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The colonization of Ireland: A human ecology perspective

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ABSTRACT

Human migration throughout northern Europe following the Last Glacial Maximum is an ideal situation to investigate human colonization and adaptation in new landscapes. This is particularly so in Ireland, which possesses a distinctly compressed archaeological record compared to the rest of Europe. While various periods of Paleolithic occupations are well-documented throughout Europe, including Britain, the initial colonization of Ireland appears to be delayed until the Early Holocene. An assessment of archaeological and paleoenvironmental data suggests that inhospitable environmental conditions, specifically the absence of mature woodland ecosystems, substantially delayed the human colonization of Ireland. Once Mesolithic peoples reached Ireland, the absence of familiar fauna led them to quickly modify existing technologies. These local adaptions are reflected in the discontinuation of composite microlith technologies that characterize the rest of the European Mesolithic record. Within 1000 years of colonization, Mesolithic hunter-gatherers developed a uniquely Irish macrolith-based technology.

1. The colonization of Ireland

Ireland has been at the forefront of much archaeological research into the European Mesolithic period in the last decade. Peter Woodman is undoubtedly to thank for this, as he spent a career developing the Irish Mesolithic into a mature field of research (Woodman, 1977, 1985, 1986; 1992, 2012; 2015; Woodman et al., 1997). Recent research into the Mesolithic record of Ireland has focused on ritual activities and human remains (Blinkhorn and Little, 2018; Cobb and Gray Jones, 2018; Meiklejohn and Woodman, 2012), timing and chronologies (Dowd and Carden, 2016; Elliott and Griffiths, 2018; Warren, 2017; Woodman, 2012), lithic technologies (Driscoll, 2017; Driscoll et al., 2016; Preston and Kador, 2018), subsistence and human-environment relationships (Overton and Taylor, 2018; Warren, 2015, 2020; Warren et al., 2014; Woodman, 2014), and the submerged/coastal archaeological record (Pollard, 2011; Westley, 2015; Westley and Woodman, 2020). However, one question that has received less attention is, "Why the delay in getting to Ireland?" (Woodman, 2015:191).

While Ireland's closest neighbor, Britain, was first occupied by hominids during the Early Pleistocene (Pettitt and White, 2012), and recolonized following the Last Glacial retreat 14,600 cal BP (Jacobi and Higham, 2011), the archaeological record of Ireland is much more compressed. There is a rich record of Mesolithic-age sites throughout the island indicating people had become well-adapted to local environments by 9000 cal BP (Woodman, 2015). Mesolithic sites predating 10,000 cal BP have been proposed, but generally do not hold up to scrutiny (Woodman, 2012). Evidence for a preceding Paleolithic population in Ireland is less clear and there are currently no known artifact assemblages indicating a human presence in Ireland during the Pleistocene; however, incised bear bones have been dated to 12,800 and 10,600 cal BP (Dowd and Carden, 2016).

The initial colonization of Ireland is a perplexing topic in large part due to limited datasets (Warren, 2020; Woodman, 2015). Because of the small number of relevant sites that have been excavated and reported, and the paucity of associated radiocarbon ages, the Mesolithic chronology in Ireland is challenging to decipher. Moreover, as Woodman (2015:120) notes, strictly relying on lithic typologies, specifically the perceived notion that microliths are Earlier Mesolithic and macroliths are Later Mesolithic is problematic because if "these represent the Irish Mesolithic then the question must be how do we identify the technological attributes of a Neolithic assemblage?" As such, only artifact assemblages associated with reliable radiocarbon ages form the basis of this investigation.

To fully understand the colonization process of Ireland we must rely on more than the archaeological record alone. This is inherently an interdisciplinary problem that requires integrating data from many fields of study to establish a synthesis. Data from sites throughout the islands of Ireland and Britain are brought to bear on

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this problem (Fig. 1). However, as Warren (2020) advises, caution should be taken in over interpretation of the data and causal relationships. The research presented here considers the colonization of Ireland by focusing on the questions: 1) When was it ecologically viable for people to colonize Ireland after the Last Glacial Maximum (LGM)? 2) When was an antecedent population 'in position' to migrate to Ireland? and 3) What were the mechanics of the colonization process? The answers to these questions are then used to develop a human ecology-based model to understand the apparent delay in Irish colonization and how people adapted to new environments once they reached Ireland.

1.1. A note about terminology

Much of the terminology related to the Late Pleistocene and Early Holocene archaeological record of Europe has become highly regionalized – or as Warren (2017) contends, archaeological terminology has become nationalized. For example, scholars frequently ascribe modern nationalities to Mesolithic peoples who lived in northern Europe 10,000–6000 years ago (e.g. Ballin and Bjerck, 2016; Barton and Roberts, 2004; Bonsall et al., 2013; Elliott and Little, 2018; Fischer et al., 2007; Woodman, 1989, 2012, 2015). While there may be meaningful reasons to do so, ultimately this practice obscures our interpretations when assessing broad cultural patterns across large regions.

The terminology used here is chosen to reflect the spread of human populations across northwestern Europe during the Pleistocene-Holocene transition. Using uniform terminology emphasizes the spread of technologies across larger areas. In their summary of Later Upper Paleolithic technologies, Jacobi and Higham (2011:226) forgo using Creswellian in favor of the term Final Magdalenian "to emphasise that recolonisation of the British Isles by Later Upper Paleolithic groups was as part of the spread of the Magdalenian" from France and Spain into new areas.

To further mitigate confusion and the conflation of terms used here, specific date ranges are provided when referring to cultural and environmental periods rather than relying solely on terms such as *Early* versus *Earlier* Mesolithic. All radiocarbon ages (^{14}C yr BP) presented here are calibrated based the IntCal 20 calibration curve using OxCal 4.4 (Bronk Ramsey, 2009; Reimer et al., 2020), and reported in calendar years before present (cal BP; present being AD 1950).

2. When was it ecologically viable for people to colonize Ireland after the LGM?

Starting from the generally accepted premise that the first people migrated to Ireland from what is now Britain (Woodman, 2015), we must frame *the peopling of Ireland* in appropriate contexts. That is to say, when were people in Britain at the right place and right time, and who were they? Until relatively recently the island of Britain was the extreme end of the northwestern peninsula of Europe. From 32,000 until 16,000 cal BP much of Ireland and Britain were covered by the British-Irish Ice Sheet, with the maximum extent of the ice sheet occurring about 27,000 cal BP (Clark et al., 2012; Hughes et al., 2016). Ireland has been separated

Fig. 1. Key sites discussed in the text and other figures. Inset shows study area in a regional context.

from Britain and the rest of Europe following the retreat of glacial ice sheets since 16,000 cal BP (Clark et al., 2012; Peters et al., 2015).

The islands of Ireland and Britain are currently separated by 20–30 km at the closest points, leading to the assumption that they would possess highly similar landscapes, ecologies, and climates. A similar distance separated Ireland from Britain at the end of the Pleistocene (Bailey et al., 2008; Sturt et al., 2013). However, a particular set of circumstances led to the development of a unique ecology in Ireland beginning during the Late Pleistocene and Early Holocene (Montgomery et al., 2014; Warren, 2017; Woodman et al., 1997). Ireland was completely covered by the British-Irish Ice Sheet during the LGM, with the retreating ice sheet splitting into separate British and Irish ice sheets 16,000 cal BP (Clark et al., 2012). Parts of northern Ireland, as well as Scotland, remained ice-covered until 15,000 cal BP (Clark et al., 2012), with localized ice remaining in or returning to parts of western Ireland and Scotland during the Younger Dryas 12,900–11,600 cal BP (Ballantyne et al., 2008; Palmer et al., 2020; Shennan et al., 2006). While lower relative sea level greatly expanded the terrestrial landscape of northwestern Europe during the Late Pleistocene and Early Holocene, there was not a terrestrial connection between Ireland and Britain (Edwards and Brooks, 2008). Thus, initial human colonization of Ireland required the knowledge, skill, and equipment necessary for open water navigation.

Following the post-LGM retreat of the British-Irish Ice Sheets the combined forces of isostatic rebound and sea level rise impacted the coastal margins of Ireland and Britain. While there is some debate as to the specific effects in Ireland (e.g., Brooks et al., 2008; Edwards et al., 2008; McCabe, 2008), the Late Pleistocene-Early Holocene Irish coastline was somewhat lower than modern. Archaeologically, this poses a particular problem when investigating the initial colonization of the island. As others have noted (e.g., Pollard, 2011; Warren, 2020), post-glacial sea level rise has inundated coastal sites in Ireland, particularly along the northern-northeast coast where critical information related to initial migration routes may have previously existed.

The modern temperate climate of northwestern Europe is, in part, due to fluctuations in the Polar Front remaining generally above 60° north latitude. Eynaud et al. (2009) used paleohydrological proxy data (planktonic foraminifera, polar foraminifera, and ice-raft detritus concentrations) to model fluctuations of the Polar Front during the Late Pleistocene and Early Holocene. They found that the maximum southern advancements occurred during Heinrich Event 1 (18,000–15,000 cal BP) and the Younger Dryas (12,900–11,600 cal BP). The Polar Front pushed south past Ireland to about 40° north latitude during both of these periods (Eynaud et al., 2009). Beginning around 12,500 cal BP the Polar Front began a final retreat northward, reaching Ireland by approximately 11,500 cal BP (Bard et al., 1987), bringing with it Holocene-like climate conditions.

Southerly shifts in the Polar Front during the Younger Dryas and Heinrich stadials brought oceanic conditions with arctic temperatures and salinity levels to northwestern Europe (Maslin et al., 1995). In response to such conditions, the North Atlantic thermohaline overturning stopped, or was greatly reduced, resulting in decreased air temperature (Hemming, 2004). Associated climatic deterioration took place throughout northwestern Europe (Tsakiridou et al., 2020), but was most pronounced in Ireland during the Younger Dryas where the mean winter monthly low temperatures reach −25 °C (−30 °C difference from modern temperatures; Isarin et al., 1998). Expansion of winter sea-ice exacerbated the deterioration of climatic conditions resulting in very cold, dry winters with strong winds (Isarin et al., 1998). Such conditions would likely have prevented sustained human occupation.

Climate deterioration, particularly during the Younger Dryas, impacted biotic communities in profound ways. Lake sediments throughout Ireland are dominated by non-arboreal pollen in Younger Dryas-age layers (Andrieu et al., 1993). Palynological data indicate that a broadly herb and shrub-dominated arctic tundra landscape existed during the Younger Dryas, which gave way to juniper (*Juniperus*), then birch (*Betula*)-dominated pollen assemblages in a predominantly open landscape during the Early Holocene (Andrieu et al., 1993; Fyfe et al., 2013; Walker et al., 2012). A prevalence in willow (*Salix herbacea*) and heath (*Empetrum*) correspond to high frequencies of charcoal during the Younger Dryas, reflecting increased wildfire activity (Jeffers et al., 2012; Mitchell and Maldonado-Ruiz, 2018). Successive peaks in heath, juniper, and birch pollen at the onset of the Holocene are documented throughout Ireland and reflect relatively rapid warming conditions (Jeffers et al., 2012; Mitchell, 2006; Mitchell and Maldonado-Ruiz, 2018; Watts, 1977). Oak (*Quercus*), elm (*Ulmus*), and pine (*Pinus*) expanded during the Early Holocene (Birks, 1989), and arboreal pollen dominates (>90%) pollen assemblages 9500–9000 cal BP indicating the establishment of woodland environments (Mitchell and Maldonado-Ruiz, 2018).

While Britain shares a similar Early Holocene faunal record with the rest of northwestern Europe, Ireland's limited faunal suite is unique (Monaghan, 2017; Woodman, 2014; Woodman et al., 1997). The reduction in Ireland's Holocene faunal diversity can be traced to deteriorating environmental conditions during the Younger Dryas. A relatively broad suite of mammalian species, consisting of giant deer (*Megaloceros giganteus)*, red deer (*Cervus elaphus*), reindeer (*Rangifer tarandus*), brown bear (*Ursus arctos*), wolf (*Canis lupus*), stoat (*Mustela ermine*), and mountain hair (*Lepus timidus*), were present in varying frequencies in Ireland during the Bølling-Allerød (14,600–12,900 cal BP). The faunal record is markedly reduced by island-wide extinctions going into the Younger Dryas, with only reindeer, brown bear, and maybe giant deer surviving into the Younger Dryas (Monaghan, 2017; Woodman et al., 1997). There is some debate, however, as to whether or not giant deer survived the Younger Dryas in Ireland. As Carden et al. (2012) have demonstrated, misidentification of deer species has been a reoccurring issue in reconstructing faunal biogeography. Additionally, as Monaghan (2017) points out, redating of some giant deer specimens indicate they are older than initially thought and pre-date the Younger Dryas.

However, while extinctions were taking place in Ireland, red deer, reindeer, elk (*Alces alces*), horse (*Equus ferus*), auroch (*Bos primigenius*), and even mammoth (*Mammuthus primigenius*) were present in northwestern Europe and Britain (Monaghan, 2017; Woodman et al., 1997). Notably, horse was a staple of Late Magdalenian diets in Britain 14,600–14,200 cal BP (Jacobi and Higham, 2011), while red deer played important spiritual roles in Early Mesolithic life in Britain 11,300–10,500 cal BP (Milner et al., 2018).

Extreme climate oscillations impacted mammal species more severely in Ireland than throughout Britain and northwestern Europe because of the more restricted land area and reduced primary productivity in Ireland (Montgomery et al., 2014). Species would have had greater adaptive flexibility in Britain and northwestern Europe because of less severe climatic conditions and great migratory ability. For instance, the extinction of Ireland's quintessential charismatic megafauna, the giant deer (also known as Irish Elk), is closely linked to environmental deterioration during the Younger Dryas (Lister and Stuart, 2019). However, giant deer persisted in Eurasia until the Middle Holocene, where its territory was able to shift in response to oscillating climatic conditions (Lister and Stuart, 2019).

It was partly this unique set of ecological conditions that resulted in a delayed colonization of Ireland. Glacial ice would have restricted human occupation until after 16,000 cal BP. Harsh environmental conditions during the Younger Dryas drove island-wide faunal extinctions in Ireland, while human populations in Britain were being pushed south (Barton, 2009; Barton and Roberts, 2004; Jacobi and Higham, 2009). Climate amelioration following the Younger Dryas suggests Ireland was becoming ecologically viable by the onset of the Holocene around 11,700 cal BP. Based on paleoecological conditions, it is unlikely that any sustained human presence could have existed in Ireland prior to the Holocene.

3. When were people 'in position'?

For the successful colonization of new lands to occur, viable populations of people must be in the right place at the right time. That being said, in order for people to migrate to Ireland, they must have been located in an adjacent area at the correct time – most likely Scotland. Thus, any discussion of the initial human colonization of Ireland must be understood in a broader context. The technological and cultural characteristics of Late Pleistocene-Early Holocene populations in Britain provide a regional context through which the first peoples of Ireland migrated.

3.1. The British record

Following the post-LGM glacial retreat, the earliest, unequivocal human occupation of Britain took place 14,600 cal BP and is characterized by Late Magdalenian (Creswellian) lithic assemblages at Gough's Cave and Sun Hole (Fig. 2) (Barton, 2009; Jacobi, 2004; Jacobi and Higham, 2011). Broadly speaking, these assemblages fit into a group of Late Pleistocene blade-based lithic technologies that existed throughout northern Europe after the LGM (Wygal and Heidenreich, 2014). The British expression of the Late Magdalenian consists of Cheddar and Creswell points, along with end scrapers, piercers, burins, and a variety of miscellaneous blade tools and debitage with éperon platform preparation to thin the proximal end of lithic flakes and bladeletes (Barton, 2009; Barton et al., 2003). At present, there is no evidence of anything resembling a Late Magdalenian occupation in Ireland (Barton, 2009; Warren, 2020; Woodman, 2015).

Tanged projectile points are known from sites and isolated finds throughout Scotland, but are largely undated (Ballin, 2017; Ballin and Bjerck, 2016; Ballin and Saville, 2003; Ballin et al., 2010; Mithen et al., 2015). Typological similarities of the tanged points in Scotland suggest they relate to Federmesser and Ahrensburgian style points, which are typically found to the east and south of the North Sea Basin 14,000–11,000 cal BP (Wygal and Heidenreich, 2014). The Scottish site of Howburn provides some of the best evidence of northern forays made by Late Pleistocene hunter-gatherers into extreme northwestern Europe around 14,000 cal BP (Ballin et al., 2010; Mithen et al., 2015). Federmesser and Ahrensburgian-like points in Scotland may reflect westward movement by Late Magdalenian groups who were beginning to experience geographic displacement due to the inundation of the North Sea Basin.

An apparent reduction in population occurred in Britain during the Younger Dryas 12,900–11,600 cal BP when archaeological sites were concentrated in the south (Pettitt and White, 2012; Tolan-Smith, 2003), which calls into question the existence of a requisite founding population needed to colonize Ireland during this

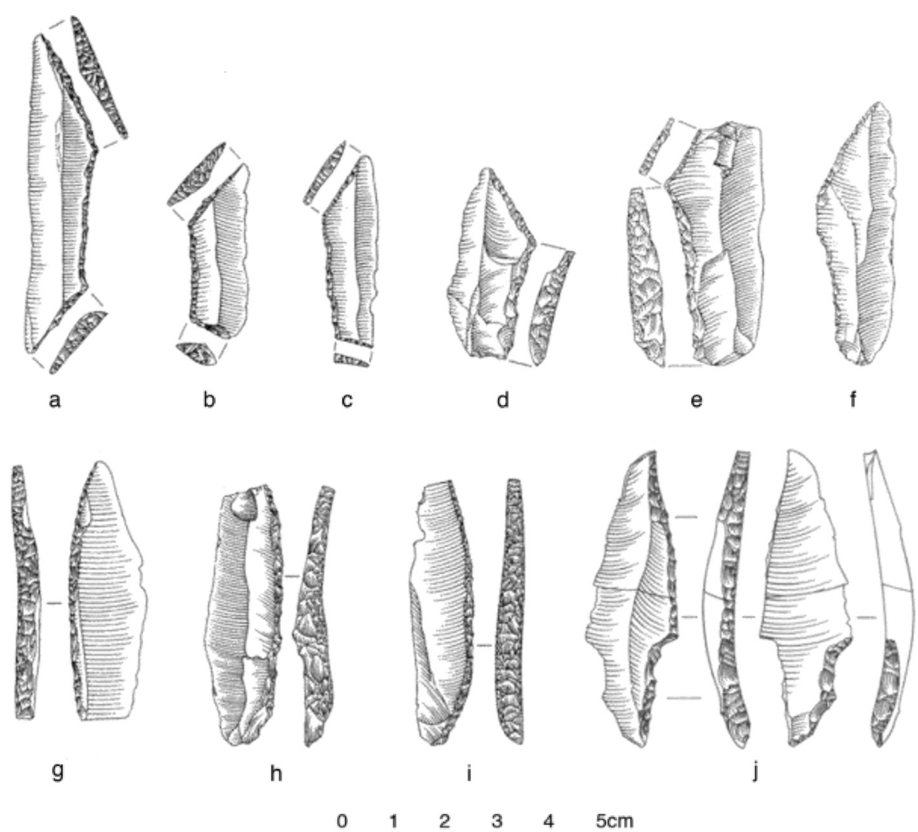

Fig. 2. Examples of Paleolithic lithic industries discussed in the text. Late Magdalenian artifacts: Cheddar points (a–c) and Creswell points (d–f) from Gough's Cave (redrawn from Jacobi, 2004). Federmesser points (g–i) from Gough's Cave (redrawn from Jacobi, 2004). Ahrensburgian point (j) from Howburn (redrawn from Ballin et al., 2010).

time (Fig. 3). Recent work at the multicomponent site of Rubha Port an t-Seilich on the Isle of Islay, Scotland, has yielded evidence of a buried Ahrensburgian occupation. An underlying tephra layer suggests an Ahrensburgian style point was discarded immediately after the Younger Dryas (Berg-Hansen et al., 2019; Mithen et al., 2015, 2020). This may indicate a transition from what Tolan-Smith (2003) refers to as a population standstill to a period of demographic expansion spreading northward following climate amelioration (Mithen et al., 2020).

A series of Mesolithic sites throughout the Hebrides on the west coast of Scotland are critical to understanding the colonization of Ireland. Mithen et al. (2020) place the initial exploration phase of western Scotland at 11,600–9500 cal BP, just prior to the earliest occupation of Mount Sandel in Ireland. This corresponds to the beginning of a period of rapid regional population expansion that Tolan-Smith (2003) identified throughout Britain (Fig. 4). Acknowledging a lack of precision, Mithen et al. (2015) contend that the earliest occupation of western Scotland occurred at the end of the Younger Dryas ~11,600 cal BP based on tephrochronology and artifact typology. Subsequent periods of occupation are identified at Criet Dubh and Kinloch and radiocarbon dated to 10,300–9500 cal BP (Mithen et al., 2020). Mesolithic occupations around 10,000 cal BP at Howick, in northern England (Bayliss et al., 2007; Boomer et al., 2007) and East Barns, in southeastern Scotland (Gooder, 2007) are associated with microlith technology similar to that present in the earliest dated deposits at Mount Sandel in northern Ireland. These dated sites place Early Mesolithic populations on the doorstep of Ireland immediately preceding the earliest occupation of Mount Sandel and demonstrate people were geographically primed to colonize Ireland by 10,000 cal BP.

Mesolithic populations in western Scotland expanded as people appear to settle into the area 9500–8200 cal BP (Mithen et al., 2020) – at the same time Mesolithic sites appear throughout Ireland (Woodman, 2012, 2015). The initial colonization of the Scottish Hebrides Islands undoubtedly relied on watercraft – settlement of the Outer Hebrides required traversing more than 20 km of open water (Bonsall et al., 2013). This demographic expansion throughout the islands of western Scotland corresponds to the establishment of mature forest ecosystems needed for the production of watercraft.

3.2. The Irish record

Archaeological evidence for the earliest period of human colonization of Ireland is limited. The datasets that exist are plagued by a lack of stratigraphic integrity, dearth of radiocarbon-dated components, and non-analog lithic technologies (Costa et al., 2005; Warren, 2017, 2020; Woodman, 2015). While the most reliable archaeological evidence indicates that Ireland was colonized by Mesolithic peoples during the Early Holocene, Pleistocene-age sites are occasionally proposed to support a Paleolithic presence in Ireland.

3.2.1. An Irish upper paleolithic?

A brown bear patella and an axis vertebra dating to the Late Pleistocene were recovered in 1902–1903 with purported cutmarks from two caves ~380 m apart in western Ireland (Dowd and Carden, 2016). The intriguing nature of the incised bones led Dowd

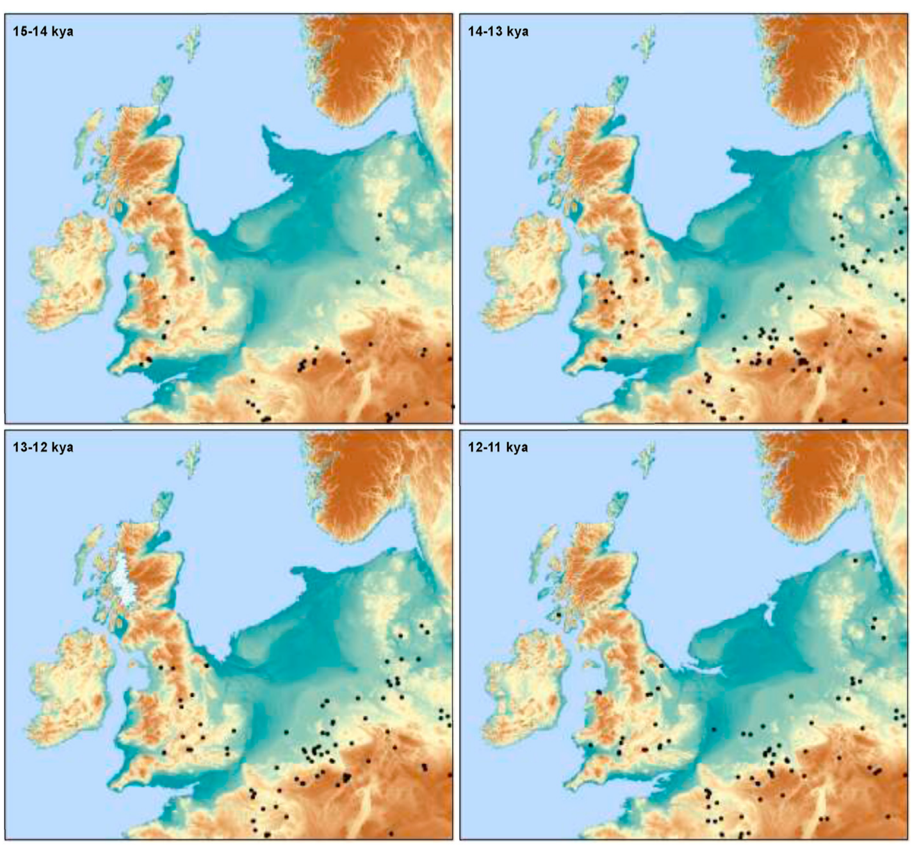

Fig. 3. Late Pleistocene landscape and archaeological site distribution in northwest Europe 15,000–11,000 cal BP. Paleogeography based on Brooks et al. (2011), Clark et al. (2004), and Sturt et al. (2013). Archaeological data from d'Errico et al. (2011) and Vermeersch (2019) with redundancies removed. Only archaeological sites with radiocarbon ages associated with artifacts and sufficient reference information are included.

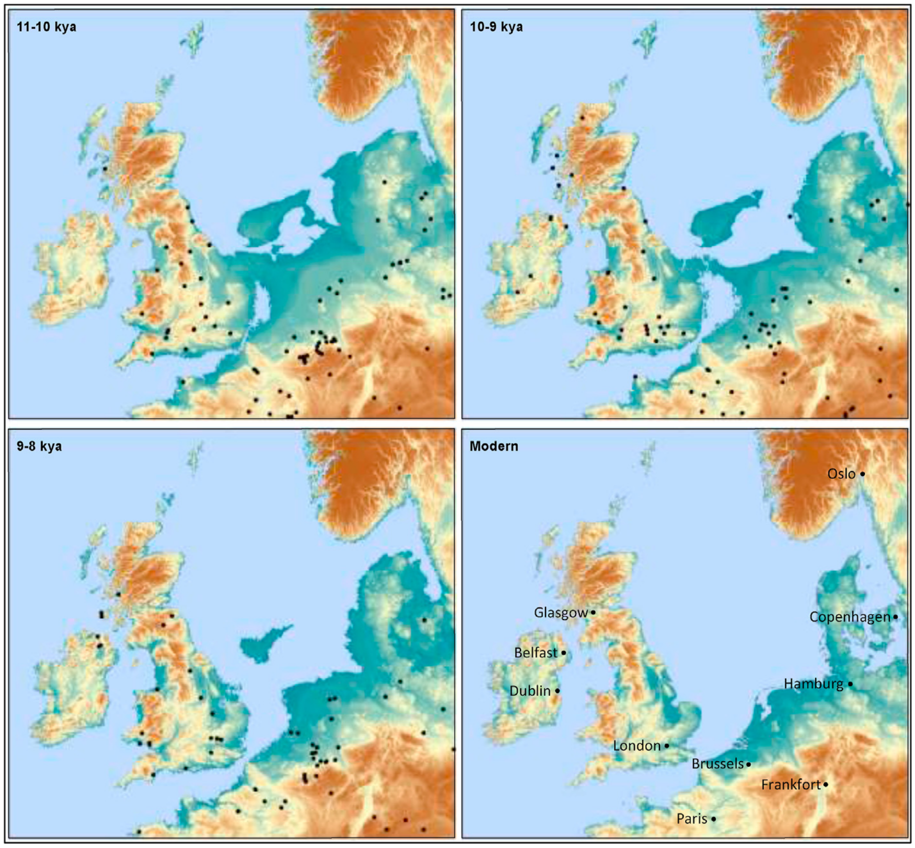

Fig. 4. Early Holocene landscape and archaeological site distribution in northwest Europe 11,000–8000 cal BP, and modern coastlines and cities. Paleogeography based on Brooks et al. (2011), Clark et al. (2004), and Sturt et al. (2013). Archaeological data from d'Errico et al. (2011) and Vermeersch (2019) with redundancies removed. Only archaeological sites with radiocarbon ages associated with artifacts and sufficient reference information are included.

and Carden (2016) to radiocarbon date them using two different laboratories (Chrono, Queen's University Belfast and ORAU, University of Oxford) and investigate the incised marks, which included conducting independent examinations by zooarchaeological specialists. The patella was recovered from Alice and Gwendoline Cave and is dated to 12,790–12,760 cal BP (OxA-29358, 10,850 ± 50 ^{14}C yr BP; UBA-20194, 10,798 ± 71 ^{14}C yr BP). The vertebra was recovered from the Catacombs and is dated to 11,070–10,440 cal BP (UBA-20195, 9414 ± 57 ^{14}C yr BP).

Excavation methods in the early 1900s do not allow for an in-depth analysis of the sediments; however, some helpful information was recorded in field notes, as reported by Dowd (2015) and Dowd and Carden (2016). Three distinct strata are recorded for Alice and Gwendoline Cave – the incised bear patella was recovered from the second *or* third deepest strata. The cave sediments were heavily bioturbated and extinct fauna were present in all three strata (Dowd and Carden, 2016). Both caves held sediments containing extensive assemblages of extinct and extant fauna, human remains, and Neolithic, Bronze Age, and Norse artifacts (Dowd, 2015). Recent damage to the patella during or after excavation resulted in modifications to the purported cut marks, as well as the production of additional linear striations to the opposite side of the patella (Dowd and Carden, 2016). In addition to the incised bear bones, cutmarks and/or burning are reported on an antler fragment and bones of hare (*Lepus* sp.) and fox (*Vulpes* sp.) (Dowd and Carden, 2016). Given the imprecise stratigraphic provenience of specimens and the disturbed nature of the sediments, there is no way to determine what artifacts might have been associated with the bear bones.

Though cut marks may demonstrate direct human action, the identification, analysis, and interpretation of cut marks remains controversial largely because of a lack of standardization in analysis and reporting – an issue Merritt et al. (2019:71) characterize as a "scientific replicability crisis." As Krasinski (2018) demonstrates, there is currently no consensus on interpreting cut marks because of the large body of research demonstrating that multiple processes can be responsible for creating features once considered diagnostic evidence of human agency. For a detailed discussion of concerns in cut mark analysis and interpretation see: (Domínguez-Rodrigo et al., 2017; Haynes et al., 2020; James and Thompson, 2015; Krasinski, 2018).

While the incised brown bear bone is intriguing, the absence of associated artifacts and lack of a thorough geoarchaeological study of the cave sediments renders it equivocal. The heavily disturbed sediments prohibit definitive associations between the patella and other possibly modified specimens. Moreover, while the brown bear patella is dated to 12,700 cal BP (~3000 years older than the earliest occupation at Mount Sandel), there are no known artifacts of a similar age anywhere in Ireland, making the origin of the incisions questionable. Ultimately, while the bones are directly and reliably dated, it is not possible to unequivocally determine when the incisions were produced.

3.2.2. Ireland's mesolithic record

Woodman (2012, 2015) divides the Mesolithic record of Ireland into the Earlier (9800–8800 cal BP) and Later Mesolithic (8800–6000 cal BP). In comparison to broader regional chronologies, the Earlier Mesolithic in Ireland generally corresponds to the

Late Mesolithic period in Britain and Europe (Woodman, 2012). In spite of decades of searching for older sites, the earliest unequivocal archaeological site in Ireland is Mount Sandel, which was initially occupied 9800 cal BP (Bayliss and Woodman, 2009; Woodman, 1985, 2015). Approximately 50% of the roughly 300–325 radiocarbon ages for all Mesolithic sites in Ireland come from only eight sites, with Mount Sandel accounting for approximately 15% of all radiocarbon ages (Woodman, 2015).

Mount Sandel sits atop a bluff overlooking the River Bann estuary in Northern Ireland. Here, a series of postholes indicate circular structures surrounding hearth features associated with activities areas and a series of large pits. Geometric microlithics, core and flake axes, and other Mesolithic-period tools were recovered during excavations. Bayliss and Woodman (2009) use Bayesian modelling of radiocarbon ages to show that the earliest occupation at Mount Sandel took place 9800–9700 cal BP.

Although sites have been suggested to predate the Mount Sandel occupation, as Woodman (2012, 2015) explains, the dating and context of each of these sites is problematic. An early age from Port of Larne, 9840 cal BP (UB 11668, 8806 ± 29 ^{14}C yr BP), is from a charcoal sample in a stratigraphic level that contained highly variable radiocarbon ages, which may be indicative of old wood or contamination (Woodman, 2012, 2015). At Clynacartan an age of 9970 cal BP (I1 3641, 8910 ± 150 ^{14}C yr BP) was obtained from a fragment of oak at the base of a platform, but not directly associated with artifacts (Woodman, 2012). Ballyoran's age of 10,080 cal BP (UB 6780, 8958 ± 53 ^{14}C yr BP) is from 'brush wood' with an unknown anthropogenic association (Woodman, 2012). The earliest age for Lough Boora, 10,150 cal BP (UB 2268, 8980 ± 350 ^{14}C yr BP), is from a charcoal sample with an exceptionally large deviation, rendering it unreliable (Ryan, 1980). Lufferton's early age of 10,740 cal BP (LU 1809, 9440 ± 100 ^{14}C yr BP) also has a large deviation and is from diffuse charcoal in a beach deposit not directly associated with artifacts (Woodman, 2012). Finally, Toome Bypass produced an early age of 11,110 cal BP (BT 219463, 9720 ± 50 ^{14}C yr BP) from charcoal in a feature (Woodman, 2012). However, this feature also produced later ages from individual hazelnut shells, which provide more reliable ages associated with a Later Mesolithic/Neolithic occupation; the lithic assemblage confirms a later cultural affiliation (for a detailed description, see Dunlop and Woodman, 2015; Woodman, 2015).

The Mount Sandel lithic assemblage is characteristic of the Earlier Mesolithic in Ireland (9800–8800 cal BP), which consists of microlith composite tools and soft hammer blade technology, as well as axes and core tools (Woodman, 2012). Irish microliths are dominated by geometric forms of scalene triangles and backed blades and bladelets (Fig. 5; Costa et al., 2005; Woodman, 2012). This contrasts with the Later Mesolithic in Ireland (8800–6000 cal BP), which consists of broad macrolithic and hard hammer blade technology, as well as the appearance of proximally-thinned Bann Flakes (Costa et al., 2005; Woodman, 2012, 2015). Thus, it appears that composite microlith technology was abandoned in favor of larger handheld knives and notched tool forms during the Mesolithic period in Ireland (Costa et al., 2005).

Subtle differences in microlithic technologies often used to identify earlier and later Mesolithic assemblages throughout Europe may not serve as meaningful ways to differentiate occupation periods in Ireland. There are currently only four sites with secure associations between microliths and reliable radiocarbon dates: Mount Sandel (Bayliss and Woodman, 2009), Castleroe (Woodman, 1985, 2015), Lough Boora (Ryan, 1980), and Hermitage (Woodman, 2015). Some of the best documented macrolithic Mesolithic sites in Ireland are Port of Larne, Toome, and Newferry, all dating after 8800 cal BP (Woodman, 2015). Therefore, we are left with little data to rely on. It may be more useful to move beyond splitting hairs over terminologies to *define* typologies and begin to think about the purpose, or function, to *describe* artifact assemblages. This is particularly true when only a few sites provide data and there are minimal radiocarbon ages to develop a chronology.

Stepping back to look at assemblage-level data, the oldest Mesolithic assemblage in Ireland (9800 cal BP) is remarkably similar to tool assemblages found on Scottish Mesolithic sites (Mithen et al., 2020). Sites throughout western Scotland demonstrate, without question, that people were living ~30 km from Ireland (~65 km from Mount Sandel) by 11,600 cal BP and using a high similar lithic toolkit as that found in Ireland.

4. What were the mechanics of Irish colonization?

Perhaps more challenging than the question of *when* did people first get to Ireland is *how* did people get to Ireland. Because Ireland has been an island since the Pleistocene, we know that colonization required watercraft. Beyond this, however, there is very little evidence to inform us about those early watercraft. The is no direct archaeological evidence of Early Mesolithic watercraft predating 10,000 cal BP (Bjerck, 2017). The earliest logboats in northern Europe are known from Mesolithic sites dating 9900–8400 cal BP around the North Sea Basin and were made from pine (McGrail, 2001). The earliest logboats known from Ireland and Britain date to about 6000 cal BP (Lanting, 1997; McGrail, 2001). A purported Early Mesolithic birch-wood 'paddle' was recovered from Star Carr (Clark, 1954; Milner et al., 2018); however, scholars have recently argued for alternative uses of this object (Darvill, 2010; Huntford, 2013; Taylor et al., 2018). Designs of watercraft have also been observed in Mesolithic rock art going back to 6500 cal BP in the Alta Fjord (Norway) and are particularly prominent in Fennoscandia rock art (Gjerde, 2010; Nimura, 2015). Scholars generally believe these rock art images depict hide-covered boats (Johnstone, 1988), but as Pickard and Bonsall (2004) contend, a Mesolithic association with these images is uncertain.

Simple logboats with shallow drafts are not well-suited for open water navigation and have been recovered mainly from river and estuary settings (Burov, 1996; Gregory, 1997; McGrail, 2001). While sewn-plank boats may have been better suited for navigation of open water across the Irish Sea, they were not in use until the Bronze Age (McGrail, 2001). Thus, we are left with little definitive evidence for the type of watercraft used by the first Mesolithic colonists of Ireland.

An essential requirement of logboats is the presence of mature forests to provide the basic construction materials (Bjerck, 1995, 2009; McGrail, 2001). The dimensions of logboats, specifically the waterline beam, is directly related to the size of the parent tree (McGrail, 2001). Mature forests with larger trees are needed to produce wider, more inherently stable logboats, and it is unlikely that such forests existed in Ireland or Britain during the Late Pleistocene (McGrail, 2001). There is no evidence of Mesolithic-age logboat modifications to increase stability, and only limited evidence to support prehistoric logboats ever being lashed together to increase stability (McGrail, 2001).

While logboats in Ireland are nearly exclusively made from oak, the earliest known Irish logboat (6600 cal BP) is from Carrigdirty in the Shannon estuary and made from poplar (*Populus* sp.) (Gregory, 1997; Lanting, 1997). McGrail (2001) notes that the earliest logboats in the Netherlands and France were made from pine. Thus, the question of when mature oak, polar, and pine forests developed in Ireland and Britain after the LGM becomes a critical question. Today, in Ireland poplar (*Pupulus nigra)* is primarily found in the Shannon, Suir, and Liffey Valleys (Cross, 2006); however, it is uncertain when poplar became established following deglaciation. Oak forests were not present in Ireland and Britain until after

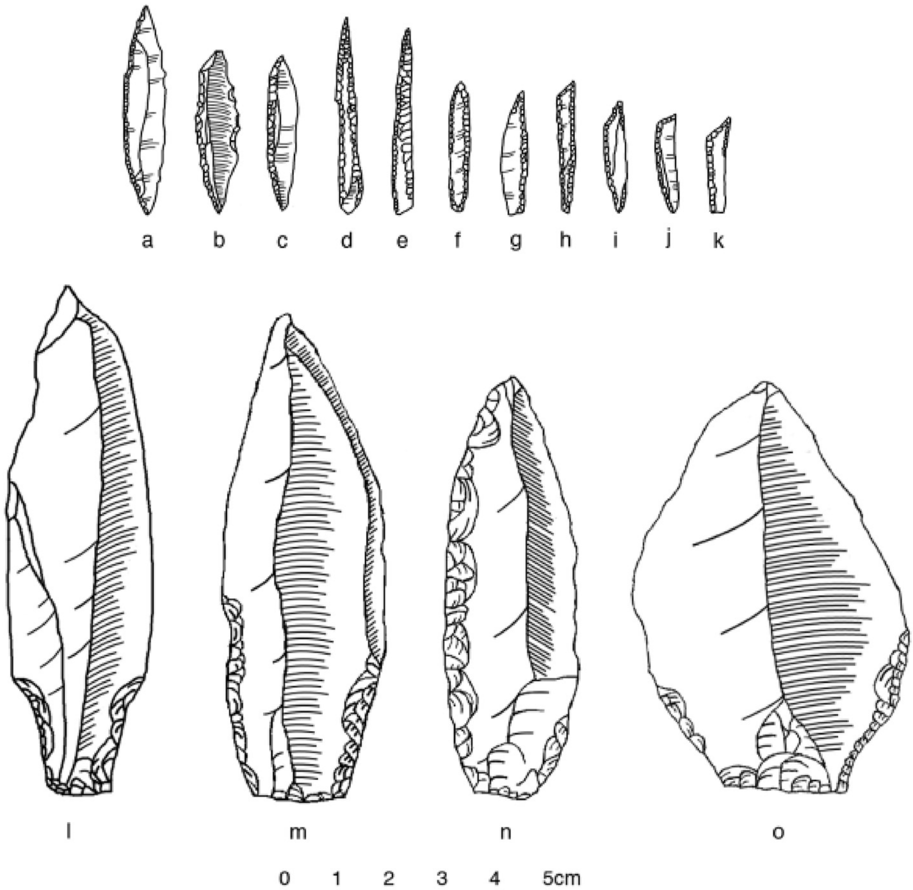

Fig. 5. Examples of Mesolithic artifacts from Ireland. Earlier Mesolithic microliths (a–k) from Mount Sandel, Lower site (redrawn from Collins, 1983). Later Mesolithic macroliths (l–o) (redrawn from Woodman, 2012).

9500–9000 cal BP and were not established in northern Ireland and Scotland until 8500 cal BP (Birks, 1989). Scots Pine (*Pinus sylvestris*) migrated northward through Britain at roughly the same time as oak. Genetic data indicates a post-glacial Scots Pine refugium in Ireland (Sinclair et al., 1998); however, pollen data broadly suggests the dispersal of pine trailed the migration of oak in Ireland by about 1000 years (Birks, 1989). The first tree species to establish a widespread presence in Ireland and Britain was birch, which shows up in pollen assemblages 10,000–9500 cal BP (Birks, 1989). Therefore, without available materials for boat building in the vicinity of Ireland prior to 10,000 cal BP, we are left with an interesting conundrum.

If people did arrive in Ireland before 10,000 cal BP, then they had to use either use log-based watercraft that originated south of ~50° north latitude or rely on other materials for boat construction. As there is no sound evidence indicating Ireland was colonized from the south (Woodman, 2012, 2015), it is plausible that hide-covered, wood-framed boats were used in the initial colonization of Ireland. Hide boats are well-documented in the ethnographic record and typically made from seal skin stretched over a wooden frame, making their designs light, flexible, and stable; thus, hide boats are inherently superior to logboats in open water and rough sea conditions (McGrail, 2001; Pickard and Bonsall, 2004). However, the use of hide boats in the colonization of Ireland is purely hypothetical at this time because there is no evidence of such Mesolithic-age boats (McGrail, 2001; Pickard and Bonsall, 2004). If people did use hide boats to colonize Ireland, then we should expect to find some evidence of systematic hunting and processing of seals at this time. The lack of such evidence would suggest hide-covered boats were not used.

There is only limited evidence that Mesolithic peoples ever exploited seals in Ireland and Britain during the Early Holocene. Woodman (2015; Woodman et al., 1997) hypothesizes that Mesolithic hunters may have hunted and processed seals on islands like Inishtrahull. However, Warren (2015) notes that Dalkey Island is the only actual evidence of seal hunting in Ireland, despite Mesolithic sites often being located in proximity to modern day seal habitats. Oronsay, in the Scottish Hebrides, provides some of the best evidence for Mesolithic exploitation of seals, as well as other marine species. Harbour seal (*Phoca vitulina*) and grey seal (*Halichoerus grypus*) are both near-shore species and dominate the Late Mesolithic (6500–6300 cal BP) assemblage at Cnoc Coig (Grigson and Mellars, 1987; Mellars, 2004). While baleen whales (*Balaenoptera* spp.) are present in Mesolithic assemblages on Oronsay, Pickard and Bonsall (2012) point out that it is more likely they were opportunistically scavenged from the shoreline rather than directly hunted at sea using boats. There is no reliable evidence that Mesolithic groups in northwestern Europe regularly practiced seal hunting or subsistence fishing in open waters (Pickard and Bonsall, 2004).

Subsistence data from Early Mesolithic sites in Scandinavia suggest that ameliorating climates led the earliest coastal human populations to possibly rely on seal hunting as a significant dietary component (Milner et al., 2004, 2006; Richards and Schulting, 2006). While there is no direct evidence of Mesolithic watercraft capable of being used for open water seal hunting, Bjerck (2017) argues that archaeological evidence of site locations and an absence of fishing gear in coastal assemblages reflects a reliance on seal exploitation during the initial Mesolithic colonization of coastal Scandinavia. Limited wood for boat building further suggests that Scandinavian Early Mesolithic boats may have been based on hide-covered designs (Bjerck, 2017).

While it is possible that Mesolithic peoples were exploiting marine resources and using some type of hide-covered boats in Scandinavia (Bjerck, 2009, 2013, 2017), the question becomes, were people doing this in other parts of northern Europe prior to 10,000 cal BP? The use of watercraft to exploit marine resources or travel across open water was not an isolated task. Rather, such activities and technologies were inherently embedded within a marine lifestyle (Bjerck, 2013). That is to say, Mesolithic people adapted to a terrestrial lifestyle and economic base would have been ill-equipped to construct seafaring boats and set off across the Irish Sea to colonize Ireland.

Shifting from a terrestrial to marine economy is not a simple matter of changing diets. New technologies must be developed, and adaptations made to new environments (Bjerck, 2008, 2009). The timing of such adaptations has been studied in Norway where there appears to be a roughly 3000 year delay in the colonization of coastal landscapes. Gregory (1997) contends this delay indicates that coastal adaptations, including a fully developed watercraft industry, were not established until the Holocene.

Isotopic data consistently reflect terrestrially-focused diets in Britain before 10,000 cal BP, with subsistence patterns becoming more variable throughout the Mesolithic (Pickard and Bonsall, 2020; Barton and Roberts, 2004). Terrestrial components of Mesolithic diets in Scotland are notably dominated by red deer and wild boar (*Sus scrofa*) (Kitchener et al., 2004; Mithen et al., 2020) — both of which were absent in Ireland following deglaciation (Carden et al., 2012; Warren et al., 2014). The Late Mesolithic site of Cnoc Coig in western Scotland is the only location where diets appear to have been heavily focused on marine resources (Pickard and Bonsall, 2020), and temporally corresponds to the exploitation of coastal resources and the spread of shell middens after 7000 cal BP (Mithen et al., 2020). Trends in isotopic analysis of human remains from the submerged North Sea Basin broadly support a terrestrial-to-marine dietary shift throughout the Mesolithic as well (van der Plicht et al., 2016). Isotopic-based subsistence data are scarce in Irish Mesolithic research, however, existing data do provide some insights. Warren's (2015) review of Mesolithic subsistence data in Ireland indicates that while diets were variable, there is a broadly terrestrial pattern present. Some debate exists, however, as to the weight that should be given to isotope data in determining Mesolithic diets in northwestern Europe (Milner et al., 2004, 2006; Richards and Schulting, 2006). Nevertheless, increasingly varied Mesolithic diets with greater amounts of marine components correspond to population expansion throughout the islands of Ireland and Britain.

As Bailey et al. (2008) explain, marine resources likely played an important role in facilitating colonization processes as Mesolithic peoples spread into new environments. For instance, subsistence data from Late Mesolithic sites on the island of Orosany, in western Scotland, suggest people were consuming a diverse suite of aquatic resources by 7000 cal BP (Mithen et al., 2020). Fish species are abundant at all sites and are dominated by cod (Gadidae) and saithe (*Pollachius virens*) (Pickard and Bonsall, 2012). Both of these species live out part of their lives in littoral environments (Riede, 2004; Steele, 1963), and can be exploited from the shoreline. Large baleen whales, and either dolphin (*Delphinus delphis*) or porpoise (*Phocaena phocaena*) are present in Mesolithic assemblages on Oronsay; however, Pickard and Bonsall (2012) point out that it is more likely they were scavenged from the shoreline rather than directly hunted at sea. While Late Mesolithic sites throughout coastal Europe reflect the exploitation of a broad diversity of fish, Pickard and Bonsall (2004) review of fish biology and behavior demonstrates that all of these species were likely obtained in shoreline or near-shore settings.

The initial occupation of Mount Sandel corresponds to a period of exploration in western Scotland 11,650—9500 cal BP (Fig. 4), which Mithen et al. (2020) link to postglacial climate amelioration during the Early Holocene. Waddington (2007, 2015) suggests this influx of people into Scotland (and presumably Ireland) was, in part, motivated by the inundation of the North Sea Basin. Approximately 50,000 km^2 of the North Sea Basin was inundated between 12,000 and 9600 cal BP, while Ireland and western Scotland experienced relatively little loss of land area (Bailey et al., 2008; Sturt et al., 2013). If Coles (1998) notion of Doggerland being a core area of a Mesolithic occupation in the North Sea Basin is correct, then a substantial population was displaced by sea level rise during the Early Holocene. Crombé (2019) argues that Mesolithic populations occupying the North Sea Basin 11,000—8000 cal BP were displaced by marine transgression based on the appearance of a new diversity of lithic technologies in the southern North Sea Basin and southern Britain, as well as increases in radiocarbon ages and site frequencies. Ballin (2017) study of lithic technological diversity around the North Sea Basin provides additional support for demographic displacement and reorganization caused by sea level rise during the Early Holocene. The exploration and subsequent rapid population expansion in Scotland is particularly important when considering the colonization process of Ireland. Mesolithic peoples living along the western Scottish coast and Hebrides Islands would have been well-adapted to coastal environments and continually innovating new ways to explore and exploit marine resources. This would have been taking place within sight of the Irish coastline, offering additional incentive for the development of water craft.

5. Discussion on the human ecology during the peopling of Ireland

Once the colonization of Ireland began, it progressed quickly. Ireland and Britain were generally ice free by 16,000 cal BP. Late Magdalenian hunter-gatherers began recolonizing Britain during the Bølling-Allerød by 14,600 cal BP, with sites primarily concentrated in southern Britain (Fig. 6). As the deteriorating environmental conditions of the Younger Dryas set in 12,900—11,700 cal BP, much of northern Europe saw a reduction in human occupation (Wygal and Heidenreich, 2014). Following the onset of ameliorating climates during the Early Holocene, populations once again moved north and established a series of sites in western Scotland and the Hebrides Islands 11,600—9500 cal BP. The first Mesolithic peoples in western Scotland carried with them a geometric microlith, composite tool technology with a variety of stone axe forms. At this time, the coastlines of western Scotland and northern Ireland were beginning to stabilize and people were developing more intensive coastal adaptations. Simultaneously, birch, pine, and oak forests were spreading through Ireland and Britain, and were fully established by 8500 cal BP.

The earliest occupation at Mount Sandel in northern Ireland dates to 9800 cal BP and is characterized by what Woodman (2012) refers to as the Earlier Irish Mesolithic consisting of geometric microlith, composite tools and a variety of stone axe forms. Following the earliest occupation at Mount Sandel, subsequent Mesolithic sites are found throughout Ireland and concentrated in riverine settings (Woodman, 2015). By 9000 cal BP there were Mesolithic settlements throughout Ireland as people had successfully adapted to local ecologies, and learned and mapped onto local

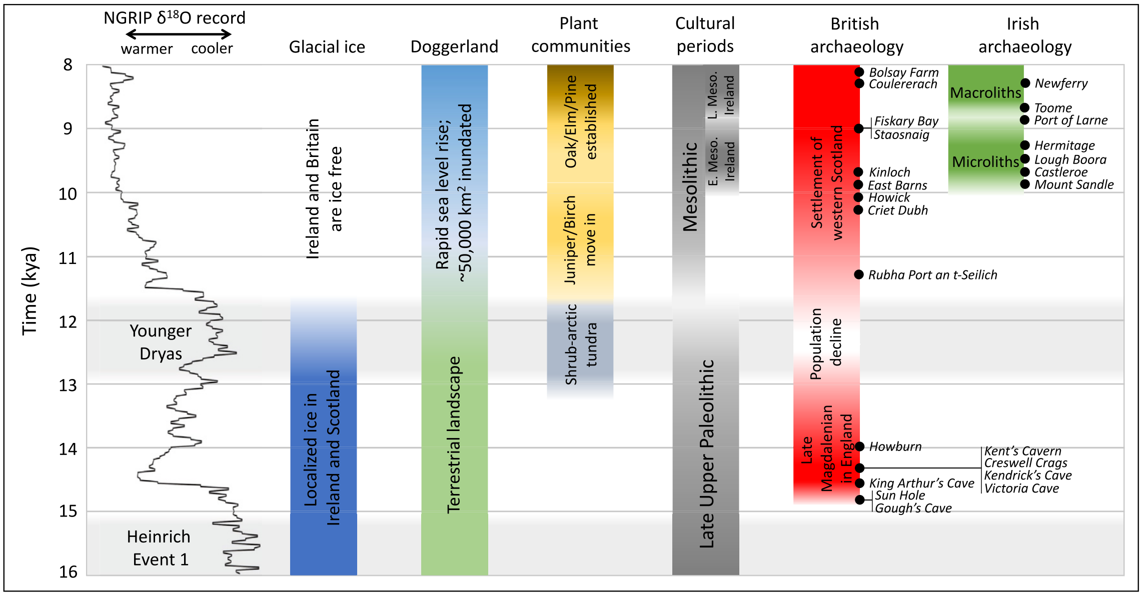

Fig. 6. Relationships of climate, landscape, vegetation, and archaeological records for the study area from 16,000 to 8000 cal BP. NGRIP $\delta^{18}O$ data from Andersen et al. (2004) https://www.ncdc.noaa.gov/paleo-search/study/2481. Glacial ice (Ballantyne et al., 2008; Clark et al., 2012; Shennan et al., 2006), terrestrial landscape (Sturt et al., 2013), and vegetation data (Andrieu et al., 1993; Fyfe et al., 2013; Walker et al., 2012) provide a record of environmental change from the Late Pleistocene to the Early Holocene. Archaeological data (Jacobi and Higham, 2011; Mithen et al., 2020; Woodman, 2015) provide a record of fluctuations in human populations. Placements of archaeological sites represent the earliest occupation for each site; some sites have multiple dates of occupation that are not represented.

landscapes. Archaeological data in Ireland indicate an increasing familiarity and exploitation of local resources within 1000 years of colonization. This *in situ* Irish adaptation saw people abandon microlith composite tools in favor of macrolithic technologies that were not used by Mesolithic hunter-gatherers in Britain or northern Europe.

If early exploring groups made their way to Ireland before 10,000 cal BP, they would have found a landscape with few and unfamiliar resources. Particularly, the absence of red deer and other species Mesolithic populations depended on in northwestern Europe may have made Ireland unappealing for sustained colonization. Mesolithic hunters were well-adapted to hunting red deer throughout northern Europe. However, while red deer inhabited Ireland prior to the LGM, they were scarcely present across the island from the Younger Dryas until the Neolithic (Carden et al., 2012). Red deer not only served as a vital subsistence resource and held particular spiritual role in Mesolithic peoples' lives, but they were also critical in the construction of microlith composite tools — the hallmark of the European Mesolithic. Without this osseous component, the characteristic Mesolithic composite toolkit could not exist (Burdukiewicz, 2005).

Similarly, plant communities were greatly reduced in Ireland compared to other regions of northwestern Europe (Bell and Walker, 2004). The delay in the colonization of Ireland may be further explained by watercraft technology dependent on mature oak forests rather than seal skin boats. As Bang-Andersen (2013) contends, the absence of oak, pine, and poplar makes the production of logboats unrealistic during the Late Pleistocene. Oak logboats in Ireland and Britain are only known from Holocene-age sites. However, because there is no evidence of systematic seal exploitation, it is highly unlikely that hide-covered boats were used to colonize Ireland prior to the expansion of woodland environments. Rather, logboats were more likely to have been used in the colonization process and required the establishment of mature forests. An analog for this scenario may be found in Denmark where Jessen et al. (2015) have documented evidence closely linking Early Holocene regional settlement with ameliorating climates and maturing forest environments.

Given the dearth of resources at the end of the Pleistocene, it is unlikely that a *pull* factor motivated people to colonize Ireland. It is unlikely that Mesolithic hunter-gatherers made logistical forays to Ireland in search of resources. Rather, the migration of people to Ireland is best seen as a residential move. Certain *push* factors may have been the primary drivers (e.g., Anthony, 1990). The inundation of the North Sea Basin and its impact on Mesolithic populations living in northern Europe may have very well been the final push needed to colonize Ireland (Ballin, 2017).

The delayed colonization of Ireland meant that Mesolithic populations were well-established in Britain and northern Europe, and a certain degree of social complexity had developed by the time people were living at Mount Sandel 9800 cal BP. This may further explain the unique evolutionary trajectory observed in Irish lithic technology. The first Irish colonists had a broad suite of behaviors and Holocene-based environmental knowledge at their disposal. Such a knowledge base could immediately be put to use facilitating the rapid development of a unique set of technologies and behaviors in response to Ireland's ecological conditions. Barton and Roberts (2004) suggest that the spread of deciduous forests throughout Britain may have led to increased isolation of communities during the Early Mesolithic, which in turn led to more regionalization of microlith styles. Cultural drift fueled by increased isolation may have also led to modifications of lithic technology in Ireland. Within less than 1000 years of the earliest occupation at Mount Sandel, Mesolithic tools in Ireland transitioned from microliths to macroliths and became distinct from contemporaneous tool assemblages in Britain and the rest of Europe. Interestingly, this technological transition may have had more to do with a lack of red deer antler than access to lithic resources.

6. Conclusion

Ireland was in close proximity to human populations throughout northwestern Europe at the end of the Pleistocene. However, local environmental conditions appear to have significantly delayed the human colonization of Ireland. Once hunter-gatherer populations became established, however, they quickly adapted their technologies and behaviors in response to local resource availability. While aspects of this colonization process may be unique to Ireland, understanding human responses here may be informative to studying the initial colonizations of unfamiliar landscapes in other areas.

Author statement

Jesse W. Tune: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Visualization, Project administration

Declaration of competing interest

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

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