passage tombs as previously proposed (Bergh 2002a, 140). This also leads to further questions about human interaction with the mountain. Bergh has already established that the natural topography of Knocknarea was utilised to emphasise some monuments by increasing their visibility as well as concealing or limiting the visibility of others (*ibid.*, 148-9). But does the spatial organisation on Knocknarea reach beyond visibility and making a statement of authority? Was the interaction with the mountain much more intimate and, to a degree, even determined by its natural topography?

6.2 The ritual Neolithic landscape of Knocknarea

Almost all the archaeological sites on Knocknarea are confined to a highly organised ceremonial space that is delimited by natural and artificial boundaries. The artificial boundaries are the banks; their termini coincide with a transition in the mountain's topography from gentle slope to steep cliffs thus symbolically continuing and completing the natural boundary that is formed by the cliffs (fig. 6.12). The banks not only formed a boundary between the sacred and the secular but also controlled how the sacred inner sanctum was approached. The bank is segmented and a double banked gap probably marks the location of the principal entrance, and it may have intentionally forced an approach not directly from the east, which is the modern yet steeper access path, but

Figure 6.12: Knocknarea seen from the south-west, showing the southernmost section of the bank terminating on steeply sloping ground that gradually gives way to vertical cliffs (photo: Irish Air Corps).

rather via the eastern ridge where the high concentrations of worked chert and a chert quarry occur. A passage tomb was built on the easternmost edge of the ridge that could have functioned as a beacon or guide to visitors to the mountain. Now located in dense woodland, the tomb could have been visible from the east whilst overlooking visitors as they progressed towards the summit via the banked pathway. The parallel segment of the bank or path faces towards the group of 16 hut sites at the bank's southern terminus. Bergh (1995, 58) interprets the direction of the path simply as convenient, as a diagonal approach to the summit is less laborious. However, the path ends on level ground on the 290m contour and turns from facing southwest, roughly towards the summit, to south. Instead of guiding the visitor towards the summit, and thus providing a convenient access, the path follows the bank below the south-eastern passage tomb and towards the southern hut site group. Following this path, the large cairn of Míosgan Méadhbh remains obscured by the steep natural terraces. Similarly, four hut sites are clustered around the northern terminus of the bank system are also located out of sight from any of the monuments, with a further two located in close proximity to the entrance gap. These two huts are the only ones that allow views onto Míosgan Méadhbh.

It is entirely possible that the huts were built deliberately at these specific locations, not following conventions of convenience but rather to control access to, and movement around, Knocknarea in accordance to its ceremonial layout. Firstly, climbing the mountain along the banks would have led any visitors directly to one of the hut site clusters. During funerary activity, amongst other ritual activities, these could have served as locations where some of the funerary rites were carried out. Excavations at two of the hut sites (Bergh 1981, Osterholm 1981) did not reveal any substantial occupation levels indicative of long-term occupation. This was originally explained with erosion by rain and flooding (Osterholm 1981, 120), but it is also plausible that the huts were never intended to be used for domestic activity. Bergh (2009, 110-1) suggests that the hut sites are tightly connected to the activities that took place in and around the passage tombs on the summit. A similar relationship between a seemingly domestic dwelling and a monument comes from Drummenny Neolithic house, Co. Donegal. This house was built close to a cremation pyre and court tomb but saw little domestic use. Smyth (2014, 54) suggests that this close proximity coupled with its sub-ideal location on sloping ground may be of significance. Alternatively, industrial activity could be implied by the presence of substantial quantities of worked chert and some flint tools inside and near the huts (Bergh 1981, 2000; Osterholm 1981). The dominance of concave scrapers in the assemblage is something of a conundrum and Bergh attributes them to the ritual activity on top of Knocknarea (Bergh 2009, 110). Bergh's excavation at one of the southern hut sites also produced similar results, with no discernible occupation layer and substantial amounts of worked chert and flint at either of the sites (Bergh 2000, 17).

The occurrence of concave scrapers on Knocknarea poses incur questions about their significance in the ritual and religious activity that happened on the mountain. Hollow scrapers, which are closely related to concave scrapers (Woodman *et al.* 2006, 161), are found in funerary contexts such as caves and megalithic tombs (Dowd 2015, 108-9; Eogan 1974, 54-6). Osteological studies of Neolithic human bones from megalithic tombs have shown that defleshing or dismemberment was practised in Ireland and Britain during the Neolithic (Reilly 2003; Smith and Brickley 2004; Thomas 2000a, 660). Bergh speculated about a possible use of the scrapers in defleshing activities (Bergh 2009, 111) and the recent finds of possible excarnation rituals in the Knocknarea caves warrants further investigation to establish if these tools have been used for defleshing. Additionally, elevated phosphate levels inside hut site 2 (Osterholm 1981, 119) could be related to such funerary activities, perhaps defleshing, although these could have been the result of other Neolithic human activity or modern animal activity as Knocknarea Mountain is extensivley used for sheep grazing.

If the huts played a role in funerary rituals associated with the caves, the path taken by funerary parties would probably have been guided by several other landmarks. A plausible path would have taken them over the limestone saddle via the chert quarries and the single passage tomb to the east (fig. 6.13). Then, following the bank up and around Knocknarea, the funerary party could have turned either north or south towards the hut sites where

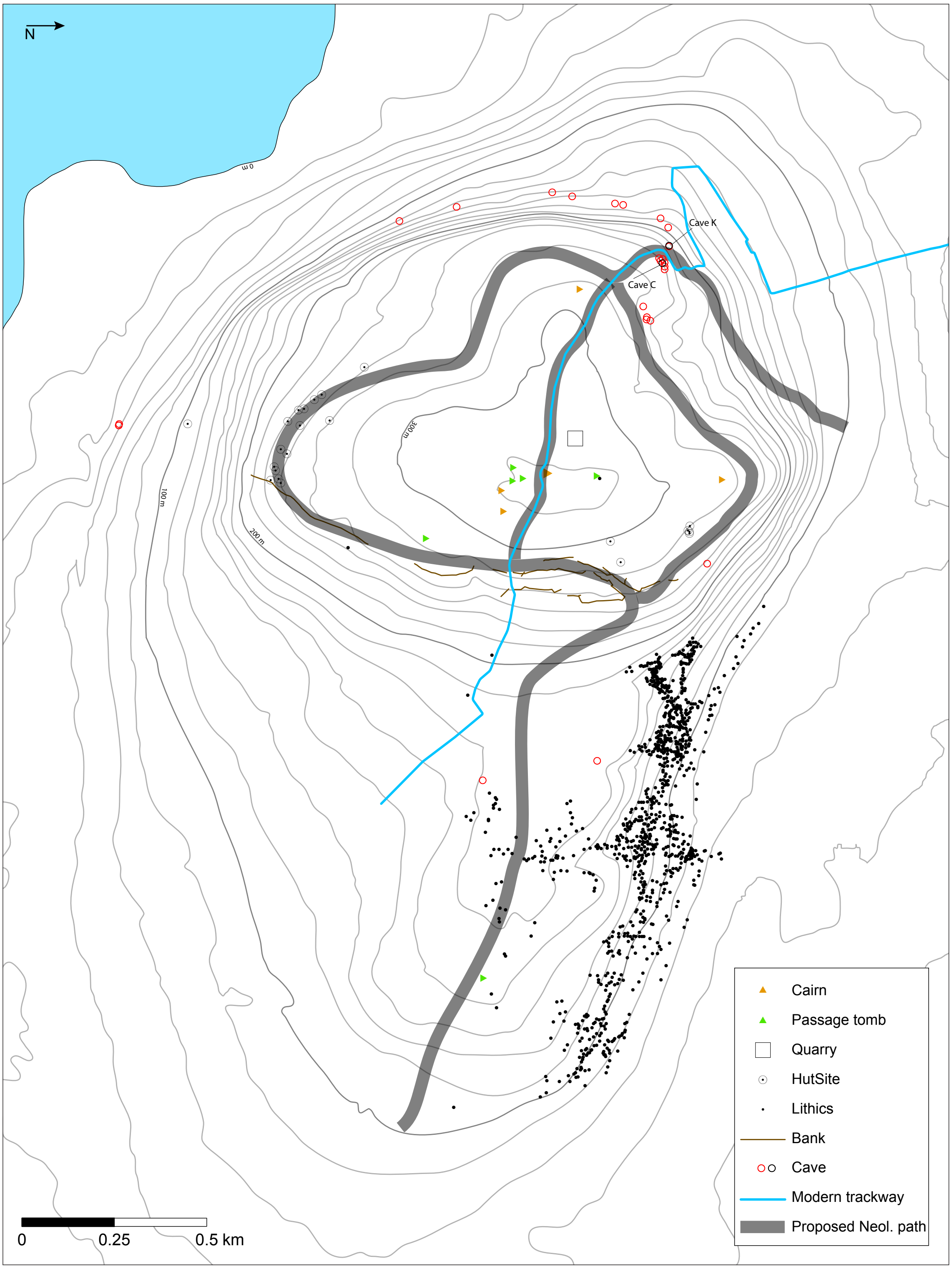


Figure 6.13: Proposed routes taken by Neolithic people to reach funerary caves.

preparations for primary funerary rites, perhaps defleshing, could have been carried out. Avoiding the monuments on top, the funerary party would have then followed one of the level terraces that lead around Knocknarea towards the caves. The caves of the northwest group (fig. 6.14) are located between contours 230m and 260m, approximately the same

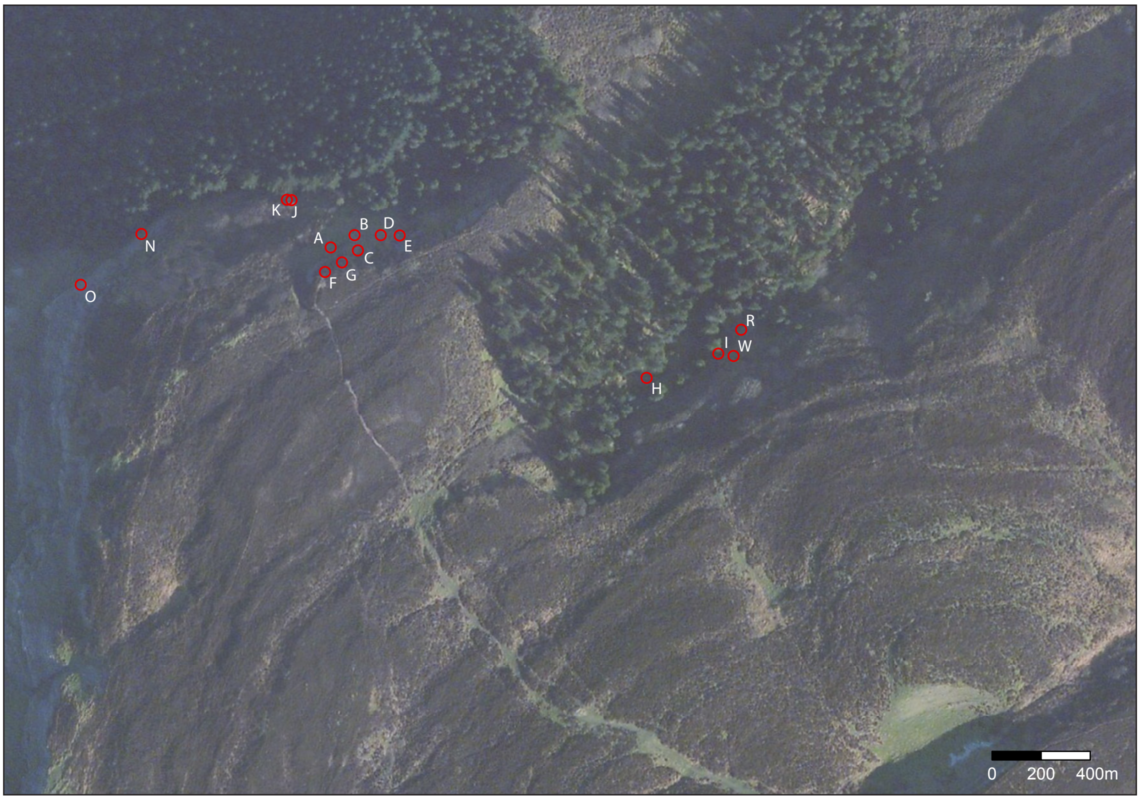


Figure 6.14: Distribution of caves on the northwest side of Knocknarea (red circles).

elevation as the hut sites, so the path around the summit would not have necessitated any steep climbs. Two cairns flank the area of the north-western cave group, which contain most of the caves suitable for ritual usage (fig. 6.15). If Neolithic in date, these two cairns may have signified the departure from the realm of the living into that of the dead, signalling to the funeral party that they were nearing the end of their journey.

The passage tombs on top of Knocknarea, as prominent as they are to the east, are not visible from the west and their visibility (and lack of) may have been of significance in forming the dichotomised ritual landscape of Knocknarea. According to Bergh (2000, 2002a), the passage tombs on Knocknarea were placed deliberately to maximise their visibility to the west, overlooking an open and hospitable fertile landscape. Similarly, they could have been intentionally excluded from sight from the west which was associated with the inhospitable and seaward-facing northern half of Knocknarea. This impression is reinforced when considering that all passage tombs on top of Knocknarea have their entrances facing east, away from the sea (Bergh 1995, 127; 2002b, 148).

Figure 6.15: Site of the southern of the two cairns that flank the northwest cave group on Knocknarea.

The setting of the monuments, huts, and banks indicate a highly structured landscape confined within natural features to the west and built enclosing banks to the east. Access to and movement within the sacred space probably was highly controlled as were locations where specific activities took place. With the presence of human remains in two, and possibly more, caves on the northwest side of the mountain, this landscape is extended by a mortuary dimension. It dissected the mountain into two realms: one was dedicated to the living, facing east towards the habituated lowlands of the peninsula where chert quarrying, tool production and various ritual and religious activities took place with the passage tombs as a focal point. The western half of the mountain was the realm of the dead. It faces the inhospitable sea and is virtually devoid of any built structures. The only tangible evidence of human activity on this side of the mountain are the human remains from the caves.

6.3 How to make an ancestor

In modern society, death, in its unaltered form, is perceived as an unpleasant experience that is often avoided (Douglas 1966; McCorkle 2010). Soon after cessation of all metabolic and vital processes, decay sets in and the corpse begins to change colour, followed by the decomposition of soft tissues which is accompanied by strong odours. A decomposing body attracts bacteria, fungi, insects and, if exposed, scavenging animals. The once beloved friend or family member turns into a biohazard that swarms with toxins and disease (Cantor 2010, 76-9; Vass 2001). The physiological and physical evidence does not support the perceived imminent danger associated with a decomposing corpse; however there is a strong cognitive association with death that triggers responses of disgust, repulsion, and fear (McCorkle 2010, 71*ff.*). At the end of the decomposition process, soft tissue has rotted away, leaving behind only white dry bones. The clean and white dry bones' appearance stands in stark contrast to the preceding process of decomposition.

The physical changes that accompany the decomposition process may remind us of our own mortality, which can instil a sense of fear or anxiety (Moore and Williamson 2003, 11). A natural fear of death can extend into fears of being haunted by spirits or a return of the dead as a living corpse, which have given rise to zombie and vampire myths. Popularised during the 18th century, their origin may reach back as far as the Neolithic (Beresford 2008, 31*ff.*). Such beliefs necessitated the removal of the deceased from the world of the living for the duration of decomposition, during which body and spirit were in a transitional state between life and death, person and ancestor. This liminal state is often perceived as being unstable and the spirit could cause harm to individuals or community as a whole (Barber 2008, 168; Bloch and Parry 1982, 4; Parker Pearson 2003, 25).

Fear of the decaying body and its potential threat to the living during putrefaction is a recurring, albeit not universal, phenomenon in many societies (Palgi 1984, 394; Watson 1982, 155). For example, in Zoroastrianism the dead body is perceived as being polluted by evil spirits until the corrupted flesh is removed during excarnation (Modi 1928). During the Neolithic, fear of the contaminating physical and spiritual properties of a decomposing body could be reflected in defleshing and excarnation rituals. These funerary practices are evident in cut marks, particularly on long bones and skulls as well as the find of incomplete disarticulated skeletal remains in caves, megalithic tombs and some enclosures (Barnatt and Edmonds 2002, 121-2; Cooney 2000, 111; Dowd 2008, 2015; Fowler 2010; Schulting 2007). A ditch surrounding Fourknocks II was interpreted by Cooney (2000, 111) as a measure to "*sanctify what may well have been regarded as a dangerous polluted area*". Parallels to the practise of open-air burial similar to that found at the Darkhans of the Parsi Zoroastrians can be observed at the causewayed enclosure at Hambeldon Hill, Dorset. Schulting notes, *"bodies may have originally been left exposed within the enclosure, slowly decomposing and becoming incorporated into the ditch fills over time.* [..] *There is also evidence for more active disarticulation in the form of cutmarks on human bones"* (2007, 2).

In Neolithic Ireland, caves were predominantly used for funerary activity including excarnation and, to a lesser degree, inhumation burials, with the majority of activity taking place between 3600 and 3350 BCE (Dowd 2008, 306). The dead were placed in caves which allowed for the body to be protected from scavenging animals for the duration of the decomposition process (Dowd 2008, 309; 2015, 104-5). Lack of gnaw marks on bones from caves are most likely the result of blocking of the cave entrance, but the primary intention could have been different (Dowd *et al.* 2006, 17). Shielding the dead from scavengers may have been a secondary effect of measures that were taken to control contact with a corpse. Dowd (2015, 107-8) proposes that Neolithic people may have frequently accessed caves to monitor the decomposition of a dead person as part of the mourning process. Blocking caves would have significantly slowed down decomposition, thus prolonging the mourning phase. An alternative possibility is that a symbolic or physical separation between the living and the dead was sought during decomposition, which may have been seen as dangerous or contagious as outlined earlier. While the separation of the decomposing body from the community was achieved in a more symbolic manner at places such as Fourknocks II, the placement in and subsequent sealing of a cave may have been a similar, yet more effective measure. The corpse was physically removed from the face of the world and concealed in a confined space. The evidence from caves in Ireland and Britain shows that it was probably of no great concern if excarnation and the resulting transformative process did not take place in any formal built structure. Whether it was due to the fact that some Neolithic people did not discriminate between natural and built places, as proposed by some (Barnatt and Edmonds 2002, 115-6; Bradley 2000, 2820; Schulting 2007, 11), or if caves were perceived as special natural places that provided access to the otherworld is debatable. Caves were used independently from megalithic tombs in their religious significance (Dowd 2015, 109-11). Regardless of how they were perceived, it has to be acknowledged that the ascribed spiritual power of caves rendered them suitable places to house a corpse during its physical and spiritual transformation.

Cremation, a funerary rite common in Neolithic Ireland and mostly associated with passage tombs and court tombs (Cooney and Grogan 1999, 67), could have served a purpose similar to excarnation. Rather than leaving corpses to decompose naturally, the remains were purified by fire, leaving behind white and cleansed calcined bones that could have been placed in a megalithic tomb to be united with the communal ancestors.

Excarnation and cremation are not necessarily mutually exclusive but can be complementary in secondary funerary rites, where defleshing is followed by cremation. Secondary funerary rites have been observed in Scandinavia where cut marks were found on cremated human bones (Larsson 2003). Only a few funerary pyres of Neolithic date have been identified in Ireland, such as Ballymarlagh court tomb, Co. Down (Davies 1949) and Fourknocks II, Co. Meath (Cooney 2000, 106-8). Herity (1974, 122) notes that large fireplaces opposite the entrances to some passage tombs may have been used for cremation. Three substantial possible cremation pyres were identified at Drummenny Lower, Co. Donegal in close proximity to a court tomb and a Neolithic house structure (Desmond 1998; Smyth 2014, 54). For the smaller examples, a different interpretation could be that the defleshed human remains were cremated before they were deposited inside a monument, leading to significantly smaller pyres. Examination of cremation deposits for cut marks and heat damage (Larsson 2008, 121) may help to establish if excarnation and cremation were indeed part of the same funerary rites during the Irish Neolithic.

Indications for defleshing following cremation, in the form of scorching of bones at low temperatures, was identified on some bones from Parknabinia chambered tomb and Poulnabrone portal tomb, both Co. Clare (Beckett 2011, 405). Poulnabrone shows evidence of a variety of complex funerary practices that took place over a period of

1,000 years (Beckett 2011, 411; Schulting 2014, 96-7). Poulnabrone provides further evidence for an intrinsic relationship between megalithic tombs and caves. Sixty-six bones and bone fragments, comprising 0.4% of the assemblage, displayed calcium-carbonate deposits, which could have been the result of exposure of defleshed bones in a cave environment (Beckett 2014, 57-8). Similar deposits have also been observed on human bones from long cairns in the UK at Ascott under Wychwood, Oxfordshire and Parc le Breos Cwm on the Gower Peninsula and were interpreted as evidence for temporary exposure in a cave environment (Barnatt and Edmonds 2002, 114; Dowd 2015, 111). While the representation of adult skeletal elements suggests that Poulnabrone functioned as an excarnation site (Beckett 2014, 60), the presence of calcium carbonate deposits on some of the bones indicates that the function of Poulnabrone may have extended to being a place of secondary deposition from other excarnation sites, particularly caves. This is further substantiated by the absence of gnaw marks on and bleaching of the human bones (Beckett 2011, 412). Both calcium-carbonate deposits and absence of gnaw marks are common in human bone assemblages from caves (Dowd 2015, 95).

Regardless of whether the dead in Neolithic Ireland received a mostly uniform treatment in the form of primary and/or secondary burials, or whether funerary practices varied in type and complexity within a community, maybe reflecting social status, significant effort was put into the treatment of those who were chosen to join the ancestral ranks. Both excarnation and cremation drove that transformation process by stripping away an individual's identity, its familiar appearance, and possibly defused potentially undesirable aspects of an ancestor by releasing them into powerful natural places (Fowler 2010, 15).

The transformation of a dead person into a living ancestor is also likely to have been a significant event that transformed relationships. It may have reinforced interpersonal bonds and created new ones that would have strengthened the entire community. Extending the continuous line between the living and more distant ancestors may have created a sense of having defeated death among the bereaved. Paraphrasing Bloch and Parry (1982) in her interpretation of the human remains from the Middle Neolithic Pitted Ware Culture of eastern Sweden, Larsson (2008, 124-5) states that "*death affects the individual/person, very consciously equated with the flesh, whereas the community/kingroup, associated with the durable bones, survives and even triumphs. By equating indisputable biological processes with ideological concepts, the latter achieve the status of being part of the natural order as well.*" Regardless of the form of treatment the dead received, in the end what remained of the person had lost all resemblance with the once living individual. They had joined the collective of the ancestors personified by their anonymous bare bones.

6.4 The case of the caves

The discovery of human remains of Neolithic date in Knocknarea Cave K has allowed for a new interpretation of the ritual landscape of Knocknarea as a location where complex multi-stage funerary rites took place. Previous studies of this iconic mountain and its sites (Bergh 1995, 2000, 2002a, 2009; Burenhult 1980, 1981, 1984; Wood-Martin 1888b, 1895) isolated the passage tombs as the only sites that were connected to the treatment of the dead, although Bergh (2000, 18) acknowledges the existence of a spatial relationship between the passage tombs and other Neolithic sites and monuments. The earlier find from Knocknarea Cave C did not trigger any further investigation into the caves by Bergh and others concerning their potential as Neolithic ritual sites, although they clearly matched the morphological attributes for this type of site (Dowd 2008, 311-12). The exclusion of the caves from research to date has resulted in an incomplete picture of the Neolithic mortuary landscape on Knocknarea and is an insight into archaeologists' focus on the monumental to the exclusion of natural places.

On Knocknarea, the majority of the caves of the northwest group, with the exception of Caves D, E, W, H, and I, fit into Dowd's proposed cave type preferred for excarnation rituals and token deposition during the Neolithic. Simple caves with relatively long straight passages and widths of less than 1m dominate the body of known Neolithic excarnation caves (Dowd 2008, 313; 2015, 106). The entrances are large enough to admit a human yet small enough to be blocked easily after placing a corpse inside (fig. 6.13). Blocking a cave's entrance probably served two purposes: protection from scavengers (Dowd 2008,

309) and protecting the living from physical or spiritual threats from the dead. In this respect, I argue that the liminal location furthest away from the activities of the living emphasised that the corpse needed to be isolated for the duration of decomposition. Supported by the occurrence of human remains of Neolithic date in Caves C and K, it is thus quite likely that other caves in this group of 15 contain human remains. The close proximity of suitable caves would have allowed for the simultaneous interment of bodies in different caves without having to interfere with an already ‘occupied’ cave.

The process of interring a body in a cave would have involved an intimate and close encounter with a corpse. Firstly, the body had to be carried up the steep slopes of Knocknarea to the caves. There are three likely routes that could have been taken, although alternative, albeit more laborious, routes were also possible. Deliberately avoiding the monuments on the summit, the body could have been carried around the 260m contour north or south along the enclosing banks and past the huts. A second approach could have led directly across the summit, past the passage tombs, taking a route that is commonly used today. A third option may have been a direct ascent from the north, the shortest but also steepest option (fig. 6.13). Regardless of the chosen route, carrying a body to the caves would have been a substantial effort. Close to the caves, the terrain slopes at a steep angle of at least 25º and there is no level ground, which makes access to the caves with a corpse even more difficult. Cave C as well as Cave K both sit on top of a *c.* 35º slope and are more easily accessed from above than from below. However, either approach would have required great care to get a body to the entrance.

Due to the limited space inside and outside these two caves, only two people could have manoeuvred a body into the cave. To enter Cave K, one nowadays has to slide face down through the tight cave mouth, below an overhang (fig. 6.16) and down a steep mud slope that leads onto the cave floor (fig. 6.17). The corpse had to take a similar journey, partially pulled, partially pushed, through the small aperture and onto level ground. Cave C requires a sideway slide-through onto a gravel covered cave floor. Although this cave has a larger cross section that allowed for a less restricted movement, it remains low and narrow,

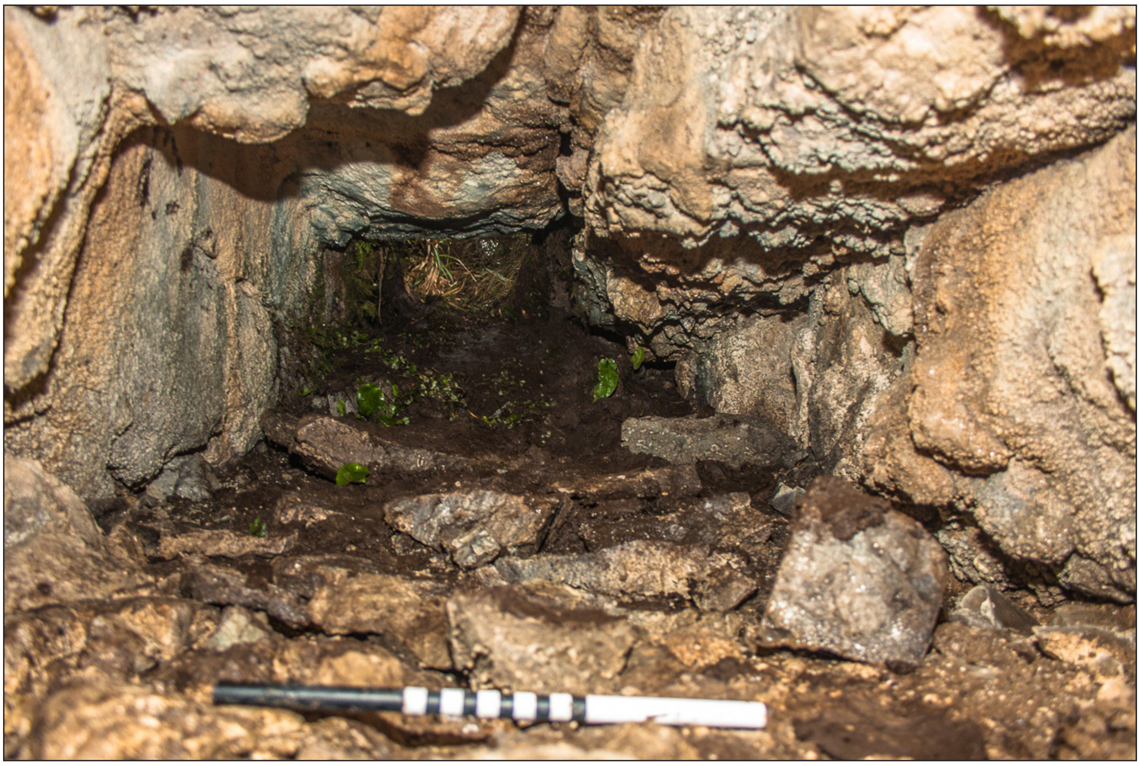


Figure 6.16: Entrance passage of Knocknarea Cave K showing entrance and mud slope leading onto rubble floor.

Figure 6.17: Entrances to Knocknarea Cave K (left) and Cave C (right).

thus making it difficult to move a corpse. Depending on the state of decomposition, this ‘close encounter’ could have been a very unpleasant experience with the odours of death and decay filling up the small cave passage rapidly. Once interred, the cave was probably blocked to isolate the body from the outside world and to protect it from scavengers during the excarnation process. as discussed in Section 6.3, the lack of gnaw marks on excarnation remains from Irish caves suggests that this may have been a common practice. Over the course of one to two years excarnation was complete, and the bones were removed for the next stage of the funerary rite, perhaps cremation or secondary interment in a megalithic tomb. Considering the high frequency of cremation deposits versus the rare occurrence of unburnt skeletal elements in passage tombs, the former may have been the more common practice on Knocknarea where passage tombs occur.

Journeying towards the northern cave group on Knocknarea, there is a sense of seclusion and liminality when one traverses the broken terrain and leaves behind all indications of human occupation as the top of Míosgan Méadhbh falls out of sight. At some point, when walking towards the edge of the last northwest shelf before the ground slopes steeply towards the sea, it almost feels like one is walking off the edge of the world. In a sense, it was the edge of the world for those who lived in the Cúil Irra peninsula with the vast and inhospitable Atlantic Ocean stretching to the horizon. It is at this threshold, the natural boundary between the enclosed sacred space and the outside world, where the northwest cluster of caves that includes Caves C and K is located. Carrying out a very intimate part of a funerary rite in one of these confined spaces close to death would have enhanced the sense of otherworldliness, liminality and the finite nature of one’s own existence. For the bereaved, it probably represented a very significant part of the burial rite, as it was also the last time to behold the deceased in their familiar appearance before decomposition processes would remove any resemblance to the living person.

Chapter 7: A discussion of archaeological predictive modelling for caves

The past two decades have seen an increasing interest in caves of archaeological significance in Ireland and, to date, cave archaeology here is probably better researched than in most countries. Yet much of our knowledge is founded on excavation campaigns that are over 70 years old, most of which were conducted by antiquarians. These early excavation and recording methods lacked detail and context, and much of the recovered material as well as many of the original records are now lost (Dowd 2015, 30 *ff.*). Today, archaeologists tend to have a reactive approach to cave archaeology in that they do not actively target caves for their archaeological value but rather react to chance finds, mostly by the caving community. Yet new excavations and new data from undisturbed contexts are needed to build on the existing foundation and close the gaps in knowledge left by a fragmented record.

This doctoral research was designed to pro-actively address the problem of a lack of new sites and increase the potentiality of caves in further understanding Neolithic funerary activity. Through the application of two different methodological approaches used in archaeological predictive modelling (APM), i.e. correlative vs. cognitive, I was able to assess these methods for their applicability in this particular research setting, and contribute to the on-going wider discussion over the usefulness of correlative and cognitive predictive modelling in archaeology (Gaffney and van Leusen 1995; Kamermans 2010; Wheatley 2004; Whitley 2003). How did the models perform in Ireland? And is APM useful in finding new archaeological caves? How does this research contribute to our knowledge of the Neolithic?

7.1 Outputs of the Sligo and Leitrim cave surveys

The main outputs from the fieldwork in counties Sligo and Leitrim can be summarised as follows:

1. Discovery of human remains in Knocknarea Cave K

2. 48 Caves identified by Drew vs.120 identified by Kahlert
3. 83% of 91 Sligo/Leitrim Caves were surveyed for the first time
4. Establishment a coherent database and catalogue of Caves visited
5. Accurate locations for 91 caves in Sligo /Leitrim
6. A methodological recording technique
7. New, extended, and detailed plan of Keash plus addition of four further caves
8. Discovery or re-discovery of 51 new or lost caves

Following a desk assessment of known caves in counties Sligo and Leitrim, I originally proposed to focus on caves in eight geographic study areas that contain clusters of caves as well as Neolithic megalithic tombs. Based on Drew's (2006a) database, these regions initially encompassed a combined total of 48 caves. By the end of the fieldwork phase, I had increased this figure to 120 caves and potential cave sites in these specific study areas. The unexpectedly large increase of caves forced me to focus on six of the eight original study areas for the analysis phase, which resulted in a detailed database of 91 caves across six study areas in counties Sligo and Leitrim (fig. 7.1). Only 17% of these (17 Keash Caves, Knocknarea Cave C and Sramore/Ravens Wing Cave) had been previously surveyed. With the exception of the Keash Caves, the majority of caves in this project are considered short and thus are rarely surveyed by cavers, or the surveys remain unpublished. However, while short caves are of little interest to the caving community, they are a valuable resource for archaeologists, geologists, biologists, environmental scientists, and paleoecologists, to name but a few. The current database of surveyed caves now provides researchers in archaeology with a readily accessible body of potential research targets for new projects that, for example, can be utilised in landscape studies or to explore spatial relationships between specific monument types and caves. The catalogue that emerged from my research provides a valuable resource for cavers and scholars in other disciplines. It has already contributed significantly to David Drew's database of Irish caves (2006a) by the addition of location data for 51 formerly unrecorded caves, and the correction of location data for 30 previously recorded caves.

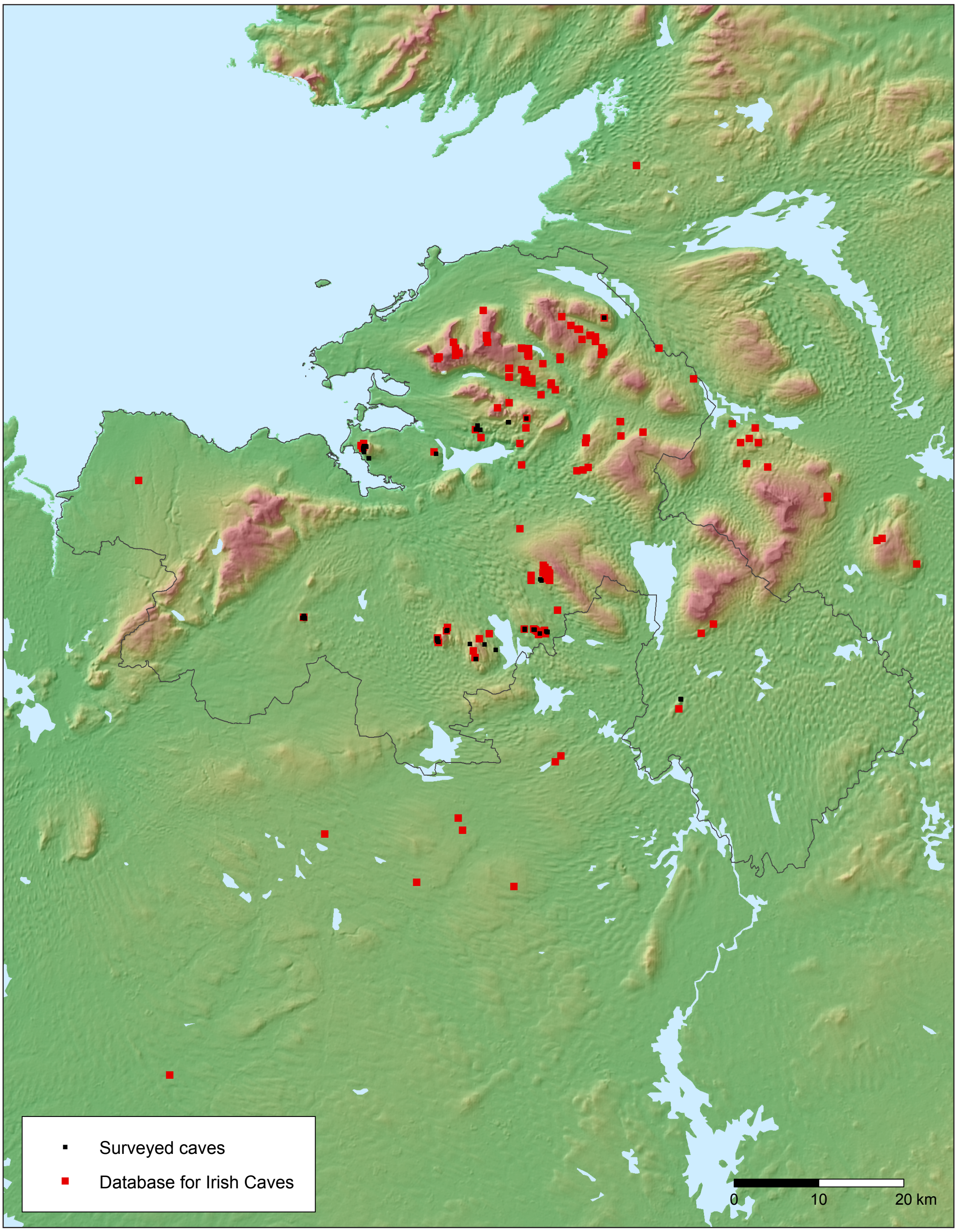


Figure 7.1: Map of 91 caves surveyed during this doctoral research in contrast to David Drew's Database for Irish Caves (2006a). Where markers do not overlap, either recorded locations of caves differ from Drew's database or caves do not appear in it.

The correction of incorrect published cave locations is a result of this research that should not be underestimated. For instance, an assessment of five caves at Ailtnasheabach near Geevagh, Co. Sligo based on Bunce and Sweeney (2003) (later omitted from the predictive model) revealed differences between their published locations and the actual site locations in the field. Despite intensive searches over a three-day period, only two of the recorded caves could be located and an additional two caves were recorded that were not featured in the article. Similarly, Dixon's (1973) survey of some caves around Moytirra, Co. Sligo (later omitted from the predictive model) and Wilson's (1965) note on the Knocknarea caves revealed significant discrepancies between published locations and their actual locations on the ground. In the pre-GPS era, location data for caves was commonly not more than a rough estimate, but even searches within a radius between 50 and 100m proved fruitless in several instances. Since David Drew based a substantial portion of his database on secondary published sources, the poor grid references of cave locations were also mirrored there. These three cases illustrate that there is a need to re-assess published location data from caving literature prior to the introduction of affordable GPS. Furthermore, my suggestion to the caving community is to accompany published location data with a notice of whether GPS was used and to what accuracy a location was recorded. Finally, for these 91 caves we now have - for the first time - accurate locations.

A considerable amount of time was invested in surveying - employing best cave survey techniques and its adaptation to meet the requirements for my own research. I developed new ways of recording caves and processing survey data that now allow for an easy integration of survey data into a GIS without having to learn additional cave survey applications. Existing electronic cave survey applications had proved to be inflexible, out-dated, or too cumbersome to operate. The availability of a new generation of survey tools, such as modified LDMs, that allow for a one-shot measurement of bearing, distance and inclination and that can send the data directly to smart phones or tablets, further improves and simplifies surveys. While integrated LDMs were not available for my own surveys, the customised spreadsheet solution for surveys that I created and used in this research can easily be adapted for future studies.

The value of surveying cave sites to modern archaeological standards is best illustrated by the survey of the Keash Caves (Bricklieves research area). This complex was subject to three antiquarian excavation campaigns but only an early plan drawing of the entire system and two partial plans of the caves existed prior to my 2014 survey (Gwynn *et al.* 1940; Scharff *et al.* 1903a). The new 2014 survey not only provides a much more detailed plan of the system, but also added four additional small caves - Keash Caves F1, J1, N1, and O1 - which received little or no mention in older publications. Apart from incorporating the footprints of the antiquarian excavation trenches that put the written descriptions of the trenches from the reports into their spatial context, a number of cuttings were also identified during my survey that did not correlate with any written descriptions. Other trenches, such as Gwynn's 1929 trenches 1 and 2 (Gwynn *et al.* 1940), are no longer visible on the ground, whereas Scharff's 1901 trench across the entrance of Coffey Cave (Scharff *et al.* 1903a) was not a cutting as such, but rather seems to have incorporated the entire entrance chamber of the cave (see also Appendix 1, 153*ff.*). This illustrates the extent of the antiquarian excavations, which is not always evident in the available reports. Scharff's plan of the Keash Caves was quite accurate but lacked detail and some passages were not recorded, as is the case with the western section of Keash Cave O (fig. 7.2).

Secondary outcomes of my fieldwork was the discovery or re-discovery of 51 new or 'lost' caves, such as the Legendary Tunnel, Fork Rift Cave, Calcite Cavern (all Bricklieves research area), The Doons Caves (Leean research area), and the Culleenduff Caves (Knocknarea research area). While some of these caves may have been known locally, they were not published in caving literature and were unknown to the caving and the archaeological community. Caves such as Fork Rift Cave and Legendary Tunnel were recorded by caver Dónal Gilhoys (unpublished) but never made public. His archive and manuscripts had the potential to become the most concise catalogue of caves in the Northwest, equalling *Caves of County Clare and South Galway* (Mullan 2003). However, despite a 15-year joint effort of cave exploration by Gilhoys and his colleagues, their book never reached completion. Despite its fragmented state, my assessment of parts of the Gilhoys archive (unpublished) that were relevant to my research areas demonstrates that further, dedicated research will reveal more unknown caves in the Northwest.

Figure 7.2: Left - new 2014 survey of Keash Caves. Right - antiquarian plan of the Keash Caves (after Scharff 1903a).

The different nature of discovery of human bones in Graineaters and Knocknarea Cave illustrates the contrast between a reactive and a pro-active approach to cave archaeology. Because caves have traditionally not been regarded as archaeologically significant places, they were often excluded from targeted archaeological research in Ireland, thus leaving the onus on cavers to report archaeological discoveries. This frequently led to a loss of archaeological data or, to a lesser extent, a loss of an entire archaeological site. For instance, the Late Mesolithic human remains from Sramore townland were not discovered in the cave reported by Dowd (2008, 307) but in Graineaters Cave, as I discovered as a consequence of my research. The original discovery was made and reported by cavers in 1995 (Dowd 2015, 86) but because of their conflicting reports, the find was attributed to the morphologically distinct Ravens Wing Cave (Sramore Cave according to Dowd 2008) and not to Graineaters Cave. With this, significant contextual information for one of the rare instances where human remains of Late Mesolithic date in Ireland have survived (Conneller 2006; Dowd 2015; Meiklejohn and Woodman 2012; Woodman 1996) is all but lost. Furthermore, only archaeological excavations in Graineaters Cave will determine with certainty whether or not this is the actual site of the Mesolithic bones found in 1995.

My discovery of human remains in Knocknarea Cave K (Dowd and Kahlert 2014, see also Chapter 6 and Appendix 1.6) in the course of fieldwork is the first instance of an archaeological discovery in a ‘new’ cave by an archaeologist. This in itself illustrates the general lack of interest in caves as targets for archaeological investigation, but it shows that small caves have excellent potential to produce undisturbed archaeology. The advantages of ‘first-hand’ discoveries by archaeologists are obvious: cave sediments are left intact while all archaeological and potentially paleoecological finds can be systematically recorded before they are recovered to the highest standards. Because the sediments in Knocknarea Cave K were not disturbed by cavers or casual visitors, and only minimally disturbed by animals, a full excavation has the potential to reveal less disturbed stratigraphy and more secure contextual information.

These two cases of Graineaters Cave and Knocknarea Cave K illustrate that a pro-active stance in cave archaeology is preferable to the traditional reactive one. Targeted research campaigns supported by predictive models, such as the two predictive models developed here for Munster (Chapter 4) and North Connaught (Chapter 5), tackle the challenge on a large scale, but surface inspection of caves by archaeologists during field visits have also shown to be successful approaches, as demonstrated by Knocknarea Cave K. Generally, there is excellent communication between archaeologists and cavers in Ireland that frequently results in collaborative excavations and publications in caving and, to some degree, archaeological journals (Anderson and McCarthy 1991; Casserly and Dowd 2011; Dowd and Bunce 2009; Dowd *et al.* 2011; Thomas and Critchley 1995). Yet it cannot be expected that cavers are as trained as archaeologists in identification of archaeology. In particular, less obvious archaeology such as cut features, small lithics, or small sherds of prehistoric pottery may be overlooked by cavers. The identification of such elements in cave sediments is a challenge even for experienced archaeologists. The discovery of human skull fragments in Graineaters Cave, for instance, is typical of archaeological discoveries in Irish caves, as is accidental disturbance of already sensitive stratigraphy (Connolly *et al.* 2005, 1; Dowd 2007, 36; 2010b; Ó Floinn 1992, 19; O'Shaughnessy 1993; Woodman 1996). Archaeologists are frequently called in to investigate sites that have suffered some damage before digging cavers fully realise the significance of their discovery. The two archaeological predictive models developed for this thesis form a pro-active approach to this situation, that not only - albeit indirectly - resulted in the discovery of a new Neolithic cave site, but also identified a manageable number of potentially archaeological caves that can now be excavated.

As a direct consequence of this doctoral research, Knocknarea Cave K provides the first tangible evidence that caves and Neolithic megalithic monuments were used contemporaneously in close proximity to one another. Prior to my research, only a small skull fragment from Knocknarea Cave C provided some indication of contemporaneous use but - probably because it was only a single small fragment - it was mostly ignored in subsequent publications (Bergh 2002a, 2002b, 2009). Despite 35 years of research and excavations on Knocknarea Mountain and the Cúil Irra peninsula (see also Chapter 6 and Appendix 1), there had been no archaeological appraisal of caves in the region. Regardless of the indicators of the role that caves played during the Neolithic (Dowd 2002, 2008; Dowd *et al.* 2006), they were not considered in the principal publications that addressed the ritual landscape of Knocknarea (Bergh 1995, 2000, 2002a, 2009, 2015). The discovery in Knocknarea Cave K, paired with the predicted high likelihood of finding more Neolithic activity in further caves on this mountain (see Chapter 5), strongly suggests that the archaeological potential of caves on Knocknarea is far from exhausted. The excavations of cave complexes at Edenvale, Co. Clare and Dungarvan, Co. Waterford demonstrate that funerary activities took place in multiple suitable caves where they occurred in clusters (Dowd 2015, 121-4). The north-western series of caves on Knocknarea, of which Knocknarea Caves C and K are part of, consist of groups of caves that are morphologically very similar to one another, which makes them ideal for funerary activities based on the data from Clare and Waterford. Supporting this assessment is the North Connaught Predictive Model (Chapter 5), which identified three further caves - Knocknarea Caves A, B, and R - which are highly likely to contain Neolithic archaeology (fig. 7.3).

7.2 Observations on environmental variables and research bias, and their effects on the performance of the Munster correlative-inductive predictive model

The majority of potential environmental predictor variables (e.g. soil, slope, distance to water, elevation *etc.*) that were analysed in this research had little to no effect on the dependent variable (e.g. Neolithic use/ no Neolithic use), thus making them poor predictors for the presence of Neolithic archaeology in caves. Independent variables for archaeological predictive models are often chosen from freely available environmental, topographical, geological, or archaeological data sets and this model attempted to utilise such data. While pre-fabricated datasets are convenient and cost-effective for developing a predictive model (Canning 2005, 7; Ducke 2011, 431-2), their applicability to the Munster APM was limited.

● Caves used during the Neolithic ■ Caves of likely Neolithic significance predicted by model

1 - Knocknarea Caves C and K
2 - Edenvale-Newhall Complex (5 caves)
3 - Annagh Cave
4 - Killuragh Cave
5 - Grange Hill Cave
6 - Connabery Cave C
7 - Killavullen Cave 3
8 - Dungarvan Valley Complex (6 caves)

9 - Knocknarea Caves A, B and R
10 - Deerpark Cave 1
11 - Treanscrabbagh Cave
12 - Fox Skull Cave
Glen One Cave
Glen Two Cave
13 - Ratty River Caves 1 and 2
14 - Ballynahemery Cave

Figure 7.3: High probability caves, and caves of Neolithic significance.

The failure of these variables as viable predictors can be explained by the type of archaeology a model attempts to predict. Topographical variables such as elevation, slope, proximity to water, hydrology, and shelter are frequently used in APMs to predict the occurrence of industrial and settlement sites (Kamermans 2010). In a sense, these variables basically filter out locations that are generally unsuitable for human occupation rather than providing genuine new insights into past human behaviour (Whitley 2003, 7-8; Woodman and Woodward 2002). In the case of the Munster APM, these *'lowest common denominator variables'* (Whitley 2003, 7-8) had little or no predictive ability because the model was developed to predict aspects of Neolithic religious beliefs and practises which were not necessarily chosen with practical considerations such as access to fresh water or accessibility in mind. Rather, the factors that guided location choices for ritual and funerary activity were determined by the underlying religious belief system, which we know very little about.

An alternative explanation may be that the 16 analysed caves of Neolithic significance in Munster were insufficient and too biased to make viable predictions. The distribution of values was heavily skewed across most variables, such as soil drainage or aspect, and the range of values hardly showed any discernible trends. A larger sample size would have led to a clearer picture, reducing the effect of extreme values while correlations would have become more pronounced. Altitude and distance to water, for example, showed trends that may have turned into statistically significant correlations if a larger sample size had been available. The potential significance of waterbodies in ritual cave use during the Irish Neolithic was proposed by Dowd (2015, 104-7). She proposed that in Neolithic Ireland lakes and rivers may have functioned as secondary burial sites where defleshed bones of the deceased were deposited in nearby water bodies (2015, 123). Chamberlain made similar inferences for caves in his archaeological predictive model in England (Holderness *et al.* 2007, 96). He detected an inverted correlation between archaeological caves and distance to water may have been related to the fact that, in the Peak District, caves at higher altitudes tended to be further away from water bodies.

Also relevant to this point is that antiquarian research bias had a significant effect on the performance of the Munster Predictive Model. In the case of the calibration group, the spatial distribution of caves in the 'Neolithic' group was a result of antiquarian excavation campaigns of the late 19th and early 20th centuries (Dowd 2015, 60-1). Of the cave sites that were excavated in Munster during these campaigns, Neolithic material appeared to occur in two concentrations at the Edenvale-Newhall cave complex and the Dungarvan caves. Only later discoveries such as Annagh Cave and Killuragh Cave suggests that cave use was also occurring at single cave locations. As a result, some variables displayed spatial auto-correlation, an effect that produces significant correlations between variables due to their shared proximity to certain features and environmental traits. Distance to embanked enclosures, for example, produced such a pattern in the Munster Predictive Model. With an increase of caves that contain Neolithic archaeology, a more widespread and random distribution of these caves will either resolve the effects of auto-correlation or prove that clustered cave use during the Neolithic was intentional.

Considering the limited number of known Irish caves that were used during the Neolithic, and the effects of auto-correlation, the seemingly good performance of the Munster Predictive Model is probably owed to internal testing methods rather than accurately reflecting reality, a shortcoming frequently observed in APM (Whitley 2010, 312). The final Munster Predictive Model had an accuracy of 1:5, meaning that at least one in five predictions it makes is wrong. The true accuracy is likely to be lower, as the training set also suffered from a considerable amount of accumulated errors and bias. Because many elements of the model were derived from secondary sources, their impact on model performance could not be quantified within the scope of this research.

The Munster Predictive Model's high classification accuracy is the result of internal testing, which relies on the assumption that all elements of the model are representative and accurately sampled. These testing mechanisms function well in a controlled laboratory environment with a rigid methodological framework but its applicability in a research environment with limited access to samples (e.g. caves used during the Neolithic) and first hand data (e.g. independent variables) is challenging. It is unlikely that the 16 caves of Neolithic significance used in the Munster Predictive Model fulfil that requirement. The model assumes that the two calibration sets, 'Neolithic' and 'non-Neolithic', represent past cave use patterns but that is unlikely to be the case (Ebert 2000; Ebert and Kohler 1988). To test model performance, a second independent data set of known sites is usually held back from the calibration group, which shows more adequately how well the model predicts the presence of archaeological sites. However, this approach requires a sufficiently large amount of known sites that can be split (Kvamme 1988a; Verhagen 2008), which was not available for this study.

There is, however, an advantage to working with a relatively small number of discrete site locations, which is the ability to verify the predictions for each site in the field. Archaeological predictive models are almost exclusively areal models that produce predictions for entire landscapes with relatively large grids. Those models typically consist of several hundred or thousand units that each cover several square metres on the ground. While field tests have proven to be the most accurate method to assess the accuracy of an APM, it is impossible to test every unit of an areal predictive model and, instead, sample-based testing strategies need to be devised, which increase the chances that sites are being missed. Models are also frequently tested internally via split samples, meaning that a portion of the 'site' and 'non-site' groups are withheld to be later run through the model. The resulting prediction accuracy is a measure of model performance (Aubry *et al.* 2012; Carlson and Baichtal 2015; Green *et al.* 2012). However, the larger the modelled area, the more challenging the testing becomes as a way of model assessment.

Can the correlative-inductive model be applied to other regions or other archaeological periods? In short, yes. The methodological framework and analytical workflow can be incorporated into future models that strive to evaluate caves in other regions and for different archaeological periods. To directly apply the predictive model with the same variables and coefficients would presume equal topographical and environmental settings as well as equal decision making processes, which is an unlikely scenario and has been shown to be a problem in this model. Looking further afield, caves in North Connaught are more frequently located at higher altitudes and their closer proximity to Neolithic monuments is primarily due to the higher density of megalithic sites in the region. Cave use also changed over time. In historic periods, for instance, evidence indicates a move away from religious/ritual use toward industrial/habitual use, which probably led to changed selection criteria, as different activities required different environmental settings (Dowd 2004, 295). In areal archaeological predictive modelling, certain human activities are tied to specific environments and proximity to resources (Kvamme 1988a, 333-5). Farmsteads, for example, required fertile and well-drained land, low, preferably south-facing slopes, and access to freshwater. This need for the presence of certain resources can also be observed in some Irish caves. For example, Killavullen Cave 3 lies near a crossing of the River Blackwater in the village of Killavullen, Co. Cork and was occupied by a blacksmith in recent centuries (Burke 1991). A functioning smithy would have required an adequately sized space with ease of access, proximity to settlement, as well as access to water and fuel; all of these conditions were present at Killavullen Cave 3 and are likely to be found at other caves that were used for utilitarian purposes. A predictive model for caves that predicts activities that depend on the presence of certain environmental conditions has a higher chance of being successful.

Models that strive to predict cave use in later prehistoric as well as historic periods, and for various specific activities, need to be adapted to reflect the types of activities that are to be predicted. In particular, activities during the Early Medieval period would especially have a greater chance of being predicted at a higher accuracy through a correlative model. A larger number of caves have produced a higher quantity of Early Medieval material than of any other period. This material is frequently associated with habitation and agricultural activities (Dowd 1997, 2004, 2015). Since habitation requires the presence of a very specific set of environmental, topographical, and cave morphological factors (accessibility, distance to freshwater, proximity to food, sufficiently large and level internal space *etc.*), a correlative-inductive predictive model for this period has the best chance of succeeding.

7.3 Explanatory-based predictions through intuitive cognitive-deductive predictive modelling

The likelihood values scores calculated by the cognitive-deductive model (Chapter 5) can only reflect on our current knowledge about past cave use, which is much better today than it was 20 years ago. Still, the data available at present is too varied and not abundant enough to develop a model that fully conceptualises past preferences and religious practices. Therefore, the model outputs do not provide definite answers but provide indications of where to look for Neolithic activity in caves.

That is not to say that caves that do not fit the 'picture' of a Neolithic funerary cave should be ignored in the long term. The status quo of what we believe to know about the past should constantly be challenged by looking for the unexpected in unlikely places (Kincaid 1988, 561-2; Lieskovský *et al.* 2013, 178). A site that does not fit the expected pattern is potentially of higher significance than the one that merely verifies what is already known (Whitley 2003, 2). For instance, up until recently there was a distinct spatial separation between Irish caves used during Neolithic and contemporary megalithic monuments and one could have argued that Neolithic material is more likely to appear in caves where megalithic monuments are less common. However, Knocknarea Cave K has challenged this perception. Notwithstanding, the presence of Neolithic human remains in one cave are far from being a pattern, thus research efforts should focus on exploring the possibility of close relationships between caves and megalithic monuments. Research in Neolithic funerary and ritual deposition of human remains in caves and their relationship with megalithic monuments elsewhere in Europe frequently suggest a close relationship, both spatially and functionally (Orschiedt 2002, 106; Schulting 2007, 7-8; Weiss-Krejci 2012, 123). It is equally important, however, to follow new lines of enquiry and challenge the status quo in our knowledge of Neolithic cave use.

The predictions made by the North Connaught cognitive-deductive model (Chapter 5) identified six caves as highly likely to contain Neolithic material based on cognitively derived patterns in cave morphology among caves from Munster that were used during the

Neolithic. Using histograms to calculate the likelihood of an event occurring (i.e. presence of Neolithic archaeology) was an alternative cognitive method to put expert knowledge and intuition into a quantifiable framework. Unlike Bayesian Inference and DST, the likelihood scores that resulted from my analysis did not utilise a contrasting set of 'non-sites' to discriminate between background variation and real patterns (Kvamme 1988a, 357). This approach overcame a frequently voiced criticism of correlative models using sites of unknown archaeological status as control sets (i.e. non-site). Such approaches assume that the absence of archaeology equals the absence of an archaeological site, and as such ignores that the majority of the archaeological record has either not survived or has not yet been discovered. The chances of this occurring have been estimated at 1% for areal models in the USA, which means that 1 acre in 100 acres classified as non-site contains a site (Kvamme 1988a, 357). This may be seen as an acceptable risk but the stated ratio of 1:100 is highly speculative and unlikely to be the same for Ireland and, more specifically, not the same for archaeological caves in the Munster research area. Here, the ratio between caves used during the Neolithic and those that are potentially suitable (i.e. horizontal relict caves) is one in seven at best, when using the incomplete dataset for archaeological caves as a conservative estimate. The density of archaeological sites in general is much higher than the RMP leads to believe (Mount 2001). This is due to a significant backlog of unprocessed commercial archaeological excavation report that have not yet been added to the RMP. Mount (2011) extrapolated site densities from various excavation to the whole area of Ireland and estimates a site density of 1/5.6ha *versus* the calculated 1.49ha derived solely from the RMP. Thus, not relying on assumptions about a non-site calibration set, the calculated likelihood coefficients of the North Connaught Predictive Model reflect what is known about Neolithic cave use without speculating about what is not known.

7.4 Contextualising the two Irish predictive models for archaeological caves: which methodological model fares better?

Chapter 2 synthesised the main aspects of the on-going discussion between proponents and opponents of predictive modelling. Part of this is also the efficacy of correlative-inductive and cognitive-deductive approaches as well as their relevance in academic archaeological research (van Leusen 2002; Whitley 2003, 2005). The consensus that cognitive-deductive methods are more suitable for academic research, whereas correlative-inductive methods are favoured in CRM applications, was partially echoed in the two models developed for this doctoral thesis.

The quantitative Munster Predictive Model was easier to implement as it was not concerned with causal relationships between the dependent and independent variables, but the relevance of the detected correlations and thus the predictions made by this model are difficult to interpret. The inclusion of each independent variable was determined by the strength of its correlation with the dependent variable. Traditionally used environmental factors had no impact on the outcome, whereas factors that could indicate some ritual behaviour fared better. 'Distance to embanked enclosure' and 'slope aspect' showed a strong relationship with Neolithic funerary activity. However, with a mean distance of 13km between caves used during the Neolithic and embanked enclosures, almost certainly there is no meaningful relationship here. Because this variable was the strongest predictor, the general relevance of the model outcome is questionable.

It is unlikely that in its current form the correlative predictive model for Munster will be successful in predicting the presence of funerary activity in caves. I have demonstrated that the deterministic correlative method shown is too inflexible to include social, cultural, and religious aspects because they can not be quantified through environmental variables (Kohler and Parker 1986, 401). Like the North Connaught Predictive Model, a cognitive element needs to be introduced to the modelling process to provide a rationale for the selection of predictor variables that goes beyond simple correlations. This requires the selection of a new set of variables, similar to those used for the North Connaught Predictive Model, which entails extensive field visits to collect necessary data.

The incorporation of expert knowledge in the North Connaught cognitive-deductive predictive model and its less stringent methodological framework is the more appropriate option to overcome the difficulties of relevance faced in the correlative-inductive model for Munster. Its methodological framework was able to include a multitude of variables and apply it to a relatively small number of caves without violating rules for the number of permissible variables (Vittinghoff and McCulloch 2007). The variables were chosen carefully to reflect aspects that are currently believed to have been essential to Neolithic religious, and particularly funerary, activities in caves (Dowd 2008, 2015), thus establishing a direct causal relationship between variables and outcome. Manually weighting each variable to control how much influence each one had on the outcome made the model more representative of those real-world observations.

From an academic point of view (*contra* CRM), the cognitive-deductive approach in combination with input data from primary sources has proven to be superior to correlative-inductive models that mostly rely on existing data sources (Church *et al.* 2000, 145). Having stopped short of field-testing the predictions made by this model, excavating the most likely and most unlikely caves would not only validate the North Connaught Predictive Model itself, but would also assess the explanatory framework upon which the model was built. It would be unfair, however, to dismiss the results of the Munster Predictive Model entirely because it demonstrated how limited environmental deterministic models are at predicting aspects of human behaviour that transcend environmental considerations.

7.5 Predictive modelling: the way forward in locating new archaeological caves?

The two archaeological predictive models identified 11 caves throughout Ireland that are most likely to be of Neolithic significance (fig. 7.2) out of a body of 176 caves within the two model areas. Regardless of the validity of the modelled predictions (and in particular the Munster Predictive Model (Chapter 4)), for the first time a pro-active stance has been taken in the identification of new caves of archaeological significance. An opportunity now exists to validate the predictions through excavation, and to further build on the lessons learned. The North Connaught Model (Chapter 5) in particular strongly highlights that some if not all of the predictions will reveal more Neolithic archaeology. The finds from Knocknarea Cave K (Chapter 6) have already substantiated the hypothesis that the variables used in that model are viable predictors for the presence of this type of archaeology.

The current body of Neolithic caves in Ireland is too small and not representative of the real distribution of caves of Neolithic significance, which makes the selection of a representative sample of caves for model building a considerable challenge. Most sampling strategies are currently based on the false assumption that archaeological sites are distributed randomly in the landscape, but as Whitley pointed out, archaeological sites are inherently auto-correlated, meaning that even if all parameters are equal, archaeological sites would not be randomly distributed across the landscape but would occur in discrete clusters (Whitley 2010, 312). It is currently impossible to distinguish site location choices made by Neolithic people from the choices made by antiquarians of which sites to investigate. Until further sites are discovered, predictions need to be considered with caution.

A successful predictive model for archaeological caves primarily requires accurate and representative data. The use of variables derived from topographical, geological, and geographical models in archaeological predictive modelling is controversial (Ebert 2000; Whitley 2010; Woodman and Woodward 2002) and the Munster model has shown that models that utilise such data are limited in their application. The potential errors introduced by extrapolated data, such as geological and soil maps, are difficult to quantify and subsequently compromise their reliability (Hageman and Bennett 2000, 132-3). Furthermore, using data from contemporary sources to make inferences about the past is questionable. Models that rely on such data assume that water levels, river courses, lakes, land cover, and topography have not changed since a site went out of use and/ or over the course of its use, which is unlikely to have been the case (*ibid.* 140-1).

The outcome from the Munster Predictive Model (Chapter 4) corroborates Church *et al.* who argued that modern soil and land cover maps do little to aid the reconstruction of ancient landscapes for predictive modelling (2000, 150). Anthropogenic and natural processes have changed the face of Ireland from the Early Neolithic onwards, with a decline in woodland and the development of raised and blanket bog that affected almost the entire island (Cole and Mitchell 2003, 514; Stolze *et al.* 2013). The difference in land cover becomes more prominent the further back in time one goes. For example, the Burren, Co. Clare and the Céide Fields, Co. Mayo are impressive examples of how deforestation and bog development can erode or bury entire archaeological landscapes and permanently alter the way we perceive them (Cooney 2000, 27; Lynch 2014, 19). A similar picture can be drawn for the Bricklieve Mountains where a decline in woodland cover and bog formation significantly altered the appearance of the local landscape (Stolze *et al.* 2013, 34-5). Some of these changes were dramatic and of long-term consequence, while others occurred within a relatively short time frame. Similarly, photos from the early 20th century explorations of Bats' Cave illustrate how in less than 100 years the surrounding landscape changed its appearance entirely from pastoral land to dense forest (fig. 7.4). The environment is prone to sudden changes but we cannot determine how these changes affected local populations through time in detail.

The same is true for individual caves, which can be highly dynamic environments with constantly changing morphologies due to fluctuating floor levels, continuous erosion, animal activities, and anthropogenic alterations, which destroy past activity horizons

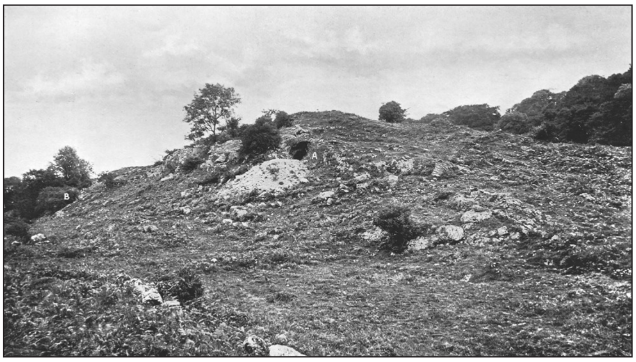


Figure 7.4: Left: antiquarian photo of the limestone outcrop that hosts Bats' Cave (centre) free from vegetation (Scharff et al. 1906). Right: recent photo looking out from Bats' Cave into the dense vegetation that covers the entire outcrop.

and subsequently hinder the reconstruction of a cave's appearance at certain points in time. Changes in floor levels can block entire passages, cut off connections, alter ceiling heights, and change passage widths. For instance, reconstructing Neolithic floor levels for Kilgreany Cave was challenging because they had already disappeared when it was excavated in 1928 and 1934 (Movius *et al.* 1935; Tratman 1929). As discussed in Chapter 5 (fig. 5.4, p. 132), the two existing plan drawings, one by Movius *et al.* (1935, 257) - probably showing its pre-excavation state - and the other by Ryder (2009, 78), illustrate how much the floor plan, and thus the cave's morphology, was changed by fluctuating sediment depth. Without knowing the level of the Neolithic activity horizon, it could not be determined if the ceiling was high enough to stand upright or if the deeper parts of the cave were at all accessible in the Neolithic, which had direct consequences on creating a morphological profile of this site. Natural as well as anthropogenic factors have had a significant influence on the setting and current morphology of each cave that was part of this doctoral research. While these factors were accounted for as much as possible, there is no way of knowing how closely these reconstructions match the caves' original Neolithic appearance.

In sum, archaeological predictive modelling has its place in cave archaeological research as a tool to help select the caves where archaeology is most likely to be found. The models developed for this doctoral thesis have achieved that in terms of Neolithic funerary activity and it is now a matter of assessing whether the predictions hold any merit. The caves predicted by the North Connaught Predictive Model are the most promising candidates, whereas the Munster model failed to detect significant variables that fit into a plausible explanatory framework. If developed well, archaeological predictive modelling can be a powerful tool to present researchers with potential targets for excavations, but it is not a means to an end. The explanatory dimension of the cognitive-deductive method is preferable to the purely correlative-inductive approach, although with a larger dataset of caves of Neolithic significance, correlative analysis will also yield better results.

7.6 New insights into cave use during the Neolithic

Dowd (2008, 311) stated that caves used for funerary activity during the Neolithic were often single long narrow passages or chambers, a statement corroborated by this analysis but which also illustrates the difference between cave use during the British and Irish Neolithic. At least half of all caves of Neolithic archaeological significance fall into the small/low category across all analysed morphological traits. Caves that did not fall into this category were either not of verified Neolithic significance, i.e. human remains have not been dated yet or they were associated with ritual deposition rather than funerary activity. The strong correlation between cave complexity and the presence of artefacts not associated with human remains implies that artefacts relate to ritual activity outside of a funerary context. This contrasts with Chamberlain who identified a correlation between the occurrence of prehistoric artefacts and human remains in British caves (Holderness *et al.* 2007, 105). This trend was not present in Ireland where Neolithic artefacts were only found in 50% of the caves that contained human remains.

Contrary to Chamberlain (2012), evidence suggests that cave use in Ireland and Britain differed significantly in some aspects, which is also mirrored in other funerary customs in Britain (Fowler 2010, 14). Inhumation seems to have been the dominant form of burial in British caves, often associated with grave goods and a larger proportion of infants than in above-ground funerary contexts (Chamberlain 2012, 81-6; Fowler 2010; Gilks 1973, 53-4; Schulting 2007, 7-8). In Ireland, inhumations could only be confirmed from two caves, plus another two or possibly three instances where human bones of Neolithic date may represent inhumation burials (Dowd 2015, 104). The remaining Irish caves produced disarticulated human remains that are either the result of token deposition or excarnation practices. Irish cave burials differ from their British counterparts insofar as only Kilgreany Cave included infants and only the Annagh Cave burials included pottery as grave goods. Annagh Cave is an exception in terms of burial rites and morphology, which makes it an extraordinary albeit unrepresentative cave burial site (Ó Floinn 1992, 2011). Dowd pointed out further differences between Irish and British Neolithic caves, such as the higher abundance of stone axes and arrowheads in British caves, and a tendency of bone sorting (2015, 98-9) which mirrors the evidence from British long barrows (Chamberlain 1997).

While Neolithic archaeology from caves in Munster is frequently found in closer proximity to embanked enclosures, this relationship does not hold up to scrutiny. These particular caves and embanked enclosures are located too far apart from one another to justify any meaningful relationship. One could argue that caves could have been important places of worship and destinations of pilgrimages that attracted visitors from further afield. However, one might expect to find higher concentrations of votive offerings at these places. The paucity of Neolithic artefacts from caves rather indicates that their significance was limited to local funerary activities.

Instead of a meaningful relationship between caves of Neolithic archaeological significance and Neolithic monuments in Munster, a distinct spatial separation between Neolithic monuments and caves, particularly caves of Neolithic archaeological significance, is noticeable (fig. 7.5). An exception can only be found in the Burren, where a greater spatial overlap between caves and Neolithic monuments exists but none of the caves in that area have yielded Neolithic archaeology to date. The only close spatial relationship between caves of Neolithic archaeological significance and Neolithic monuments exists at Grange Hill Cave and Red Cellar Cave, both located within or near the Neolithic/Bronze Age complex at Lough Gur. However, Grange Hill Cave did not produce any human remains and while Red Cellar Cave contained human remains of Neolithic date, its precise location is currently unknown (Grogan *et al.* 1987, 501).

The chronologies of caves of Neolithic archaeological significance and embanked enclosures currently do not overlap to any meaningful extent. Although none of the associated embanked enclosures in Munster have been dated, other examples indicate that they are most likely of Late Neolithic and Bronze Age date (Stout and Holloway 1991). For instance, the Drumwood embanked enclosure, Co. Tipperary and the Knockboy embanked enclosure, Co. Waterford are likely to be of Bronze Age date (Farrelly 2014; Moore 1999). The vast majority of human remains from caves occurred during the

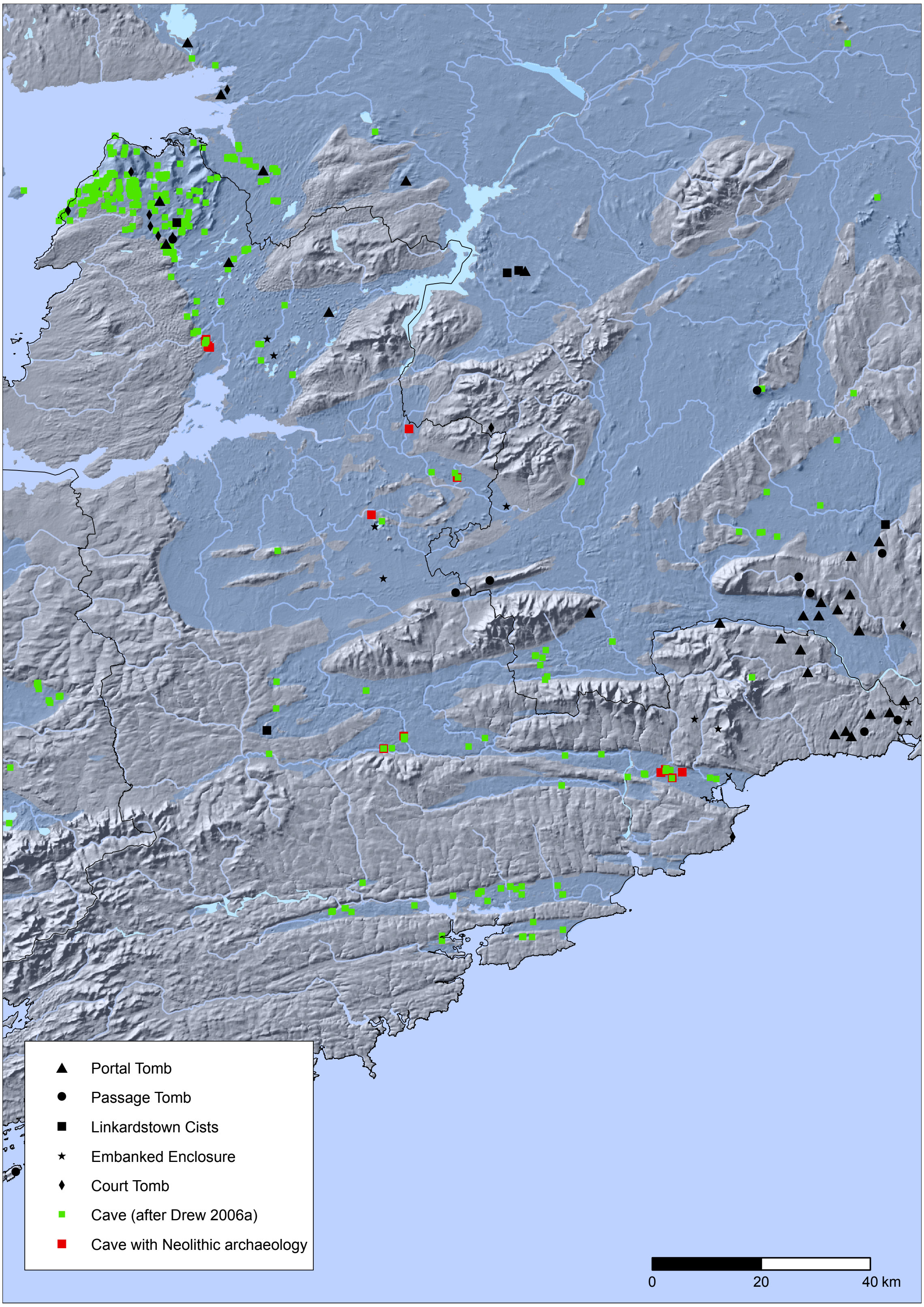


Figure. 7.5: With the exception of the Burren, caves and Neolithic monuments do not coincide in the Munster research area.

Middle Neolithic, clustering around 3500calBCE (Dowd 2015, 96-7). Contradicting the Late Neolithic/ Bronze Age is the recently excavated embanked enclosure at Balregan, Co. Louth which was dated to the Middle Neolithic (Donnchadha and Grogan 2010) thus making embanked enclosures contemporaneous time with the caves from the Munster APM. It is possible that further dating evidence could overthrow this perception and extend their date range further back into the Neolithic.

The spatial association between caves and Neolithic monuments for the North Connaught area is currently limited to Knocknarea Mountain. Chapter 6 demonstrated how these two caves integrate well into a previously reconstructed Neolithic landscape (Bergh 2000, 2002a) in terms of spatial organisation, contemporaneity, and funerary activity. The presence of small skeletal elements in two caves within the ceremonial space of Knocknarea showed that caves were also used for funerary activities where, contrary to Munster, megalithic monuments frequently occur. Caves located within, or close to, megalithic complexes could have a higher potential of being of archaeological significance. A number of caves in the Carrowkeel-Keshcorran complex possess suitable morphologies and locations to have been considered for religious use in the Neolithic.

Caves were not mere receptacles in which the dead were deposited but, as Dowd (2015, 93) put it, they were "*theatres in which a variety of different rituals were enacted*" and it cannot be assumed that these rituals were uniform on a geographical level of any scale. The human remains from Irish Neolithic caves show how complex and varied funerary rites were, even within small geographic regions such as the Edenvale-Newhall complex (*ibid.* 122-3). Yet, parallels have been drawn between Irish and British Neolithic cave use to explain less understood local Neolithic cave archaeology on either side of the Irish Sea (Dowd 2008, 313; 2015, 114-5). Differences may be more frequent than commonalities, which may be the expression of individual religious frameworks. In Munster, for instance, caves containing Neolithic archaeology tend to be located at lower altitudes, which stands in contrast to Chamberlain's observations of caves tending to be located at higher altitudes in the Peak District. The same does not hold true, however, for the Yorkshire Dales, where a correlation between altitude and the occurrence of archaeology in caves could not be observed (Holderness *et al.* 2007, 82-3) - however, Chamberlain's observations do not include a specific temporal frame and conclusions have to be taken with caution. Supporting the hypothesis that cave use differed significantly during the Irish and British Neolithic is Dowd's (2015, 110-1) disagreement with Barnatt and Edmonds (2002), who proposed that caves and chambered tombs were used interchangeably.

I agree with Dowd's proposition (2015, 110) that Neolithic people in Ireland made a clear distinction between caves and megalithic monuments. The human remains from caves and megalithic monuments are rather distinct. On the one hand, we have caves with mostly small skeletal elements, very few complete inhumations, and almost no cremations (Dowd 2015) whereas the human remains from megalithic monuments consist predominantly of cremations, disarticulated large skeletal elements, and no inhumations from passage tombs or court tombs (ApSimon 1985; Herity 1974, 1987). Looking at Barnatt and Edmond's analysis of three caves in the Peak District that contained possible Neolithic human remains shows some parallels with contemporaneous Neolithic monuments. For instance, the presence of specific skeletal elements and their arrangement within a cave, possibly a consequence of moving defleshed bones to make space for new interments, as well as modifications to caves such as the creation of cists and walls to carry out specific burial rites, overlap with the evidence from nearby burial monuments (Barnatt and Edmonds 2002). What can be seen as a certain commonality between the Neolithic uses of Irish and British caves is the complexity of, and variation in, the funerary and religious rites that were carried out within them.

Data driven correlative-inductive predictive modelling has shown to be of little use in the prediction of ritual activity where only small data sets were available, yielding little or no tangible results. Through a cognitive-deductive approach that follows principles of Bayesian inference, I was able to explain patterns in cave morphology and make predictions that are based on best current knowledge. Furthermore, I have been able to generate new knowledge through discovery of Neolithic human remains in Knocknarea Cave K, which subsequently led to new interpretations of the Neolithic ritual landscape on

Knocknarea. I detected a relationship between cave morphology and presence of artefacts that indicates that different cave types may have been preferred for different ritual activity. I also challenge perceived similarities between Neolithic cave use in Britain and Ireland by contrasting Neolithic cave use in Britain and Ireland. To provide researchers with a new method to survey caves and digitise survey data into GIS applications I developed a new survey and recording technique for caves. While this doctoral research has added new insights to cave use during the Neolithic, it has also opened the door for future research projects.

Chapter 8: Emerging from the darkness - conclusions and recommendations

This doctoral research set out to identify caves that had a greater potential of having been used for Neolithic funerary activities in Ireland by means of archaeological predictive modelling. What began as a straightforward exercise in site location modelling turned into a multi-season, multi-disciplinary research project. The thesis involved new survey techniques for small caves; an evaluation of qualitative and quantitative predictive modelling; the adaption of Bayesian principles into a new intuitive predictive modelling technique; extensive mapping and recording of caves in counties Sligo and Leitrim; as well as the discovery and excavation of human remains of Neolithic date from a cave on Knocknarea Mountain.

Caves most likely to contain Neolithic deposits

The aim of this doctoral research was to identify caves that are most likely to have been used during the Neolithic. This aim was achieved by not only identifying such caves in North Connaught and Munster (table 8.1) but also through the discovery of human remains of Neolithic date in Knocknarea Cave K, which allows us to consider the relationship between monuments and natural places in this already significant Neolithic ritual landscape. The caves identified by the North Connaught Predictive Model should be regarded as the most likely candidates.

Cave Name	County	probability* / lhs**
Knocknarea Cave R	Sligo	0.762**
Treanscrabbagh Cave	Sligo	0.751**
Knocknarea Cave A	Sligo	0.747**
Knocknarea Cave B	Sligo	0.747**
Deerpark Cave 1	Sligo	0.747**
Ratty River Cave 1	Clare	0.9*
Ratty River Cave 2	Clare	0.9*
Ballynahemery Cave	Waterford	0.836*
Fox Skull Cave	Clare	0.824*
Glen One Cave	Clare	0.822*
Glen Two Cave	Clare	0.82*

Table 8.1: Caves predicted to have a high potential of containing Neolithic archaeology.

Cave surveys

The extensive catalogue of caves appendixed here, currently consisting of 91 caves, is the single largest body of recorded caves in the northwest of Ireland, and is a valuable contribution to cave research. This resource allows for future spatial analysis and the exploration of the relationship between caves and other archaeological sites. The rapid cave survey technique I developed for this research enables a person working solo to fully survey a cave, while it is also adaptable to demands on survey accuracy and detail. In conjunction with the customised custom excel spreadsheet, I found this method the most intuitive and inclusive approach as it does not require specialised software applications nor the use of particular equipment. This approach, however, has not reached its full potential in terms of full integration into a GIS where the progress of a survey can be monitored directly in a GIS application. Especially when used in conjunction with GPS and total station, one could directly monitor how well survey data from the different sources tie together, an aspect that would have been of advantage during the survey of the Keash Caves, for instance.

A significant insight was the limited usability of the reflectorless total station, which had many difficulties with light diffusion on irregular rock surfaces. It took several attempts to register a particular point in some instances, yet the ability to record locations that were otherwise out of reach was a major advantage. If this type of survey is to be used in other caves, it is advisable to use targets where possible and only resort to reflectorless where required.

Cognitive-deductive predictive modelling - the way forward to make meaningful predictions

Quantitative methods used in the Munster Predictive Model have shown to be of very limited use, while the cognitive-explanatory approach yielded comprehensible predictions. This model's results corroborate with frequently voiced criticisms that APM is incapable of quantifying abstract human behaviour, such as social norms and religion (Gaffney and van Leusen 1995, 374). Furthermore, they support the growing body of evidence that cognitive-deductive APMs are preferable over purely correlative ones (Church *et al.* 2000; Verhagen *et al.* 2008; Whitley 2005).

At the time of writing, the cognitive-deductive model for North Connaught is currently the best available method to assess a cave for its Neolithic archaeological potential. This is not to say that correlative methods will not work in the future; the growing body of caves of Neolithic significance may reveal patterns other than those detected in the archaeological predictive models for Irish caves. In particular, the lack of evidence for religious activity not associated with human remains hindered the inclusion of environmental variables into the predictive models. The correlation between the presence of Neolithic artefacts and cave complexity demonstrated that modelling ritual deposition has a promising potential and would benefit from new data from future excavations.

Neolithic ritual landscapes and natural landscapes

The discovery of human remains of Neolithic date in Knocknarea Cave K (Dowd and Kahlert 2014) during survey work was unexpected and fortuitous. It opened new doors for hypotheses about the iconic Knocknarea Mountain and the people who carried out religious activities and who buried their dead on the mountain. People may have symbolically and, to an extent physically, divided Knocknarea Mountain into not only an inner sanctuary and the secular outside world as defined by discontinuous earthen banks and the mountain's natural topography; it was also divided into the part that faced inland onto the Cúil Irra peninsula, and the part that faced the sea, away from the land of the living. This seems to be where the dead were transformed via excarnation in caves to be later interred into passage tombs on the summit or used in further ritual activities.

The study has shown that Neolithic archaeological landscapes extend beyond the monumentality of built structures. Natural places that are embedded in these landscapes form an integral part of Neolithic religious beliefs. To avoid drawing a picture that revolves around the most visible remains - the commanding passage tombs - it is necessary to explore the hidden, natural surroundings in which these monuments were built and include them into our interpretative frameworks in equal measure to constructed features. In that respect, Knocknarea Cave K and Knocknarea Cave C both require a full excavation to reveal the extent of their use and to search for evidence that further illuminates the role that caves on Knocknarea played in Neolithic belief systems.

Future work

Being one of the very first archaeological predictive models in Ireland, and only the second in Europe that focuses on caves (Holderness *et al.* 2007), this doctoral research should be understood as a starting point for archaeological predictive modelling in academic research in general, and cave archaeology in particular. Following from the main results of this thesis, a number of future research projects are suggested which would further contribute to this field of research:

1. Excavation of caves identified as highly likely to contain Neolithic archaeology:

The two models have each identified a number of caves to be targeted in future excavations (table 8.1). A distinction, however, between the Munster and the North Connaught Predictive Model outcomes should be made. Since the North Connaught Predictive Model is based on an explanatory framework, it is likely to be more successful than the Munster model. However, because of their location within the Edenvale-Newhall cave complex, I recommend that Foxskull Cave, Glen One Cave and Glen Two Cave should also be considered for excavation.

Cave excavations are complex and time consuming, and a full excavation of a cave demands considerable financial and physical investments. However, I would not recommend small test trenches. Neolithic activity tends to be limited to the daylight zone of a cave, remains are usually sparse, and as such, test trenches may miss the archaeology. A partial excavation, limited to the daylight zone of a cave, is preferable with the option to excavate deeper inside if necessary. Best practices, such as 100% sieving of sediments and recording of the precise location of each find within the trench, should be implemented. Additionally, a 3D laser scan of the cave prior to and post-excavation would allow for an accurate reconstruction of the cave over time.

The most promising targets for future excavation are Knocknarea Caves A, B, and R as well as Treanscrabbagh Cave. These caves most closely resemble what we currently understand to have been selected for Neolithic funerary activities and their locations within major passage tomb complexes indicate that they were almost certainly known to local populations. In the case of the Knocknarea caves, work has demonstrated that other caves on the mountain were known and used during the Neolithic, making these three caves the most likely to reveal further Neolithic archaeology and ecofacts.

2. Develop archaeological predictive models for cave use in other periods:

Both correlative and cognitive modelling methods have potential to be adapted for research into cave use during other periods. Correlative analysis might identify relationships between cave use and the environment during a particular period that can be used in a predictive model. Morphological traits may also have determined if a cave was suitable for certain activities in other periods. Especially predictive models for Bronze Age or Early Medieval cave activity may yield some good results. Cave use during either period was not limited to religious activity which allows for the incorporation of environmental variables that are associated with certain activities into a predictive model. However, to avoid correlations with the modern environment re-construction of the contemporaneous environment would be required for the model area. Furthermore, a spatial correlation may be detected between contemporaneous field monuments and caves, such as ringforts which are frequently associated with souterrains that incorporated caves into their construction (Dowd 2015, 195).

3. Expand the cognitive-deductive predictive model from this research:

The results yielded by the cognitive-deductive predictive model for North Connaught are most promising and can be extrapolated onto other areas, systematically targeting areas with clear Neolithic activity as well as presence of caves. The Burren would be an ideal research area for such a model. It hosts an abundance of caves and Neolithic archaeological sites in a distinct geographic and topographical area. The caves here are better researched and the general lack of dense vegetation in the Burren is an advantage when it comes to field assessments. Following the methodology presented in this thesis, fieldwork would also be a major component in obtaining a detailed record of the caves and their landscape setting.

4. 3D scanning and reconstruction of caves of archaeological significance:

One of the major challenges encountered during data analysis for this project was to obtain the original floor levels of fully excavated caves of archaeological - in this case Neolithic - significance. Conducting a laser scan survey of caves of Neolithic importance, paired with a reconstruction of ancient floor levels through careful analysis of antiquarian excavation reports and unpublished note books, could achieve a more detailed picture of what certain caves may have looked like during the Neolithic. In particular, a reconstruction of floor levels in complex caves such as the Catacombs, Co. Clare or Brothers' Cave, Co. Waterford, along with a re-construction of quarried out parts of caves, such as at Ballynamintra Cave or Kilgreany Cave, would help to understand how the cave looked, and which parts of these caves were and were not accessible to Neolithic people. Micromorphological analysis of sediments, where they survived intact, can be applied to aid the reconstruction of ancient occupation/ activity levels.

Closing remarks

This doctoral research has shown that archaeological predictive modelling can be a viable tool to identify caves of archaeological significance in Ireland. The need for an increase of cave archaeological research efforts and the identification of new archaeological caves is one of the major factors to improve such models. To achieve this, archaeologists will have to take a pro-active stance as well as they need to consider caves as an integral part of Irish archaeological landscapes and that caves played a significant role throughout human history.

Bibliography

Adams, A., Kinahan, G. & Ussher, R. 1881 Explorations in the bone Cave Ballynamintra, near Cappagh, Co. Waterford. *Scientific Transactions of the Royal Dublin Society* 1, 177-226.

Adams, A. L. 1879 Report on the exploration of Shandon Cave. *The Transactions of the Royal Irish Academy* 26, 187-230.

Al-Muheisen, Z. & Al-Shorman, A. 2004 The archaeological site of Bediyeh: the constructed landscape. *Syria* (81), 177-90.

Altschul, J. F. 1988 Models and the modeling process. *In:* Judge, W. J. (ed.) *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling.* 61-96. Denver, Colorado: US Dept. of the Interior, Bureau of Land Management.

Altschul, J. F., Sebastian, L. & Heidelberg, K. 2004 *Predictive Modeling in the Military. Similar Goals, Divergent Paths.* Rio Rancho (NM): SRI Foundation.

Anderson, E. & McCarthy, M. 1991 Report on an excavation at Robbers Den Cave, Ballynahowan, Co. Clare, June 3-4th 1989. *Irish Speleology* 14, 11-3.

Andrews, T. 1835 On some caves in the Island of Rathlin and the adjoining coast of the county of Antrim. *Transactions of the British Association* 4, 660.

Anon 1901a Exploration of the Keish Caves. *The Irish Naturalist* 10 (12), 256.

— 1901b News Gleanings. *The Irish Naturalist* 10 (7), 141-2.

ApSimon, A. 1985 Chronological contexts for Irish megalithic tombs. *The Journal of Irish Archaeology* 3, 5-15.

Aubert, M., Brumm, A., Ramli, M., Sutikna, T., Saptomo, E. W., Hakim, B., Morwood, M. J., van den Bergh, G. D., Kinsley, L. & Dosseto, A. 2014 Pleistocene cave art from Sulawesi, Indonesia. *Nature* 514 (7521), 223-7.

Aubry, T., Luís, L. & Dimuccio, L. A. 2012 Nature vs. culture: present-day spatial distribution and preservation of open-air rock art in the Côa and Douro River Valleys (Portugal). *Journal of Archaeological Science* 39 (4), 848-66.

Balkaya, Ç., Göktürkler, G., Erhan, Z. & Levent Ekinci, Y. 2012 Exploration for a cave by magnetic and electrical resistivity surveys: Ayvacık Sinkhole example, Bozdağ, İzmir (western Turkey). *Geophysics* 77 (3), B135-B46.

Balla, A., Pavlogeorgatos, G., Tsiafakis, D. & Pavlidis, G. 2014 Recent advances in archaeological predictive modeling for archaeological research and cultural heritage management. *Mediterranean Archaeology and Archaeometry* 14 (4), 143-53.

Ballesteros, D., Domínguez-Cuestra, M. J., Jiménez-Sánchez, M. & González-Pumarieg, P. 2015 Tape-compass-clinometer, DistoX or total station, what is the best method to elaborate a cave survey? A case study in El Pindal Cave, Spain. *The*

8th IAG/AIG International Conference on Geomorphology and Sustainability. Paris, France, August 27-31, 2013.

Bar-Yosef Mayer, D. E., Vandermeersch, B. & Bar-Yosef, O. 2009 Shells and ochre in Middle Paleolithic Qafzeh Cave, Israel: indications for modern behavior. *Journal of Human Evolution* 56 (3), 307-14.

Barber, P. 2008 *Vampires, Burial, and Death: Folklore and Reality.* New Haven, CT, USA: Yale University Press.

Barnatt, J. & Edmonds, M. 2002 Places apart? Caves and monuments in Neolithic and earlier Bronze Age Britain. *Cambridge Archaeological Journal* 12 (1), 113-29.

Barry, P. & Kennedy, A. 2013 The caves of Largy: series one and two, and associated caves. *Irish Speleology* 20, 2-18.

Bayley Butler, J., Murphy, J. & O'Doherty, J. 1930 Daily diary of investigations of Cave N - Keash Carran series. Second expedition August 1930. Unpublished. *Natural History Division, NMI, Collins Barracks.*

Beck, A. & Weinstein-Evron, M. 1997 A geophysical survey in the el-Wad Cave, Mount Carmel, Israel. *Archaeological Prospection* 4 (2), 85-91.

Beckett, J. 2011 Interactions with the dead: A taphonomic analysis of burial practices in three megalithic tombs in County Clare, Ireland. *European Journal of Archaeology* 14 (3), 394 - 418.

— 2014 A taphonomic assessment of the human bone remains. *In:* Lynch, A. (ed.) *Poulnabrone: An Early Neolithic Portal Tomb in Ireland.* 56-60. Dublin: Stationary Office.

Beresford, M. 2008 *From Demons to Dracula: The Creation of the Modern Vampire Myth.* London, GBR: Reaktion Books.

Bergh, S. 1981 Hut Site 1, Knocknarea North. *In:* Burenhult, G. (ed.) *Carrowmore Excavations: Excavation Season 1981.* 38-118. Stockholm: Institute of Archaeology, University of Stockholm.

— 1985 *1985:51. Primrosegrange. Enclosure.* [Online]. Dublin. Available: http://www.excavations.ie/report/1985/Sligo/0000620/ [Accessed 18/3/2016]

— 1986 *1986:67. Carrickahorna East, Sligo* [Online]. Available: http://www.excavations.ie/report/1986/Sligo/0000695/ [Accessed 28/5/2015]

— 1995 *Landscape of the Monuments: A Study of the Passage Tombs in the Cúil Irra Region.* Stockholm: Riksantikvarieambetet.

— 2000 Transforming Knocknarea: the archaeology of a mountain. *Archaeology Ireland* 14 (2), 14-8.

— 2002a Knocknarea: the ultimate monument: megaliths and mountains in the Neolithic Cúil Irra, north-west Ireland. *In:* Scarre, C. (ed.) *Monuments and Landscape in Atlantic Europe: Perception and Society During the Neolithic and Early Bronze Age.* 139-51. London: Routledge.

— 2002b Monuments of meaning: role and symbolism of passage tombs in Cúil Irra, Co. Sligo. *In:* Timoney, M. A. (ed.) *A Celebration of Sligo: First Essays for Sligo Field Club.* 65-72. Carrick-on-Shannon: Sligo Field Club.

— 2006 Mullaghfarna, Sligo. *In:* Bennett, I. (ed.) *Excavations 2003.* Bray: Wordwell.

— 2009 Black is the colour. Chert, concave scrapers and passage tombs. *In:* Cooney, G., O'Connor, B. & Chapman, J. (eds.) *Materialitas: Working Stone, Carving Identity.* 105-12. Oxford: Oxbow Books.

— 2015 Where worlds meet. Two Irish prehistoric mountain-top 'villages'. *Il Capitale Culturale* (12), 21-44.

Berkeley, G. 1901 Description of the Cave of Dunmore. *In:* Fraser, A. C. (ed.) *Works of George Berkeley.* 73-84. Oxford: Clarendon Press.

Berry, M. S. 1984 Sampling and predictive modeling on federal lands in the west. *American Antiquity* 49 (4), 842-53.

Binford, L. R. 1962 Archaeology as anthropology. *American Antiquity* 28 (2), 217-25.

— 1964 A consideration of archaeological research design. *American Antiquity* 29 (4), 425-41.

— 1965 Archaeological systematics and the study of culture process. *American Antiquity* 31 (2), 203-10.

— 1968 Some comments on historical versus processual archaeology. *Southwestern Journal of Anthropology* 24 (3), 267-75.

Binford, S. R. & Binford, L. R. (eds.) 1968 *New Perspectives in Archeology* Chicago: Aldine.

Bjerck, H. B. 2012 On the outer fringe of the human world: phenomenological perspectives on anthropomorphic cave paintings in Norway. *In:* Bergsvik, K. A. & Skeates, R. (eds.) *Caves in Context: the Cultural Significance of Caves and Rockshelters in Europe.* 48-64. Oxford: Oxbow.

Bloch, M. & Parry, J. P. 1982 *Death and the Regeneration of Life.* Cambridge: Cambridge University Press.

Bongard, J. H. 1835 *Wanderung zur Neandershöhle: eine topographische Skizze der Gegend von Erkrath an der Düssel.* Düsseldorf: Arnz & Comp.

Boulger, G. S. 1875 Irish cave exploration. *Nature* 12 (298), 212.

Bower, B. 2015 New species of hominid found. *Science News* 188 (7), 6.

Bradley, R. 2000 An Archaeology of Natural Places. London: Routledge, Kindle edition.

— 2015 Foreword. *In:* Dowd, M. *The Archaeology of Caves in Ireland.* v. Oxford: Oxbow.

Brandt, R., Groenewoudt, B. & Kvamme, K. 1992 An experiment in archaeological site location: modeling in the Netherlands using GIS techniques. *World Archaeology* 24 (2), 268-82.

Bryce, J. 1835 On some caves containing bones near the Giant's Causeway. *Transactions of the British Association* 4, 658-60.

Buckley, V. & Mount, C. 1994 1993:199 - Carnaweeleen, Sligo. *In:* Bennett, I. (ed.) *Excavations 1993.* Bray: Wordwell.

Bunce, C. 2007 Whelan's Quarry Cave, Co. Clare, Ireland. *Proceeding of the University of Bristol Spelaeological Society* 1 (24), 71-4.

Bunce, C. & Barry, P. 2011 Caves of County Cork. Unpublished document for the SUI.

Bunce, C., Kelly, J., Jones, G. L. & Parkes, M. 2009 *The Caves of County Kerry. Unpublished document for SUI.* Speleological Union of Ireland.

Bunce, C. & Sweeney, J. 2003 *The Caves of Geevagh.* Speleological Union of Ireland.

Burenhult, G. 1980 *Carrowmore Excavations: Excavation Season 1980.* Stockholm: Institute of Archaeology, University of Stockholm.

— 1981 *Carrowmore Excavations: Excavation Season 1981.* Stockholm: Institute of Archaeology, University of Stockholm.

— 1984 *The Archaeology of Carrowmore.* Stockholm: Stockholms Universitet.

Burke, D. 1991 Killavullen Caves. *Mallow Field Club Journal* 9, 105-11.

Butler, W. B. 1987 Significance and other frustrations in the CRM process. *American Antiquity*, 820-9.

Canning, S. 2003 *Site Unseen: Archaeology, Cultural Resource Management, Planning and Predictive Modelling in the Melbourne Metropolitan Area.* PhD, La Trobe University.

Canning, S. 2005 'BELIEF' in the past: Dempster Shafer theory, GIS and archaeological predictive modelling. *Australian Archaeology* (60), 6.

Cantor, N. L. 2010 *After We Die: The Life and Times of the Human Cadaver.* Washington, DC, USA: Georgetown University Press.

Carlson, R. J. & Baichtal, J. F. 2015 A predictive model for locating early Holocene archaeological sites based on raised shell-bearing strata in southeast Alaska, USA. *Geoarchaeology* 30 (2), 120-38.

Carmichael, D. 1990 GIS predictive modelling of prehistoric site distributions in central Montana. *In:* Allen, K. M. S., Green, S. W. & Zubrow, E. B. W. (eds.) *Interpreting Space: GIS and Archaeology.* 216-25. London: Taylor and Francis.

Casserly, T. & Dowd, M. 2011 Archaeological discoveries in Moneen Cave, Co. Clare. *Descent* (December), 17-20.

Chamberlain, A. T. 1997 In this dark cavern thy burial place. *British Archaeology* (26), 6.

— 2003 Predictive modelling of archaeological caves (abstract). *Cave and Karst Science* 29 (3), 91.

— 2012 Caves and the funerary landscape of prehistoric Britain. *In:* Moyes, H. (ed.) *Sacred Darkness: a Global Perspective on the Ritual use of Caves.* 81-6. Boulder, Colorado: University Press of Colorado.

Chazan, M., Avery, D. M., Bamford, M. K., Berna, F., Brink, J., Fernandez-Jalvo, Y., Goldberg, P., Holt, S., Matmon, A., Porat, N., Ron, H., Rossouw, L., Scott, L. & Horwitz, L. K. 2012 The Oldowan horizon in Wonderwerk Cave (South Africa): archaeological, geological, paleontological and paleoclimatic evidence. *Journal of Human Evolution* 63 (6), 859-66.

Christaller, W. 1933 *Die zentralen Orte in Süddeutschland: eine ökonomisch-geographische Untersuchung über die Gesetzmässigkeit der Verbreitung und Entwicklung der Siedlungen mit städtischen Funktionen.* Jena: Gustav Fischer.

Church, T., Brandon, R. & Burgett, G. R. 2000 GIS applications in archaeology: method in search of theory. *In:* Wescott, K. & Brandon, R. (eds.) *Practical Applications of GIS for Archaeologists: A Predictive Modeling Toolkit.* 144-66. Philadelphia: Taylor and Francis.

Churchill Semple, E. 1911 *Influences of Geographic Environment: on the Basis of Ratzel's System of Anthropo-Geography.* New York: Henry Holt and Company.

Clark, D. 1999 Grahame Clark and world prehistory: a personal perspective. *Proceedings of the British Academy* 99, 1-10.

Clarke, D. 1979 *Analytical Archaeologist: Collected Papers of David L. Clarke.* New York: Academic Press.

Clarke, R. J. & Partridge, T. C. 2010 *Caves of the Ape-Men: South Africa's Cradle of Humankind World Heritage Site.* Pretoria: S. E. Publications.

Clarke, S. & Kytmannow, T. 2004 The Leean Mountain area of County Leitrim: a prehistoric landscape revealed. *Archaeology Ireland* 18 (2), 36-9.

Cleary, R. M., Lanting, J., Ó Donnabháin, B., Power, C., Lennon, A.-M., Anderson, E., Cleary, R. M. & Wijngaarden-Bakker, L. H. v. 1995 Later Bronze Age settlement and prehistoric burials, Lough Gur, Co. Limerick. *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature* 95C (1), 1-92.

Clottes, J. 2012 Ritual cave use in Palaeolithic European caves. *In:* Moyes, H. (ed.) *Sacred Darkness: a Global Perspective on the Ritual Use of Caves.* 15-26. Boulder: University Press of Colorado.

Clottes, J. & Geneste, J.-M. 2012 Twelve years of research in Chauvet Cave: methodology and main results. *In:* McDonald, J. & Veth, P. (eds.) *A Companion to Rock Art.* 583-604. John Wiley & Sons, Ltd.

Cole, E. E. & Mitchell, F. J. G. 2003 Human impact on the Irish landscape during the late Holocene inferred from palynological studies at three peatland sites. *Holocene (Sevenoaks)* 13 (4), 507-15.

Coleman, J. C. 1934 Exploration of a new cave discovered at Carrigtwohill, Co. Cork. *Journal of the Cork Historical & Archaeological Society* 39, 76-8.

— 1940 The Ovens Cave, Co. Cork. *Journal of the Cork Historical & Archaeological Society* 45, 47-52.

— 1942 Cave excavation at Middleton, Co. Cork. *Journal of the Cork Historical & Archaeological Society* 47, 63-76.

— 1944a Excavations in Ovens Cave, Co. Cork. *Journal of the Cork Historical & Archaeological Society* 49, 58-9.

— 1944b Note on excavations in Co. Cork. *Journal of the Royal Society of Antiquaries of Ireland* 74, 228.

— 1947 Irish cave excavation. *The Journal of the Royal Society of Antiquaries of Ireland* 77 (1), 63-80.

— 1965 *The Caves of Ireland.* Tralee: Anvil Books.

— 1966 An axe-head from Dunmore Cave, Co. Kilkenny. *Irish Speleology* 1 (2), 39.

Coleman, J. C. & Stelfox, A. W. 1945 Excavation at Carrigtwohill Caves, Co. Cork. *The Irish Naturalists' Journal* 8 (8), 299-302.

Condit, T. & Gibbons, M. 1989 An introduction to County Leitrim. *Archaeology Ireland* 3 (1), 6-9.

— 1991 A glimpse of Sligo's prehistory. *Archaeology Ireland* 5 (3), 7-10.

Condit, T., Gibbons, M. & Timoney, M. 1991 Hillforts in Sligo and Leitrim. *Emania* 9 (2), 59-62.

Conneller, C. 2006 Death. *In:* Conneller, C. & Warren, G. (eds.) *Mesolithic Britain and Ireland: New Approaches.* 139-64. Stroud: Tempus.

Connolly, M., Coyne, F. & Lynch, L. G. 2005 *Underworld: Death and Burial in Cloghermore Cave, Co. Kerry.* Bray: Wordwell.

Cooney, G. 1979 Some aspects of the siting of megalithic tombs in County Leitrim. *The Journal of the Royal Society of Antiquaries of Ireland* 109, 74-91.

— 2000 *Landscapes of Neolithic Ireland.* London: Routledge.

Cooney, G. & Grogan, E. 1999 *Irish Prehistory: A Social Perspective.* Bray: Wordwell.

Cooper, B. 2007 Bosch DLE 50 Laser Range Finder. *Compass Points* 38, 6-7.

Custer, J. F., Eveleigh, T., Klemas, V. & Wells, I. 1986 Application of LANDSAT data and synoptic remote sensing to predictive models for prehistoric archaeological sites: an example from the Delaware Coastal Plain. *American Antiquity* 51 (3), 572-88.

Danaher, E. 2007 *Monumental Beginnings: The Archaeology of the N4 Sligo Inner Relief Road.* Dublin: NRA.

Darwin, C. 1859 *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life.* London: John Murray.

Davies, O. 1949 Excavations at the horned cairn of Ballymarlagh, Co. Antrim. *Ulster Journal of Archaeology* 12, 26-42.

Day, A. 2002 *Cave surveying.* Buxton: British Cave Research Association.

de Valera, R. 1959 The court cairns of Ireland. *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature* 60, 9-140.

de Vries, P. 2008 Archaeological predictive models for the Elbe Valley around Dresden, Saxony, Germany. *In:* Posluschny, A., Lambers, K. & Herzog, I. (eds.) *Layers of Perception. Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA). Berlin, Germany, April 2–6, 2007.* Bonn: Dr Rudolf Habelt GmbH.

Dempster, A. P. 1968 A generalization of Bayesian inference. *Journal of the Royal Statistical Society, Series B* 30, 205-47.

Desmond, S. 1998 *Site 11, Drumhinny Lower. Prehistoric.* [Online]. Dublin. Available: http://www.excavations.ie/report/1998/Donegal/0003280/. [Accessed 15/8/2015]

Diggs, D. & Brunswick, R. 2006 Weights of evidence modeling in archaeology, Rocky Mountain National Park. *ArcUser* [Online]. Available: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Average. [Accessed 4/11/2011]

Dixon, J. 1973 Some cave sites in County Sligo. *Irish Speleology* 2 (2), 33-4.

Dodson, J. R. & Bradshaw, R. H. W. 1987 A history of vegetation and fire, 6,600 B.P. to present, County Sligo, western Ireland. *Boreas* 16, 113-23.

Donnchadha, B. & Grogan, E. 2010 *M1 Dundalk Western Bypass. Site 116: Balregan 1 and 2. Final Report.* Unpublished report for Irish Archaeological consultancy Ltd., on behalf of Louth County Council and the Nationalk Roads Authority. Available: http://www.asi-louth.ie/reports/01%20IAC%20Ltd%20Balregan%2003E0157%20Final%20TEXT.pdf. [Accessed 7/6/2015]

Douglas, M. 1966 *Purity and Danger: An Analysis of Concepts of Pollution and Taboo.* London: Routledge.

Dowd, M. 1997 *The Human Use of Caves in the South of Ireland.* Unpublished MA thesis, University College Cork.

— 2001 Archaeology of the subterranean world. *Archaeology Ireland* 15 (1), 24-9.

— 2002 Kilgreany, Co. Waterford: biography of a cave. *The Journal of Irish Archaeology* 11, 77-97.

— 2004 *Caves: Sacred Places on the Irish Landscape.* Unpublished PhD thesis, University College Cork.

— 2007 Living and dying in Glencurran Cave, Co. Clare. *Archaeology Ireland* 21 (1), 13-7.

— 2008 The use of caves for funerary and ritual practices in Neolithic Ireland. *Antiquity* 82, 305-17.

— 2009 Middle and Late Bronze Age ritual activity at Glencurran Cave, Co. Clare. *In:* Finlay, N., McCartan, S., Milner, N. & Wickham-Jones, C. (eds.) *From Bann Flakes to Bushmills: Papers in Honour of Professor Peter Woodman* 89-100. Oxford: Oxbow.

— 2010a Artefacts and bones from Glencurran Cave. *Burren Insight* (2), 10-2.

— 2010b A new archaeological site in the Burren: Moneen Cave. *Burren Insight* (4), 22-3.

— 2012 Lithics with an identity crisis. *Archaeology Ireland* 26 (1), 32-3.

— 2013a About a boy: excavations at Moneen Cave in the Burren. *Archaeology Ireland* 27 (1), 9-12.

— 2013b The archaeology and mythology of the Keash Caves, Co. Sligo. *In:* Timoney, M. A. (ed.) *Dedicated to Sligo.* 75-80. Sligo: Publishing Sligo's Past.

— 2013c The Jack Coleman archive: insights into Cork's archaeology. *Archaeology Ireland* 27 (4), 34-7.

— 2013d Seeing the light of day: the archives of Jack Coleman and Dónal Gilhoys. *Irish Speleology* 20, 34-41.

— 2015 *The Archaeology of Caves in Ireland.* Oxford: Oxbow.

Dowd, M. & Bunce, C. 2009 Glencurran Cave - gating and archaeology. *Underground* (75), 9-11.

Dowd, M. & Carden, R. F. First evidence of a Late Upper Palaeolithic human presence in Ireland. *Quaternary Science Reviews.* In press.

Dowd, M. & Corlett, C. 2002 Brothers in caves: lost archives of subterranean Waterford rediscovered. *Archaeology Ireland* 16 (1), 8-10.

Dowd, M., Fibiger, L. & Lynch, L. G. 2006 The Human Remains from Irish Caves Project. *Archaeology Ireland* 20 (3), 16-9.

Dowd, M. & Kahlert, T. 2014 Final Excavation Report for Knocknarea Cave K, Carrowbunnaun Td., Co. Sligo (SL014-288----). unpublished excavation report: Institute of Technology Sligo.

Dowd, M., Kennedy, A., Kozlowski, A. & Moore, S. 2011 Extreme archaeology: going underground in Monaghan. *Archaeology Ireland* 25 (2), 36-9.

Dowd, M., Lynch, L. G. & McCarthy, M. 2007 Recent archaeological discoveries at Dunmore Cave, County Kilkenny: Further questions regarding Viking Age activity. *Old Kilkenny Review* 59, 7-17.

Drew, D. 2006a A cave database for the Republic of Ireland. Available: http://www.ubss.org.uk/irishcaves/irishcaves.php.

— 2006b A database of caves in Ireland. *Irish Geography* 39 (2), 159-68.

Ducke, B. 2010 Regional scale predictive modelling in north-eastern Germany. *In:* Nicolucci, F. & Hermon, S. (eds.) *Beyond the Artifact. Digital Interpretation of the Past. Proceedings of CAA2004, Prato 13–17 April 2004.* 297-301. Budapest: Archaeolingua.

— 2011 New developments in archaeological predictive modelling. *In:* Bloemrs, T., Kars, H., van der Valk, A. & Wijnen, M. (eds.) *The Cultural Landscape and Heritage Paradox: Protection and Development of the Dutch Archaeological-historical Landscape and its European Dimension.* 431-44. Amsterdam: Amsterdam University Press.

— 2014 An integrative approach to archaeological landscape evaluation: locational preferences, site preservation and uncertainty mapping. *The Archaeology of Erosion, the Erosion of Archaeology Proceedings of the Brussels Conference, April 28-30, 2008.* 13-21. Relicta Monografieën 9 Archeologie, Monumenten- en Landschapsonderzoek in Vlaanderen; Heritage Research in Flanders.

Earle, T. K., Preucel, R. W., Brumfiel, E. M., Carr, C., Limp, W. F., Chippindale, C., Gilman, A., Hodder, I., Johnson, G. A., Keegan, W. F., Knapp, A. B., Jr, P. B. P., Rolland, N., Rowlett, R. M., Trigger, B. G. & Zeitlin, R. N. 1987 Processual archaeology and the radical critique [and comments and reply]. *Current Anthropology* 28 (4), 501-38.

Ebert, J. I. 2000 The state of the art in 'inductive' predictive modeling: seven big mistakes (and lots of smaller ones). *In:* Wescott, K. & Brandon, R. J. (eds.) *Practical Applications of GIS for Archaeologists: A Predictive Modeling Toolkit.* 137-43. London: Taylor and Francis.

Ebert, J. I. & Kohler, T. A. 1988 The theoretical basis of archaeological predictive modeling and a consideration of appropriate data-collection methods. *In:* Judge, W. J. (ed.) *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling.* 97-170. Denver, Colorado: US Dept. of the Interior, Bureau of Land Management.

Edwards, D. 2004 Full tilt ahead? *Compass Points* 33, 3-5.

Edwards, N. 1996 *The Archaeology of Early Medieval Ireland.* London: Routledge.

Egan, U., Byrne, E., Sleeman, M., Ronan, S. & Murphy, C. 2005 *Archaeological Inven-*

tory of County Sligo. Volume I: South Sligo. Comprising the Baronies of Corran, Coolavin, Leyny and Tirerrill. Dublin: The Stationary Office.

Ellis, B. 1976 *Surveying Caves.* Combwich, Bridgwater, Somerset: The British Cave Research Association.

Eogan, G. 1974 Report on the excavations of some passage graves, unprotected inhumation burials and a settlement site at Knowth, Co. Meath. *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature* 74, 11-112.

Eogan, G. & Herity, M. 1977 *Ireland in Prehistory.* Routledge.

Evans, R. W. 1910 Further explorations in Desmond's Cave near Mitchelstown. *Journal of the Cork Historical & Archaeological Society* 16, 32.

Farrelly, J. 2014 *TS050-024---* [Online]. National Monuments Service. Available: http://webgis.archaeology.ie/historicenvironment/ [Accessed 09/2015 2015].

Fealy, R. & Green, S. 2004 Teagasc-EPA Soils and Subsoils Mapping Project: Final Report Prepared for the Department of Environment, Heritage and Local Government and the Environmental Protection Agency. Dublin: Teagasc.

Fernandes, R., Geeven, G., Soetens, S. & Klontza-Jaklova, V. 2011 Deletion/Substitution/Addition (DSA) model selection algorithm applied to the study of archaeological settlement patterning. *Journal of Archaeological Science* 38 (9), 2293-300.

Field, A. 2009 *Discovering Statistics Using SPSS.* London: Sage Publications.

Finke, P. A., Meylemans, E. & Van de Wauw, J. 2008 Mapping the possible occurrence of archaeological sites by Bayesian inference. *Journal of Archaeological Science* 35 (10), 2786-96.

Flannery, K. 1967 Culture history v. culture process: A debate in American archaeology. *Scientific American* 217, 119-22.

Foley, R. 1981 A model of regional archaeological structure. *Proceedings of the Prehistoric Society* 47, 1-17.

Foot, A. W. 1878 An account of a visit to the cave of Dunmore, Co. Kilkenny, with some remarks on human remains found therein. *Journal of the Royal Society of Antiquaries of Ireland* 4 (1), 73-4.

Forsayeth, G. W. 1909 Cave exploration in Co. Waterford. *Journal of the Waterford and South-East of Ireland Archaeological Society* 12, 111-2.

Fowler, C. 2010 Pattern and diversity in the Early Neolithic mortuary practices of Britain and Ireland: contextualising the treatment of the dead. *Documenta Prehistorica XXXVII* 17, 1-22.

Fritz, J. M. & Plog, F. T. 1970 The nature of archaeological explanation. *American Antiquity* 35 (4), 405-12.

Frobenius, L. 1898 *Der Ursprung der Kultur Bd. 1.* Berlin: Verlag von Gebrüder Borntraeger.

Fry, G. L. A., Skar, B., Jerpåsen, G., Bakkestuen, V. & Erikstad, L. 2004 Locating archaeological sites in the landscape: a hierarchical approach based on landscape indicators. *Landscape and Urban Planning* 67 (1–4), 97-107.

Gaffney, V. & van Leusen, M. 1995 Postscript - GIS, environmental determinism and archaeology. *Archaeology and Geographical Information Systems: A European Perspective*, 367-81.

García Sanjuán, L. 1999 Expressions of inequality: settlement patterns, economy and social organization in the southwest Iberian Bronze Age (c. 1700-1100 BC)= Expressions d'inégalité: modèles d'habitation, économie et organisation sociale dans le sud-ouest de l'Espagne à l'âge du Bronze (1700-1100 av. J.-C.). *Antiquity* 73 (280), 337-51.

García Sanjuán, L. & Rodríguez López, J. 1996 Predicting the ritual? A suggested solution in archaeological forecasting through qualitative response models. *In:* Kamermans, H. & Fennema, K. (eds.) *Interfacing the Past. Computer Applications and Quantitative Methods in Archaeology CAA95. Analecta Praehistorica Leidensia.* 203-16. Leiden University Press.

Geber, J., Hensey, R., Meehan, P., Moore, S. & Kador, T. 2016 Reassessing the Age, Sex and Metric Variation of Commingled Human Remains from a 1911 Excavation of a Neolithic Passage Tomb Complex in North-West Ireland. *International Journal of Osteoarchaeology*. (In press).

Gilhoys, D. unpublished Caving Diaries and Notebooks. Unpublished archive, *Speleological Union of Ireland*.

Gilhoys, D. 1987 New caves in Co. Leitrim. *Irish Speleological Union Newsletter* 10, 9.

Gilks, J. A. 1973 The Neolithic and Bronze Age pottery from Elbolton Cave, Wharfedale. *The Yorkshire Archaeological Journal* 45, 41-54.

Graves, D. 2009 *Predictive Modelling and Quantitative GIS-based Analysis of Ritual and Settlement Landscapes of Neolithic Mainland Scotland, c 4000–2500 BC.* Unpublished PhD thesis, University of Edinburgh.

— 2011 The use of predictive modelling to target Neolithic settlement and occupation activity in mainland Scotland. *Journal of Archaeological Science* 38 (3), 633-56.

Graves McEwan, D. 2012 Qualitative landscape theories and archaeological predictive modelling—a Journey through no man's land? *Journal of Archaeological Method and Theory* 19 (4), 526-47.

Green, P. R., Altschul, J. H., Heilen, M. P., Cushman, D. W., Homburg, J. A., Lerch, M. K., Hayden, W. E. & Trampier, J. R. 2012 *Integrating Archaeological Modeling in DoD Cultural Resource Compliance, Final rept. Jul 2007-Oct 2012.* SRI Foundation Rio Rancho NM.

Grogan, E. 1996 Neolithic houses in Ireland. *In:* Darvill, T. C. & Thomas, J. (eds.) *Neolithic Houses in Northern Europe and Beyond.* 41-60. Oxford: Oxbow.

Grogan, E., Eogan, G., Rees, J., Butler, V. G. & Henderson, J. 1987 Lough Gur excavations by Seán P. Ó Ríordáin: further Neolithic and Beaker habitations on Knockadoon. *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature* 87C, 299-506.

Gwynn, A., Mitchell, G. & Stelfox, A. 1941 The exploration of some caves near Castletownroche, Co. Cork (Studies in Irish Quaternary Deposits. No. 4). *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science* 47, 371-90.

Gwynn, A. M., Riley, F. T. & Stelfox, A. W. 1940 Report on a further exploration (1929) of the caves of Keshcorran, Co. Sligo. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science* 46, 81-95.

Hageman, J. B. & Bennett, D. A. 2000 Construction of digital elevation models for archaeological applications. *In:* Wescott, K. & Brandon, R. J. (eds.) *Practical Applications of GIS for Archaeologists: A Predictive Modeling Toolkit.* 113-27. Philadelphia: Taylor and Francis.

Halliday, W. R. 2004 Piping caves and badlands pseudokarst. *In:* Gunn, J. (ed.) *Ecyclopedia of Caves and Karst Science.* 1260-71. New York: Taylor and Francis.

Hardman, E. J. 1874 On two new deposits of human and other bones discovered in the Cave of Dunmore Co. of Kilkenny. *Proceedings of the Royal Irish Academy* 2, 168-76.

— 1892 The limestone caves of Sligo. *In:* Wood-Martin, W. G. (ed.) *History of Sligo.* 375-8.

Harney, S., Long, C. B. & MacDermott, C. V. 1996 *Geology of Sligo-Leitrim: A Geological Description of Sligo, Leitrim and adjoining parts of Cavan, Fermanagh, Mayo and Roscommon, with accompanying Bedrock Geology 1:100,000 Scale Map, Sheet 7.* Dublin: Department of Transport, Energy and Communication.

Hatton, T. J. 2013 How have Europeans grown so tall? *Oxford Economic Papers* 2014 (66), 349-72.

Hatzinikolaou, E. G. 2006 Quantitative methods in archaeological prediction: from binary to fuzzy logic. *In:* Mehrer, M. & Wescott, K. (eds.) *GIS and Archaeological Site Location Modeling.* 403-10. Boca Raton: CRC.

Heeb, B. 2009 An All-In-One Electronic Cave Surveying Device. Available: http://paperless.bheeb.ch/download/DistoX.pdf.

— 2011 Paperless Caving - An Electronic Cave Surveying System La topo sans papier - un système électronique de topographie. Available: http://paperless.bheeb.ch/download/PaperlessCaving.pdf.

Heizer, R. F. & Cook, S. F. 1960 *The Application of Quantitative Methods in Archaeology.* Chicago: Quadrangle Books.

Hensey, R. 2015 *First Light: The Origins of Newgrange.* Oxford: Oxbow.

Hensey, R. & Bergh, S. 2013 The Inns at Sligo are better than those of Auray and the scenery is far more beautiful: Carrowmore re-visited. *In:* M., T. (ed.) *Dedicated to Sligo. Thirty-four Essays on Sligo's Past.* 41-3. Knock: KPS.

Hensey, R., Pádraig, M., Dowd, M. & Moore, S. 2014 A century of archaeology - historical excavation and modern research at the Carrowkeel passage tombs, County Sligo. *Proceedings of the Royal Irish Academy* 114C, 1-31.

Hensey, R. & Robin, G. 2011 More than meets the eye: new recordings of megalithic art in north-west Ireland. *Oxford Journal of Archaeology* 30 (2), 109-30.

Henshilwood, C. S., d'Errico, F. & Watts, I. 2009 Engraved ochres from the Middle Stone Age levels at Blombos Cave, South Africa. *Journal of Human Evolution* 57 (1), 27-47.

Herity, M. 1974 *Irish Passage Graves: Neolithic Tomb-Builders in Ireland and Britain 2500 B.C.* Dublin: Irish University Press.

— 1982 Irish Decorated Neolithic Pottery. *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature* 82C, 247-404.

— 1987 The finds from Irish court tombs. *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature* 87C, 103-281.

— (ed.) 2010 *Ordnance Survey Letters Sligo: Letters Relating to the Antiquities of the County of Sligo Containing Information Collected During the Progress of the Ordnance Survey in 1836 and 1837* Dublin: Fourmasters Press.

Hodder, I. 1974a Regression analysis of some trade and marketing patterns. *World Archaeology* 6 (2), 172-89.

— 1974b Some marketing models for Romano-British coarse pottery. *Britannia* 5, 340-59.

— 1977a The distribution of material culture items in the Baringo district, western Kenya. *Man New Series* 12 (2), 239-69.

— 1977b Some new directions in the spatial analysis of archaeological data at the regional scale (macro). *In:* Clarke, D. V. (ed.) *Spatial Archaeology.* 223-351. London: Academic Press.

— 1982 Theoretical archaeology: a reactionary view. *In:* Hodder, I. (ed.) *Symbolic and Structural Archaeology.* 48-52. Cambridge: Cambridge University Press.

— 1984 Archaeology in 1984. *Antiquity* 58 (222), 25-32.

— 1985a Postprocessual Archaeology. *Advances in Archaeological Method and Theory* 8, 1-26.

— (ed.) 1985b *Theory and Practice in Archaeology* London: Routledge.

— 1986 *Reading the Past: Current Interpretive Archaeology.* Cambridge University Press.

Holderness, H., Davies, G., Chamberlain, A. T. & Donahue, R. 2007 Research report – a conservation audit of archaeological cave resources in the Peak District and Yorkshire Dales. *Capra* 7.

Hosfield, R. 2001 Quantifying the British Palaeolithic: regional data and hominid adaptations. *In:* Earl, G., Poppy, S. & Wheatley, D. (eds.) *Contemporary Themes in Archaeological Computing.* 37-46. Oxford: Oxbow.

Hudak, G. J., Hobbs, E., Brooks, A., Sersland, C. A. & Phillips, C. 2011 A Predictive Model of Precontact Archaeological Site Location for The State of Minnesota. Available: http://www.dot.state.mn.us/mnmodel/P3FinalReport/TOC.html.

Huntington, E. 1913 Changes of climate and history. *The American Historical Review* 18 (2), 213-32.

Jackson, J. W. 1929 Report on the animal remains found in the Kilgreany Cave, Co. Waterford. *Proceedings of the University of Bristol Spelaeological Society* 3 (3), 137-53.

— 1936 Kilgreany Cave, County Waterford, by Hallam L. Movius, Jr., A. M. *The Irish Naturalists' Journal* 6 (2), 56.

Jasiewicz, J. & Hildebrandt-Radke, I. 2009 Using multivariate statistics and fuzzy logic system to analyse settlement preferences in lowland areas of the temperate zone: an example from the Polish Lowlands. *Journal of Archaeological Science* 36 (10), 2096-107.

Jin, C., Zhu, J., Steen-Adams, M. M., Sain, S. R. & Gangnon, R. E. 2013 Spatial multinomial regression models for nominal categorical data: a study of land cover in Northern Wisconsin, USA. *Environmetrics* 24 (2), 98-108.

Jochim, M. A. 1976 *Hunter-Gatherer Subsistence and Settlement: A Predictive Model.* New York: Academic Press.

Jones, H. D. & Smith, J. H. 1847 On certain antiquities presented to the Academy, found near a cavern at Cushendall, in the county of Antrim. *Proceedings of the Royal Irish Academy (1836-1869)* 4, 394-6.

Jrad, A., Quesnel, Y., Rochette, P., Jallouli, C., Khatib, S., Boukbida, H. & Demory, F. 2014 Magnetic Investigations of Buried Palaeohearths Inside a Palaeolithic Cave (Lazaret, Nice, France). *Archaeological Prospection* 21 (2), 87-101.

Judge, W. J., Sebastian, L. & Altschul, J. H. 1988 *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling.* Denver, Colorado: US Dept. of the Interior, Bureau of Land Management.

Kamermans, H. 2007 Smashing the crystal ball: a critical evaluation of the Dutch national archaeological predictive model (IKAW). *International Journal of Humanities and Arts Computing* 1 (1), 71.

— 2010 The application of predictive modelling in archaeology: problems and possibilities. *In:* Nicolucci, F. & Hermon, S. (eds.) *Beyond the Artifact. Digital Interpretation of the Past. Proceedings of CAA2004, Prato 13–17 April 2004.* 271-7. Budapest: Archaeolingua.

Kamermans, H., van Leusen, M. & Verhagen, P. 2009 *Archaeological Prediction and Risk management: Alternatives to Current Practice.* Leiden University Press, the Netherlands.

Kamermans, H. & Wansleeben, M. 1999 Predictive modelling in Dutch archaeology, joining forces. *In:* Barceló, J. A., Briz, I. & Vila, A. (eds.) *New Techniques for Old Times. CAA98. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 26th Conference, Barcelona, March 1998 (BAR International Series 757.* 225-30. Oxford: Archaeopress.

Kincaid, C. 1988 Predictive modeling and its relationship to cultural resource management applications. *In:* Judge, W. J. & Sebastian, L. (eds.) *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling.* 579-67. Denver, Colorado: U.S. Department of the Interior Bureau of Land Management

Klimchouk, A. 2004 Caves. *In:* Gunn, J. (ed.) *Encyclopedia of Caves and Karst Science.* 417-21. New York: Taylor and Francis.

Kohler, T. 1988 Predictive locational modelling: history and current practice. *In:* Judge, W., Sebastian, L. & Altschul, J. (eds.) *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling.* 19-59. Denver, Colorado: U.S. Department of the Interior, Bureau of Land Management.

Kohler, T. A. & Parker, S. C. 1986 Predictive models for archaeological resource location. *Advances in Archaeological Method and Theory* 9, 397 - 452.

Kopper, J. S. 1972 Geophysical surveying of cave sites. *Pyrenae* (8), 7-16.

Krist, F. J. J. 2006 Multicriteria/Multiobjective predictive modeling: a tool for simulating hunter-gatherer decision making and behavior. *In:* Mehrer, M. & Wescott, K. (eds.) *GIS and Archaeological Site Location Modeling.* 210-25. Boca Raton: CRC.

Kvamme, K. L. 1980 *Predictive Model of Site Location in the Glenwood Springs Resource Area, in A Class II Cultural Resource Inventory of the Bureau of Land Management's Glenwood Springs Resource Area.* Montrose, CO: U.S. Department of the Interior, Bureau of Land Management.

— 1988a Development and testing of quantitative models. *In:* Judge, W. J. (ed.) *Quantifying the Present and Predicting the Past: Theory, Methods, and Applications of Archaeological Predictive Modeling.* 325–428. Denver, Colorado.

— 1988b Using existing archaeological survey data for model building. *In:* Judge, W. J. (ed.) *Quantifying the Present and Predicting the Past: Theory, Method and Application of Archaeological Predictive Modelling.* 301-23. Denver, Colorado: U.S. Department of the Interior, Bureau of Land Management.

— 1990 The fundamental principles and practice of predictive archaeological modeling. *In:* Voorrips, A. (ed.) *Mathematics and Information Science in Archaeology: A Flexible Framework.* 257-95. Bonn: Holos.

— 1992 A predictive site location model on the high plains: an example with an independent test. *Plains Anthropologist* 37 (138), 19-40.

— 1999 Recent directions and developments in geographical information systems. *Journal of Archaeological Research* 7 (2), 153-201.

— 2006 There and back again: revisiting archaeological locational modeling. *In:* Mehrer, M. & Wescott, K. (eds.) *GIS and Archaeological Site Location Modeling.* 3-40. Boca Raton: Taylor and Francis.

Kytmannow, T. 2005 New prehistoric discoveries in the Kesh Corann/Carrowkeel complex, Co. Sligo. *Archaeology Ireland* 19 (4), 20-3.

Kytmannow, T., Hunt, C., Gunn, J. & Kahlert, T. 2009a Leean Mountain Prehistoric Landscape in Context: Final Report to the Heritage Council of Ireland. Available: http://www.qub.ac.uk/sites/Leean/FileStore/Filetoupload,416201,en.pdf.

Kytmannow, T., Kahlert, T. & Gardiner, M. 2009b Leean Mountain Prehistoric Landscape Survey, Second Year. Available: http://www.qub.ac.uk/sites/Leean2/.

Kytmannow, T., Kahlert, T. & Hunt, C. 2010 The Doons Hillfort. *Archaeology Ireland* 24 (3), 18 - 21.

Kytmannow, T., Mallory, J. & Trick, S. 2008 Leean Mountain Prehistoric Landscape Survey. Available: http://www.qub.ac.uk/sites/Leean/.

Larsson, A. M. 2003 Secondary burial practices in the Middle Neolithic: causes and consequences. *Current Swedish Archaeology* 11, 153-70.

Larsson, Å. M. 2008 Organised chaos: defleshing, cremations and dispersal of the dead in Pitted Ware Culture. *In:* Danielsson, I.-M. B., Gustin, I., Larsson, A., Myrberg, N. & Thedéen, S. (eds.) *Döda personers sällskap. Gravmaterialens identiteter och kulturella uttryck.* 109-30. Stockholm: Stockholms Universitet.

Lasheras Corruchaga, J. A. 2003 El arte paleolítico de Altamira. *In:* Lasheras Corruchaga, J. A. (ed.) *Redescubrir Altamira.* 65-97. Madrid: Turner Publications.

Legg, R. J. & Taylor, D. 2006 Modeling environmental influences on the locations of Irish Early Medieval ringforts. *Geoarchaeology: An International Journal* 21 (3), 201-20.

Lerma, J. L., Navarro, S., Cabrelles, M. & Villaverde, V. 2010 Terrestrial laser scanning and close range photogrammetry for 3D archaeological documentation: the

Upper Palaeolithic cave of Parpalló as a case study. *Journal of Archaeological Science* 37 (3), 499-507.

Leucci, G. & De Giorgi, L. 2005 Integrated geophysical surveys to assess the structural conditions of a karstic cave of archaeological importance. *Natural Hazards and Earth System Sciences* (5), 17-22.

Lewis-Williams, D. 2002 *The Mind in the Cave.* London: Thames & Hudson.

Lieskovský, T., Ďuračiová, R. & Karell, L. 2013 Selected mathematical principles of archaeological predictive models creation and validation in the GIS environment. *Interdisciplinaria Archaeologica, Natural Sciences in Archaeology* 4 (2), 177 - 90.

Limp, W. F. 1985 The analysis of decision making. *In:* Carr, C. (ed.) *For Concordance in Archaeological Analysis: Bridging Data Structure Quantitative Technique and Theory.* 128-72. Kansas City: Westport Press.

Llobera, M., Wheatley, D., Steele, J., Cox, S. & Parchement, O. 2004 Calculating the inherent visual structure of a landscape ('total viewshed') using highthroughput computing. *XXXII International Conference - Computer Applications in Archaeology 2004.* 146-51. Prato.

Logue, R. 2008 Excavations at Dunseverick Cave, Feigh alias Dunseverick, County Antrim AE/07/181 AE/08/161. Centre for Archaeological Fieldwork School of Geography, Archaeology and Palaeoecology Queen's University Belfast.

Luczak, A. 2013 Using predictive modeling methods as a way of examining past settlement patterns: an example from southern Poland. *Colloqium. Non-destruction Approaches to Complex Archaeological Sites in Europe: A Round Up.* Ghent University, Belgium.

Lynch, A. 2014 *Poulnabrone: An Early Neolithic Portal Tomb in Ireland.* Dublin: The Stationary Office.

Macalister, R. A. S., Armstrong, E. C. R. & Praeger, R. L. 1912 Report on the exploration of Bronze-Age carns on Carrowkeel mountain, Co. Sligo. *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature* 29, 311-47.

MacNeill, M. 2008 *The Festival of Lughnasa: A study of the survival of the Celtic festival of the beginning of harvest.* Dublin: Four Courts Press.

Madry, S. 2006 Case study 3: incorporation of historical cartographic data in a statewide archaeological predictive model and decision support system (DSS) for the North Carolina Department of Transportation (NCDOT). *In:* Archer, S. & Bartoy, K. (eds.) *Between Dirt and Discussion: Methods, Methodology and Interpretation in Historical Archaeology.* 62-7. New York: Springer.

Madry, S., Cole, M., Gould, S., Resnick, B., Seibel, S. & Wilkerson, M. 2006 A GIS-based archaeological predictive model and decision support system for the North

Carolina Department of Transportation. *In:* Mehrer, M. & Wescott, K. (eds.) *GIS and Archaeological Site Location Modeling.* 318-34. Boca Raton: CRC.

Marble, D. F. 1990 The potential methodological impact of geographic information systems on the social sciences. *In:* Allen, K. M. S., Green, S. W. & Zubrow, E. B. W. (eds.) *Interpreting Space: GIS and Archaeology.* 9-21. London: Taylor and Francis.

May, A. M. 1943 Portbraddan Cave, County Antrim. *Ulster Journal of Archaeology* 6, 39-60.

Maynard, P. F. & Strahler, A. H. 1981 The logit classifier: a general maximum likelihood discriminant for remote sensing applications. *15th International Symposium on Remote Sensing of the Environment.* 213-22. Ann Arbor, Michigan: American Society for Photogrammetry and Remote Sensing.

McAteer, C. & Parkes, M. 2004 The Geological Heritage of Sligo: An Audit of County Geological Sites in Sligo.

McCorkle, W. W. 2010 *Ritualizing the Disposal of the Deceased.* New York: Peter Lang.

Meiklejohn, C., Schulting, R., Musgrave, J., Babb, J., Higham, T., Richards, D. & Mullan, G. 2012 The Aveline's Hole 9 cranium: a partial solution to a long standing enigma. *Proceeding of the University of Bristol Spelaeological Society* 25 (3), 275-94.

Meiklejohn, C. & Woodman, P. C. 2012 Radiocarbon dating of Mesolithic human remains in Ireland. *Mesolithic Miscellany* 22 (1), 22-41.

Millard, A. 2005 What can Bayesian statistics do for archaeological predictive modelling? *In:* van Leusen, M. & Kamermans, H. (eds.) *Predictive Modelling for Archaeological Heritage Management : A Research Agenda.* 169-82. Amersfoort: Rijkdienst voor het Oudheidkundig Bodemonderzoek.

Miller, D. & Tilley, C. (eds.) 1984a *Ideology, Power, and Prehistory* Cambridge: Cambridge University Press.

— 1984b Ideology, power, and prehistory: an introduction. *In:* Miller, D. & Tilley , C. (eds.) *Ideology, Power, and Prehistory.* 1-15. Cambridge: Cambridge University Press.

Mitchell, F. & Ryan, M. 2001 *Reading the Irish Landscape.* Dublin: Town House.

Mithen, S. J. 2001 *Hunter-Gatherer Landscape Archaeology: The Southern Hebrides Mesolithic Project, 1988-1998.* McDonald Institute for Archaeological Research.

Mithen, S. J. & Lake, M. W. 1996 The Southern Hebrides Mesolithic Project: reconstructing Mesolithic settlement in western Scotland. *In:* Pollard, T. & Morrison, A. (eds.) *The Early Prehistory of Scotland.* 123-51. Edinburgh: Edinburgh University Press.

Modi, J. J. 1928 *The funeral ceremonies of the Parsees: their origin and explanation.* Bombay: Kessinger.

Montello, D. R. & Moyes, H. 2012 Why dark zones are sacred: turning to behavioral and cognitive science for answers. *In:* Moyes, H. (ed.) *Sacred Darkness: A Global Perspective of the Ritual Use of Caves.* 385-96. Boulder: University Press of Colorado.

Moon, H. 1993 *Archaeological Predictive Modelling: An Assessment.* Resources Inventory Committee. Earth Sciences Task Force, Branch A.

Moore, C. C. & Williamson, J. B. 2003 *The Universal Fear of Death and the Cultural Response. Handbook of Death & Dying. SAGE Publications, Inc.* Thousand Oaks, CA: SAGE Publications, Inc.

Moore, M. J. 1999 *Archaeological Inventory of County Waterford.* Dublin: Stationary Office.

— 2003 *The Archaeological Inventory of County Leitrim.* Dublin: Stationary Office.

Moore, P. & Forsythe, W. 2004a. *Oweyberne Cave, Rathline Island. Rathlin Island Research Project AE/04/96.*

— 2004b *Oweydoo Cave, Rathlin Island. Rathlin Island Research Project AE/04/93.* Centre for Archaeological Fieldwork, School of Archaeology & Palaeoecology, Queen's University Belfast & Centre for Maritime Archaeology, School of Environmental Science, University of Ulster Coleraine.

Morlot, A. v. 1848 *Über die Geologischen Verhältnisse von Istrien mit Berücksichtigung Dalmatiens und der Angrenzenden Gegenden Croatiens, Unterkrains und des Görzer Kreises*. Vienna: Naturwissenschaftliche Abhandlungen gesammelt und durch Subscription herausgegeben von Wilhelm Haidinger.

Moore, S. 2004 The Carrowkeel passage tomb complex, Co. Sligo: people and a pre-monumental landscape. *Association of Young Irish Archaeologists Conference Papers 2003.* Cork: University College Cork.

Mount, C. 1996 The environmental siting of Neolithic and Bronze Age monuments in the Bricklieve and Moytirra uplands, County Sligo. *The Journal of Irish Archaeology* 7, 1 - 11.

Mount, C. 2011 There are a lot more archaeological sites in the Republic of Ireland than we thought. *The Charles Mount Blog* [Online]. Available from: http://charles-mount.ie/wp/index.php/2011/05/. [Accessed 16/3/2016]

Movius, H. L., Roche, G., Stelfox, A. & Maby, J. C. 1935 Kilgreany Cave, County Waterford. *The Journal of the Royal Society of Antiquaries of Ireland* 5 (2), 254-96.

Mullan, G. (ed.) 2003 *Caves of County Clare and South Galway* Bristol: University of Bristol Spelaeological Society.

Mullan, G. & Boycott, A. 2004 Cave notes, Co. Clare, Ireland. *Proceeding of the University of Bristol Spelaeological Society* 2 (23), 143-8.

Ó Donnabháin, B. 2011 Human Remains. *In:* Cahill, M. & Sikora, M. (eds.) *Breaking Ground, Finding Graves-Reports on the Excavations of Burials by the National Museum of Ireland, 1927-2006, Voulme 1.* 34-47. Bray: Wordwell.

Ó Floinn, R. 1992 A Neolithic cave burial in Limerick. *Archaeology Ireland* 6 (2), 19-21.

— 2011 Annagh, Co. Limerick 92E047. *In:* Cahill, M. & Sikora, M. (eds.) *Breaking Ground, Finding Graves-Reports on the Excavation of Burials by the National Museum of Ireland, 1927-2006, Voulme 1.* 17-47. Bray: Wordwell.

Ó Nualláin, S. 1989 *Survey of the Megalithic Tombs of Ireland. Volume V. County Sligo.* Dublin: Stationary Office.

O'Brien, W. 2002 Megaliths in a mythologised landscape: South-west Ireland in the Iron Age. In: Scarre, C. (ed.) *Monuments and Landscape in Atlantic Europe: Perception and Society during the Neolithic and Early Bronze Age.* 152-76. London; New York: Routledge.

O'Brien, W. & Comber, M. 2008 Archaeological investigations at Ross Island Cave, Killarney, Co. Kerry. *The Journal of Irish Archaeology* 17, 19-56.

O'Connell, M., Ghilardi, B. & Morrison, L. 2013 A 7000-year record of environmental change, including early farming impact, based on lake-sediment geochemistry and pollen data from County Sligo, western Ireland. *Quaternary Research* 81 (1), 35-49.

O'Connell, M. & Molloy, K. 2001 Farming and woodland dynamics in Ireland during the Neolithic. *Biology and Environment: Proceedings of the Royal Irish Academy* 101B (1/2), 99-128.

O'Donnobhain, B. & Tesorieri 2014 Bioarchaeology. *In:* Lynch, A. & Manning, C. (eds.) *Poulnabrone: An Early Neolithic Portal Tomb in Ireland.* 61-85. Dublin: The Stationary Office.

O'Kelly, M. J. & O'Kelly, C. 1989 *Early Ireland: An Introduction to Irish Prehistory.* Cambridge: Cambridge University Press.

O'Riordan, S. P. 1979 *Antiquities of the Irish countryside.* London: Routledge.

O'Shaughnessy, J. 1993 *1993:145 - Killuragh, Limerick* [Online]. Available: http://www.excavations.ie/report/1993/Limerick/0001523/ [Accessed 10/2014 2014].

Oldham, A. 1981 *The Caves of Co. Cork.* Dyfed: Crymych.

Orschiedt, J. 2002 Die Jungfernhöhle bei Tiefenellern - Eine Neuinterpretation - mit einem Exkurs zur Interpretation der "Knochenstäbchen". *Kulthöhlen: Funde. Deutungen. Fakten. Beiträge des Symposiums vom 7. Dezember 1996.*, 93-112. Nürnberg: Naturhistorische Gesellschaft Nürnberg e. V. Abteilung für Vorgeschichte.

Osterbeek, L. 1997 Back home! Neolithic life and the rituals of death in the Portuguese Ribatejo. *In:* Bonsall, C. & Tolan-Smith, C. (eds.) *The Human Use of Caves.* 70-8. Oxford: British Archaeological Reports (BAR) International Series 667.

Osterholm, I. 1981 Hut site 2, Knocknarea North. *In:* Burenhult, G. (ed.) *Carrowmore Excavations: Excavation season 1981.* Stockholm: Institute of Archaeology, University of Stockholm.

Oubina, C. P., Boado, F. C. & Estevez, M. S. 1998 Rewriting Landscape: Incorporating Sacred Landscapes into Cultural Traditions. *World Archaeology* 1 (30), 159-76.

Palmer, A. 2007 *Cave Geology.* Dayton, OH: Cave Books.

Parker Pearson, M. 2003 *The Archaeology of Death and Burial.* Phoenix Mill: Sutton.

Parker, S. 1985 Predictive modelling of site settlement systems using multivariate logistics. *In:* Kvamme, K. & Carr, C. (eds.) *For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique and Theory.* 173-205. Kansas City, MO: Westport Publishers.

Parkes, M., Meehan, R. & Preteseille, S. 2013 *Corries, Caves and Coast: The Geological Heritage of County Waterford.* Waterford: Waterford County Council.

Peduzzi, P., Concato, J., Kemper, E., Holford, T. R. & Feinstein, A. R. 1996 A simulation study of the number of events per variable in logistic regression analysis. *Journal of Clinical Epidemiology* 49 (12), 1373-9.

Piontek, J. & Vančata, V. 2012 Transition to agriculture in Central Europe: body size and body shape amongst the first farmers. *Interdisciplinaria Archaeologica. Natural Sciences in Archaeology* 3 (1), 23-42.

Plunkett, T. 1876 A detailed account of the exploration of Knockmore caves in Fermanagh. *Journal of the Royal Geological Society of Ireland* 4, 131-40.

— 1879a On the exploration of the Knockninny Cave, Co. Fermanagh [abstract]. *Proceedings of the Royal Irish Academy. Polite Literature and Antiquities* 1, 329-34.

— 1879b Report of the committee, consisting of the Rev. Dr. Haughton, Prof. Leith Adams, Prof. Barrett, Mr. Hardman, and Dr. Macalister, appointed for the purpose of exploring the Fermanagh caves. *Report of the 48th Meeting of the British Association for the Advancement of Science.* London: John Murrauy.

— 1898 Further exploration in the Fermanagh Caves. *Geological Magazine* 5, 570-1.

Plunkett, T., Haughton, P. & Macalister, P. 1875 On the exploration of the Knockninny Cave. With an account of the animal remains. *Proceedings of the Royal Irish Academy. Science* 2, 465-83.

Power, C. 1993 Reconstructing patterns of health and dietary change in Irish prehistoric populations. *Ulster Journal of Archaeology* 56, 9-17.

Praeger, R. L. 1937 *The Way that I Went.* Cork: Collins Press.

Press, S. J. & Wilson, S. 1978 Choosing between logistic regression and discriminant analysis. *Journal of the American Statistical Association* 73 (364), 699-705.

Raftery, B. 1976 The Hillfort at Belmont in Co. Galway. *Journal of the Galway Archaeological and Historical Society* 35, 89-95.

Randolph-Quinney, P. S. 2015 A new star rising: biology and mortuary behaviour of Homo naledi. *South African Journal of Science* 111 (9/10), 2-5.

Reilly, S. 2003 Processing the dead in Neolithic Orkney. *Oxford Journal of Archaeology* 22 (2), 133-54.

Renfrew, C. 1973 *Before Civilization: The Radiocarbon Revolution and Prehistoric Europe.* Harmondsworth: Penguin.

— 1976 Megaliths, territories and populations. *In:* de Laet, S. J. (ed.) *Culturation and Continuity in Atlantic Europe.* 198-220. Bruge: De Tempel.

Renfrew, C. & Bahn, P. 2004 *Archaeology: Theories, Methods and Practice.* London: Thames & Hudson.

Robertson, J. G. 1854 Cave of Dunmore. *Natural History Review* 1, 169-76.

Rodriguez, E., Morris, C. S., Belz, J. E., Chapin, E. C., J.M. Martin, W. & Daffer, S. H. 2005 An Assessment of the SRTM Topographic Products, Technical Report JPL D-31639. Pasadena, California: Jet Propulsion Laboratory.

Roorda, I. M. & Wiemer, R. 1992 Towards a new archaeological information system in the Netherlands. *In:* Lock, G. & Moffett, J. (eds.) *CAA91. Computer Applications and Quantitative Methods in Archaeology 1991.* 85-8. Oxford: Tempus Reparatum.

Rose, M. R. & Altschul, J. H. 1988 An overview of statistical method and theory for quantitative model building. *In:* Judge, W. J. (ed.) *Quantifying the Present and Predicting the Past.* 173-255. Denver, Colorado: U.S. Department of the Interior, Bureau of Land Management.

Ryder, P. 1989 Caves in County Waterford, October 1988. *Irish Speleology* 13 (40), 40-6.

— 2009 MSG explorations in County Waterford. *Irish Speleology* 18, 72-96.

Rynne, E. 1969 Cist-burial in a cairn at Treanmacmurtagh, Co. Sligo. *The Journal of the Royal Society of Antiquaries of Ireland* 99 (2), 145-50.

Sabloff, J. A. & Gordon, R. 1967 The collapse of Maya civilization in the southern lowlands: a consideration of history and process. *Southwestern Journal of Anthropology* 23 (4), 331-6.

Sauer, C. O. 1925 The morphology of landscape. *University of California Publications in Geography 2* (2), 296-315.

Scharff, R. F. 1895 Cave at Ballymote (Kesh), Co. Sligo. *The Irish Naturalist* 4, 94.

— 1902 Exploration of Kesh Caves, Co. Sligo, Ireland. *Geological Magazine* 9, 505-10.

Scharff, R. F., Coffey, G., Cole, G. A. J., Cole, A. J. & Ussher, R. J. 1903a The exploration of the Caves of Kesh, County Sligo. *The Transactions of the Royal Irish Academy* 32, 171-214.

Scharff, R. F., Praeger, R. L., Coffey, G., Cole, G. A. J., Cunningham, d. J. & Lamplugh, G. W. 1903b Kesh Caves, Co. Sligo. Report of the committee appointed to explore Irish caves. *Reports of the British Association for the Advancement of Science*, 1-6.

Scharff, R. F., Praeger, R. L., Coffey, G., Cole, G. A. J., Cunningham, D. J., Lamplugh, G. W., McHenry, M. & Ussher, R. J. 1905 Edenvale Caves, Co. Clare. *Report of the 74th Meeting of the British Association for the Advancement of Science*, 288.

Scharff, R. F., Ussher, R., Cole, G. A. J., Newton, E., Dixon, A. F. & Westropp, T. 1906 The exploration of the caves of County Clare. Being the second report from the committee appointed to explore Irish caves. *The Transactions of the Royal Irish Academy* 33, 1-76.

Schermer, S. J. & Tiffany, J. A. 1985 Environmental variables as factors in site location: an example from the upper Midwest. *Midcontinental Journal of Archaeology* 10 (2), 215-40.

Scholtz, S. C. 1981 Location choice models in Sparta. *In:* Lafferty, R. H., Otinger, J. L., Scholtz, S. C., Limp, W. F., Watkins, B. & Jones, R. D. (eds.) *Settlement Predictions in Sparta: A Locational Analysis and Cultural Resource Assessment on the Uplands of Calhoun County, Arkansas.* 207–22. Fayetteville: Arkansas Archeological Survey.

Schulting, R. 2007 Non-monumental burial in Britain: a (largely) cavernous view. *In:* Larsson, L., Lüth, F. & Terberger, T. (eds.) *Innovation and Continuity - Non-Megalithic Mortuary Practices in the Baltic: New Methods and Research into the Development of Stone Age Society: International Workshop at Schwerin on 24-26 March 2006.* 581-603. Schwerin: Bericht der Römisch-Germanischen Kommission.

— 2012 Skeletal evidence for interpersonal violence. *In:* Schulting, R. & Fibiger, L. (eds.) *Sticks, Stones, and Broken Bones: Neolithic Violence in a European Perspective.* 223-48. Oxford: Oxford University Press.

— 2014 The dating of Poulnabrone. *In:* Lynch, A. & Manning, C. (eds.) *Poulnabrone: An Early Neolithic Portal Tomb in Ireland.* 93-113. Dublin: The Stationary Office.

Schulting, R., Gardiner, P. J. & Murray, E. 2010 The Mesolithic and Neolithic bone assemblage from Totty Pot, Cheddar, Somerset. *Proceeding of the University of Bristol Spelaeological Society* 25 (1), 75-95.

Schulting, R., Margaret, C. & Chapman, E. J. 2013 AMS 14C dating and stable isotope (carbon, nitrogen) analysis of an earlier Neolithic human skeletal assemblage from Hay Wood Cave, Mendip, Somerset. *Proceeding of the University of Bristol Spelaeological Society* 26 (1), 9-26.

Schulting, R. & Wysocki, M. 2002 The Mesolithic human collection from Aveline's Hole: a preliminary note. *Proceeding of the University of Bristol Spelaeological Society* 22 (3), 255-68.

Schulting, R. & Wysocki, M. 2005 'In this chambered tumulus were found cleft skulls …': an assessment of the evidence for cranial trauma in the British Neolithic. *Proceedings of the Prehistoric Society* 71, 107-38.

Sebastian, L. & Judge, W. J. 1988 Predicting the past: correlation, explanation, and the use of archaeological models. *In:* Judge, W. J. & Sebastian, L. (eds.) *Quantifying the Present, Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling.* 1-18. Denver, Colorado: U.S. Department of the Interior Bureau of Land Management

Self, C. A. 1981 *The Caves of County Clare.* Bristol: University of Bristol Spelaeological Society.

Sevastopulo, G. D. & Wyse Jackson, P. N. 2001 Carboniferous (Dinantian). *In:* Holland, C. H. (ed.) *The Geology of Ireland.* 241-88. Edinburgh: Dunedin Academic Press.

Shafer, G. 1976 *A Mathematical Theory of Evidence.* Princeton University Press.

Shanks, M. 2008 Post processual archaeology and after. *In:* Chippindale, C. & Maschne, H. (eds.) *Handbook of Archaeological Theories.* 133-46. Plymouth: Altamira.

Shanks, M. & Tilley , C. 1993 *Re-Constructing Archaeology: Theory and Practice.* London: Routledge.

Sluka, M. 1999 Surveying with digital instruments. *Compass Points* 23, 6-7.

Smith, M. J. & Brickley, M. B. 2004 Analysis and interpretation of flint toolmarks found on bones from West Tump long barrow, Gloucestershire. *International Journal of Osteoarchaeology* 14 (1), 18-33.

Smyth, J. 2014 *Settlement in the Irish Neolithic: New Discoveries at the Edge of Europe.* Oxford: Oxbow.

Stančič, Z. & Kvamme, K. L. 1999 Settlement pattern modelling through boolean overlays of social and environmental variables. *In:* Barceló, J. A., Briz, I. & Vila, A. (eds.) *New Techniques for Old Times. CAA98. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 26th Conference, Barcelona, March 1998 (BAR International Series 757).* 231-8. Oxford: Archaeopress.

Stelfox, A. W. 1930 Kilgreany Cave, Co. Waterford. *The Irish Naturalists' Journal* 3 (6), 118-23.

Steward, J. H. 1937 Ecological aspects of southwestern society. *Anthropos* 32 (1/2), 87-104.

— 1938 *Basin-Plateau Aboriginal Sociopolitical Groups.* Washington: Bureau of American Ethnology, XII.

— 1955 *The Theory of Culture Change: The Methodology of Multilinear Evolution.* Urbana: University of Illinois Press.

Stolze, S., Doerfler, W. & Nelle, O. 2013 A high resolution reconstruction of landscape during the fourth millenium BC in the Carrowkeel / Keshcorran area, County Sligo. *In:* Timoney, M. (ed.) *Dedicated to Sligo: Thirty-four Essays on Sligo's Past.* 29-36. Sligo: Publishing Sligo's Past.

Stout, G. & Holloway, D. H. 1991 Embanked enclosures of the Boyne Region. *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature* 91C, 245-84.

Symes, R. G., Wilkinson, S. B., Kilroe, J. R. 1880 *Explanatory Memoir to accompany sheet 54 and the south-west portion of 42 of the maps of the Geological Survey of Ireland including the country around Easky, Dromore West, and Coolaney, in the counties of Sligo and Mayo.* Dublin: Alexander Thom & Co.

Thomas, A. 1995 Killuragh Caves and others of East Limerick. *Irish Speleology* 15, 72-4.

Thomas, A. & Critchley, G. 1995 Could your dig be a valuable archaeological site? *Irish Speleology* (15), 75-6.

Thomas, J. 2000a Death, identity and the body in Neolithic Britain. *The Journal of the Royal Anthropological Institute* 6 (4), 653-68.

— 2000b Death, identity and the body in Neolithic Britain. *The Journal of the Royal Anthropological Institute* 6 (4), 653-68.

Thorn, R., Drew, D. & Coxon, C. 1990 The hydrology and caves of the Geevagh and Bricklieve karsts, Co. Sligo. *Irish Geography* 23 (2), 120-35.

Thünen, J. H. v. 1910 *Der Isolierte Staat in Beziehung auf Landwirtschaft und national Ökonomie.* Jena: Fischer.

Tilley, C. Y. 1994 *A Phenomenology of Landscape: Places, Paths, and Monuments.* Oxford: Berg.

Todd, I. 2008 An electronic inclinometer. *Compass Points* (39), 7-9.

Tomlinson, R. F. 1967 *An Introduction to the GIS-Information System of the Canada Land Inventory.* Ottawa: Department of Forestry and Rural Development.

Tratman, E. K. 1929 Report on excavations in Ireland in 1928 [Kilgreany, Co. Waterford]. *Proceeding of the University of Bristol Spelaeological Society* 3 (3), 109-25.

— 1937 Observations on Kilgreany Cave, County Waterford, Ireland. *The Journal of the Royal Society of Antiquaries of Ireland* 7 (1), 120-4.

— 1969 *The Caves of North-West Clare.* Newton Abbott: David and Charles.

Trigger, B. G. 1989 *A History of Archaeological Thought.* Cambridge University Press.

Twohig, D. C. 1975 Background to archaeological cave research in Ireland. *The Cork Caver (unpublished)* (2), 36-43.

Ucko, P. J. 1995 Introduction: archaeological interpretation in a world context. *In:* Ucko, P. J. (ed.) *Theory in Archaeology: A World Perspective.* 1-28. London: Routledge.

Ussher, R. J. 1880 On the explorations of the caves of the south of Ireland. *Transactions of the British Association*, 210-1.

— 1881 Second report of the committee, consisting of Professor A. Leith Evans, appointed for the purpose of exploring the caves of the south of Ireland. Report on the caves and kitchen-middens near Cappagh, Co. Waterford. *Reports of the British Association for the Advancement of Science*, 218-21.

— 1882 Report on the caves and kitchen-middens near Cappagh, Co. Waterford. *Report of the 51st Meeting of the British Association for the Advancement of Science*, 218-21.

— 1902 Report of the committee appointed to explore Irish caves. *The Irish Naturalist* 11 (11), 272-3.

Ussher, R. J., Adams, A. L. & Kinahan, G. H. 1879 Abstract of report on the exploration of Ballynamintra Cave, Cappagh, near Dungarvan. *Proceedings of the Royal Irish Academy. Polite Literature and Antiquities* 2, 73-8.

van Gennep, A. 1960 *The Rites of Passage.* Chicago: The University of Chicago Press.

van Leusen, M. 2002 A review of wide-area predictive modelling using GIS. *In:* Leusen, M. v. (ed.) *Pattern to Process: Methodological Investigations into the Formation and Interpretation of Spatial Patterns in Archaeological Landscapes.* 1-23. Groningen: Rijksuniversiteit Groningen.

van Leusen, M. & Kamermans, H. 2005 *Predictive Modelling for Archaeological Heritage Management: A Research Agenda.* Amersfoort: Rijksdienst voor het Oudheidkundig Bodemonderzoek.

van Leusen, M., Millard, A. R. & Ducke, B. 2010 Dealing with uncertainty in archaeological prediction. *In:* Kamermans, H., Leusen, M. v. & Verhagen, P. (eds.) *Archaeological Prediction and Risk Management: Alternatives to Current Practice.* 123-60. Leiden University Press.

van Leusen, P. 1992 Cartographic modelling in a cell-based GIS. *In:* Andresen, J., Madsen, T. & Scollar, I. (eds.) *Computing the Past. Computer Applications and Quantitative Methods in Archaeology. CAA92.* 105-24. Aarhus University Press.

Vančata, V. & Charátóva, M. 2001 Post-palaeolithic homo sapiens evolution in Central Europe: Changes in body size and proportions in the Neolithic and Early Bronze Age. *Anthropologie* 39 (2-3), 133-52.

Vanhaeren, M., d'Errico, F., van Niekerk, K. L., Henshilwood, C. S. & Erasmus, R. M. 2013 Thinking strings: additional evidence for personal ornament use in the Middle Stone Age at Blombos Cave, South Africa. *Journal of Human Evolution* 64 (6), 500-17.

Vass, A. A. 2001 Beyond the grave - understanding human decomposition. *Microbiology Today* (28), 190-3.

Vaughn, S. & Crawford, T. 2009 A predictive model of archaeological potential: an example from Northwestern Belize. *Applied Geography* 29 (4), 542-55.

Verhagen, P. 2006 Quantifying the qualified: the use of multicriteria methods and Bayesian statistics for the development of archaeological predictive models. *In:* Mehrer, M. & Wescott, K. (eds.) *GIS and Archaeological Site Location Modeling.* 176-99. Boca Raton: CRC.

— 2007 *Case Studies in Archaeological Predictive Modeling.* PhD, Amsterdam University.

— 2008 Testing archaeological predictive models: a rough guide. *In:* Posluschny, A., Lambers, K. & Herzog, I. (eds.) *Layers of Perception. Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA). Berlin, Germany, April 2–6, 2007.* 285-91. Bonn: Dr Rudolf Habelt GmbH.

Verhagen, P. & Dragut, L. 2012 Object-based landform delineation and classification from DEMs for archaeological predictive mapping. *Journal of Archaeological Science* 39 (3), 698-703.

Verhagen, P. & Gazenbeek, M. 2007 The Use of predictive modeling for guiding the archaeological survey of Roman pottery kilns in the Argonne region (Northeastern France). *Case Studies in Archaeological Predictive Modeling.* 14-29. Amsterdam University Press.

Verhagen, P., Kamermans, H., Leusen, M. v., Deeben, J., Hallewas, D. & Zoetbrood, P. 2010 First thoughts on the incorporation of cultural variables into predictive modelling. *In:* Nicolucci, F. & Hermon, S. (eds.) *Beyond the Artifact. Digital Interpretation of the Past. Proceedings of CAA2004, Prato 13–17 April 2004.* 307-11. Budapest: Archaeolingua.

Verhagen, P., Leusen, M. v., Ducke, B., Millard, A. & Kamermans, H. 2008 The bumpy road to incorporating uncertainty in predictive modelling. *Proceedings of the 36th CAA Conference, Budapest, 2–6 April 2008.* 569-76. Budapest.

Verhagen, P., Nuninger, L., Tourneux, F.-P. & Jeneson, Bertoncellu, F. & Jeneson, K. 2013 Introducing the human factor in predictive modelling: a work in progress. *In:* Earl, G.; Sly, T.; Chrystanthi, A.; Murrieta-Flores, P.; Papadopoulos, C.; Romanowska, I. & Wheatley, D. (eds.) *Archaeology in the Digital Era. Papers from the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, 26-29 March 2012*. 379-388. Amsterdam: Amsterdam University Press.

Verhagen, P. & Whitley, T. G. 2011 Integrating archaeological theory and predictive modeling: a live report from the scene. *Journal of Archaeological Method and Theory*, 1-52.

Vittinghoff, E. & McCulloch, C. E. 2007 Relaxing the rule of ten events per variable in logistic and Cox regression. *American Journal of Epidemiology* 165 (6), 710-8.

Waddell, J. 2000 *The Prehistoric Archaeology of Ireland.* Bray: Wordwell.

Wakeman, W. F. 1866 The cave of Knockmore, near Derrygonnelly, County of Fermanagh; with remarks on the character of the primitive scorings and Early Christian symbols inscribed upon its sides. *Proceedings of the Royal Irish Academy (1836-1869)* 10, 229-32.

Walker, A. 1773 A letter to Charles Morton, M. D. Sec. R. S. from Mr. Adam Walker; containing an account of the cavern of Dunmore Park, near Kilkenny, in Ireland. *Philosophical Transactions (1683-1775)* 63, 16-9.

Wansleeben, M. 1988 Applications of geographical information systems in archaeological research. *In:* Rahtz, S. P. Q. (ed.) *Computer and Quantitative Methods in Archaeology 1988. CAA88.* 435-51. B.A.R.

Warild, A. 2007 *Vertical.* Alan Warild.

Warren, R. E. 1990 Predictive modelling of archaeological site location: a case study in the Midwest. *In:* Allen, K. M. S., Green, S. W. & Zubrow, E. B. W. (eds.) *Interpreting Space: GIS and archaeology.* 201-15. London: Taylor and Francis.

Watson, A. A. 2011 *Predictive Modeling of Archaeological Site Location in Cuba.* MA, Florida Atlantic University.

Watson, P. J. 2008 Processual archaeology and after. *In:* Chippindale, C. & Maschne, H. (eds.) *Handbook of Archaeological Theories.* 29-38. Plymouth: Altamira.

Weber, A. 1922 *Über den Standort der Industrien*. Tübingen: J. C. B. Mohr

Weiss-Krejci, E. 2012 Shedding light on dark places: deposition of the dead in caves and cave-like features in Neolithic and Copper Age Iberia. *In:* Bergsvik, K. A. & Sabine, P. A. (eds.) *Caves in Context: The Cultural Significance of Caves and Rockshelters in Europe.* 118-37. 118-37: Oxbow.

Wescott, K. L. 2006 One step beyond: adaptive sampling and analysis techniques to increase the value of predictive models. *In:* Mehrer, M. & Wescott, K. (eds.) *GIS and Archaeological Site Location Modeling.* 56-65. Boca Raton: CRC.

Westropp, T. J. 1903 Finds at Edenvale, County Clare. *The Journal of the Royal Society of Antiquaries of Ireland* 33 (1), 90-1.

Wheatley, D. 2004 Making space for an archaeology of place. *Internet Archaeology* 15.

Wheatley, D. & Gillings, M. 2002 *Spatial Technology and Archaeology: The Archaeological Applications of GIS.* London: Taylor & Francis.

Whitley, T. G. 2003 Causality and cross-purposes in archaeological predictive modeling. *Computer Applications in Archaeology Conference, Vienna, April 8-12, 2003.* 236-9. Oxford: Archaeopress.

— 2005 A brief outline of causality-based cognitive archaeological probabilistic modeling. *In:* van Leusen, M. & Kamermans, H. (eds.) *Predictive Modelling for Archaeological Heritage Management: A Research Agenda.* 125-39. Amersfoort: Rijksdienst voor het Oudheidkundig Bodemonderzoek.

— 2010 Re-thinking accuracy and precision in predictive modeling. *In:* Nicolucci, F. & Hermon, S. (eds.) *Beyond the Artifact. Digital Interpretation of the Past. Proceedings of CAA2004, Prato 13–17 April 2004.* 312-6. Budapest: Archaeolingua.

Whitley, T. G. & Burns, G. 2008 Conditional GIS surfaces and their potential for archaeological predictive modelling. *In:* Posluschny, A., Lambers, K. & Herzog, I. (eds.) *Layers of Perception. Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Berlin, 2.-6. April, 2007.* 292-8. Bonn.

Wilcock, J. D. 1973 *Computer Applications in Archaeology 1, published as Science and Archaeology no. 9.* Stafford: George Street Press.

Wilcox, W. 2010 Archaeological predictive modeling in East Anglia and Norfolk *In:* Frischer, B., Crawford, J. W. & Koller, D. (eds.) *Making History Interactive. Computer Applications and Quantitative Methods in Archaeology (CAA). Proceedings of the 37th International Conference, Williamsburg, Virginia, United States of America, March 22-26.* Oxford: Archaeopress.

Willey, G. R. 1953 Prehistoric settlement patterns in the Virú Valley, Peru. *Bureau of American Ethnology Bulletin* (155).

— 1956 *Prehistoric settlement pattern in the New World.* New York: Wenner-Gren Foundation.

— 1966 *Introduction to American Archaeology. Vol. 1, North America.* Englewood Cliffs, NJ: Prentice-Hall.

Willey, G. R. & Phillips, P. 1958 *Method and Theory in American Archaeology.* The University of Chicago.

Williams, L., Thomas, D. H. & Bettinger, R. 1973 Notions to numbers: Great Basin settlements as polythetic sets. *In:* Redman, C. L. (ed.) *Research and Theory in Current Archaeology.* 215-38. New York: Wiley and Sons.

Williams, P. 1966 Glenbeg Cave. *Irish Speleology* 1 (2), 40.

Wilson, R. F. 1965 Notes on some caves on Knocknarea, County Sligo. *Irish Speleology* 1 (1), 18.

Wood-Martin, W. G. 1884 Proceedings and papers. *The Journal of the Royal Historical and Archaeological Association of Ireland* 6 (60), 441-82.

— 1888a The rude stone monuments of Ireland (continued). *The Journal of the Royal Historical and Archaeological Association of Ireland* 8 (73/74), 254-99.

— 1888b *The Rude Stone Monuments of Ireland: County Sligo and Achill Island.* Dublin.

— 1895 *Pagan Ireland.* London: Longmans, Green & Co.

Woodman, P. C. 1986a Problems in the colonisation of Ireland. *Ulster Journal of Archaeology* 49, 7-17.

Woodman, P. C. 1986b Why not an Irish Upper Palaeolithic? *In:* Roe, D. (ed.) *Studies in the Upper Palaeolithic of Britain and N. W. Europe.* 43-54. Oxford: BAR International Series, 296.

Woodman, P. C. 1996 *1996:242 - Killuragh, Limerick* [Online]. Available: http://www.excavations.ie/report/1996/Limerick/0002373/ 2015].

— 2002 The search for an Irish Paleolithic: Rosses Point revisited. *In:* Timoney, M. A. (ed.) *A Celebration of Sligo: First Essays for Sligo Field Club.* 73-84. Carrick-on-Shannon: Sligo Field Club.

Woodman, P. C., Finlay, N., Anderson, L. & National Museum of Ireland. 2006 *The Archaeology of a Collection: The Keiller-Knowles Collection of the National Museum of Ireland.* Bray, Co. Wicklow: Wordwell Ltd.; National Museum of Ireland.

Woodman, P. C., McCarthy, M. & Monaghan, N. 1997 The Irish quaternary fauna project. *Quaternary Science Reviews* 16 (2), 129-59.

Woodman, P. E. 1997 *Archaeological Predictive Modelling using GIS: a case study from the Scottish Mesolithic.* PhD, The University of Reading.

— 2001 A predictive model for Mesolithic site location on Islay using logistic regression and GIS. *Hunter-Gatherer Landscape Archaeology: The Southern Hebrides Mesolithic Project, 1988-1998.* 445-64. Cambridge: McDonald Institute for Archaeological Research.

Woodman, P. E. & Woodward, M. 2002 The use and abuse of statistical methods in archaeological site location modelling. *In:* Wheatley, D., Earl, G. & Poppy, S. (eds.) *Contemporary Themes in Archaeological Computing.* 39-43. Oxbow Books.

Wookey, Atkinson, A., Betts, O. & Day, A. 2002 Field meet report, summer 2002. *Compass Points* 28, 6-9.

Zwertvaegher, A., Werbrouck, I., Finke, P. A., De Reu, J., Crombé, P., Bats, M., Antrop, M., Bourgeois, J., De Maeyer, P. & De Smedt, P. 2010 On the use of integrated process models to reconstruct prehistoric occupation, with examples from Sandy Flanders, Belgium. *Geoarchaeology* 25 (6), 784-814.