Holocene animal tracks from the intertidal zone in the west of Ireland

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ABSTRACT

During the winter storms of 2019, a deposit of organic-rich clay was fortuitously exposed in the intertidal zone of a beach near Streedagh (Co. Sligo). Impressed in the clay surface were a series of small (< 10cm) paired indentations arranged in rough alignments. Based on their size and shape they are suggestive of animal tracks; possibly red deer but not excluding sheep/goat. Animal tracks in Holocene sediments are well-documented from intertidal contexts in Great Britain but, to date, none have been reported from Ireland. This paper describes these tracks and discusses their chronological and paleoenvironmental context. Radiocarbon dating of the clay surface places it between ~7300–6300 cal BP, though for taphonomic reasons the tracks are argued to have been made later in the Holocene: probably after 5800 and before 4000 cal BP. As such, the deposit provides an example of palaeo-environmental evidence which can be found even under the high-energy conditions characteristic of the Irish coast, and also hints at the possibility that Holocene ichnological evidence can also be found here.

INTRODUCTION

The footprints of humans and animals preserved in the geological record provide a range of information including past activity, palaeoecology, behaviour, population structure and anatomy (Roberts *et al.* 1996; Lockley *et al.* 2008; Peeters *et al.* 2020). To date, human/hominin footprints and animal tracks dating to the Quaternary era have been found in various locations across the world (Bennett and Morse 2014). Their ephemeral nature means that their preservation requires fortuitous circumstances, most often via rapid but low energy burial of impressions made in soft sediment. Such conditions can occur where fine-grained sediments are deposited by water, such as fluvial or lacustrine floodplains (Belperio and Fotheringham 1990; Webb *et al.* 2006; Aramayo *et al.* 2015; Oliveira *et al.* 2019; Stewart *et al.* 2020) and intertidal or estuarine environments where burial occurs as part of the natural tidal cycle (Allen 1997; Bennett *et al.* 2010; Ashton *et al.* 2014; Sohn *et al.* 2015; McLaren *et al.* 2018). Present-day coastal environments are also conducive to the discovery of footprint-bearing deposits as result of erosion and removal of the overlying sediment by waves, tides and storms (Wiseman and De Groote 2018).

This is particularly evident in Great Britain and exemplified by well-known footprint sites at the coastal localities of Happisburgh, Formby/Sefton, Kenfig, Low Hauxley and the Severn Estuary (Huddart *et al.* 1999; Bell *et al.* 2000; Bell 2007a; Bennett *et al.* 2010; Eadie and Waddington 2013; Ashton *et al.* 2014; Wiseman *et al.* 2022). All the above represent former estuarine, marsh or intertidal flat environments which have since been exposed by coastal erosion. However, based on the published literature and to the best of the authors' knowledge, no such evidence has been reported to date from the neighbouring island of Ireland. This is despite the presence of numerous Holocene land surfaces (peat layers and organic deposits) which are episodically exposed in the intertidal zone, have been described since the 19th Century (Praeger 1892; Stewart 1911; Westley and Edwards 2017) and sometimes have been subject to archaeological and palaeo-environmental investigation (Godwin *et al.* 1965; Shaw and Carter 1994; O'Sullivan 2001; 2007; McErlean *et al.* 2002; Wilson *et al.* 2011; O'Connell and Molloy 2017; Westley and Woodman 2020). The reasons for the absence of footprint evidence are unclear, but could be due to the intermittent exposure of these deposits, rapid removal of ephemeral ichnological features or the lack of recognition when exposed.

In this paper we draw attention to the possibility that similar evidence may be preserved in the Irish Quaternary record on the basis of probable animal tracks recently identified from a small exposure of Holocene organic-rich clay revealed by storms on the west coast of Ireland. We first describe the tracks, provide chronological and paleoenvironmental context and, finally, discuss their significance in an Irish Quaternary context.

STUDY AREA

The study site is located at the northern end of Trawgar Bay (Co. Sligo) on the west coast of Ireland. Trawgar Bay comprises a semi-circular bay approximately 300m wide and opens to the southeast (Fig. 1). To the north, it is bounded by low cliffs of Carboniferous limestone while to the east it is backed by sand dunes up to several metres high. These separate Trawgar Bay from the larger intertidal expanse of the River Grange Estuary. The beach within Trawgar Bay is generally sandy, but when visited on March 2019 it comprised large boulders around the high-water mark, grading through gravel, cobbles and sand around the low-water mark.

On 6th March 2019, one of the authors noticed a peat-like organic-rich clay outcropping at the northern end of the beach. This had been fortuitously exposed by storm waves which had removed the overlying sand, boulders and cobbles (Fig. 2A; B). They also observed a series of small (< 10cm) paired indentations on the deposit's surface which were suggestive of animal footprints (Fig. 2C; D). Given the rarity of such evidence in Ireland, the site was re-visited as soon as possible given the possibility that further storms would erode the deposit. This second visit took place on 11th March 2019, digitally documented the organic-rich clay and potential footprints and obtained material for dating. Following this visit, another storm hit and the outcrop of organic-rich clay was again covered under sand.

MATERIALS AND METHODS

Given the highly exposed nature of the site, and the need to work within the restrictive window of both low tide and an incoming storm, the organic-rich clay was rapidly recorded using RTK (Real-Time Kinematic)-GPS, and Structure-from-Motion (SfM) photogrammetry (Larsen *et al.* 2021).

The RTK-GPS (Trimble R9 base station with R10 rover; accuracy of ±1–3cm) was used to map the exposed outline of the deposit, mark Ground Control Points (GCPs) for the SfM survey and record the location and elevation of samples. All elevation values reported here are relative to the Malin Head Ordnance Datum (mean sea level at Malin Head).

The SfM survey consisted firstly of overall documentation of the exposed clay surface followed by close-up detailed documentation of locations where possible footprints were visible. Photographs were taken with a Pentax K50 camera, handheld, set to manual exposure and with settings maintained for each individual set of photographs. Four GCPs were used to geographically constrain each set of photographs and to aid in SfM alignment. Photographs were then processed into orthoimages and Digital Elevation Models (DEMs) using AgiSoft Photoscan Pro 1.2 and subsequently imported to ArcGIS 10.5 for interpretation and analysis. ArcGIS was also used to create hillshades and slope maps derived from the DEMs to aid identification and manual digitization of potential footprints.

Two bulk sediment samples from the deposit were sent to the Chrono14C lab at Queen's University, Belfast for AMS ^{14}C dating (see Table 1). These consisted of:

- Sample 1: ~10cm-long sample taken with a gouge auger from the seaward part of the organic-rich clay ~1.5m south from the closest set of footprints. The shortness of the sample suggests refusal on a harder substrate or a stone. The top 1cm was used for ^{14}C.
- Sample 2: ~40cm-long sample taken with a gouge auger from the landward part of the organic-rich clay ~4.8m east northeast of the closest set of footprints. No refusal was met. The top 1cm was used for ^{14}C.

An additional bulk sample was collected from the northeastern side of the exposed clay where it was visibly eroding. This was sieved and the fine fraction examined with a microscope to check for micro-palaeontological remains.

RESULTS

DEPOSIT CHARACTERIZATION

At the time of survey, the exposed organic-rich clay formed a roughly L-shaped patch with the longer arm running shore-parallel over a distance of ~14m and the shorter arm running landward over ~11m. It was surrounded on its western and northern sides by boulders, on its eastern side by sand and gravel and, on its southern edge, closest to low tide, by cobble-covered sand. In this latter area, patches of the organic-rich clay were intermittently visible under the cobble-covered sand, suggesting that it continued further seaward. The highest measured point of the deposit was 0.82m OD, attained at its northernmost point, and the lowest point was 0.03m OD, attained at its southwestern-most tip. Elevation at the southeastern side of the deposit was 0.4m OD indicating that its surface slopes towards the southwest (Fig. 3).

The exposed surface comprised a firm to stiff clay with visibly embedded wood and plant remains varying in colour from brown in the north and northeast to dark grey in the south. Sample 2 from the northern part of deposit penetrated the brown clay and showed it to be a surface veneer gradually transitioning to dark grey clay beneath. This sample reached a depth of at least 40cm and showed no clear stratigraphic boundaries. Sample 1, closer to the seaward edge of the organic-rich clay, only reached a depth of 10cm, but another auger test located ~7.5m east of Sample 1 reached a depth of at least ~50cm. These samples consisted of undifferentiated dark grey clay with a slight increase in sand towards the base of the deeper sample. On its western side, the clay deposit attains a maximum thickness of ~10–15cm and is visibly eroding to reveal an underlying compact stony yellow-brown clay.

Overall, the samples were not enough to establish the full thickness of the clay, but they do suggest that it thickens to the north and east.

The two dates obtained are shown in Table 1. The order of calibrated ages accords with the elevation of the two samples; the lowermost dates to ~7200–7300 cal BP and the uppermost to 6300–6500 cal BP.

POTENTIAL FOOTPRINTS

Two locations, both on the western side of the organic-rich clay, hereafter referred to as Areas A and B (see Fig. 3 for locations), contained features suggestive of animal footprints. These comprised small, narrow indentations (<10cm long) impressed up to 3cm deep in the clay surface, sometimes consisting of two parallel elements. Based on the photogrammetric DEMs and derived products, these indentations were digitized and classified into one of three categories:

- Category 1: distinct double curvilinear and elongated indentations, arranged parallel.
- Category 2: partial, indistinct or incomplete elongated double indentation.
- Category 3: single isolated indentation.

In total, 47 sets of indentations were recorded. Area A contained one set of Category 1, five sets of Category 2 and seven Category 3 indentations, all located between 0.35–0.29m OD (Fig. 4). For Area B, three sets of Category 1, ten sets of Category 2 and twenty Category 3 indentations were identifiable, all located between 0.5–0.4m OD (Fig. 5).

The Category 1 feature in Area A consisted of two curvilinear parallel oval indentations pointing west-northwest, and with combined measurements of 82 x 93mm. This is the most immediately 'footprint-like' feature of all those recorded (Figs. 2D; 6A–C). In contrast, the Category 1 indentations from Area B are smaller, ranging from 35–59mm in length and 40–66mm in width (Fig. 6D–L). They also show clear parallel arrangements and are aligned to the northwest. One set was still partly infilled by sand at the time of recording (Figure 6J–L).

Category 2 indentations fell within a similar size range (Table 2). In a few cases, the double indentations are discrete (e.g. Fig. 7D–F), but in most cases, are they are joined by an intervening indentation (Fig. 7A–B). Clear alignments were hard to see, but there appears to be a tendency for the long axes of these indentations to point north or northwest (Fig. 4, 5).

Category 3 indentations are more irregular in shape than the other categories and an elongated form is often hard to distinguish, though sometimes hints of elongated indentations were visible (Fig. 7J–L). Nevertheless, they were recorded due to their proximity to the other indentations, the fact that they fall within the same general size range (Table 2), and that similar indentations were absent outside Areas A and B. Again, there were hints of alignment towards to north and northwest, similar to the other categories.

DISCUSSION

ARE THE INDENTATIONS FOOTPRINTS?

The Category 1 indentations are the least likely to have been formed by abiological processes, for instance by stones or shells becoming impressed or embedded into the clay surface. This can be argued on the basis of their shape and arrangement. The four examples of Category 1 indentations consist of double indentations of the same or similar size, closely spaced, arranged parallel to one another and aligned in the same direction (Fig. 6). Moreover, the most "footprint-like" example from Area A, shows distinct and nearly symmetric indentations which are smaller at one end (Fig. 6A–C).

Stones or shells could make impressions of a similar size, but the chances of multiple, parallel and aligned indentations would seem to be highly unlikely. For example, Knight (2005) described small (a few cm across) oval indentations in Holocene clay at Formby Point which were created by *Scrobicularia plana* shells. However, the examples shown in Knight (2005) have a random arrangement and do not occur as aligned pairs. Moreover, at the time of survey no shells of comparable size to the indentations were observed either embedded in the clay or lying loose on its surface. Similarly, although pebble- and cobble-sized clasts could make similar indentations (and examples of embedded stones were evident at the time of survey), these also result in random shapes and orientations.

Consequently, an animal footprint interpretation is considered most likely for the Category 1 indentations. If so, we exclude the possibility that they are recent animal tracks made into an ancient surface on the basis of two observations. Firstly, the firmness of the exposed clay. During the survey, boots made little to no impression on the clay surface, compared to the indentations which are up to 30mm deep. This is in line with similar arguments made for ancient prints in other locations (e.g. Formby: Burns 2019; Wiseman *et al.* 2022). The firmness of the substrate is further substantiated by a lack of observable erosion between the 6th March and 11th March visits: the Area A Category 1 print appears to have remained largely unchanged during this period of exposure (compare Figs 2D; 6A). Secondly, that the organic-rich clay is rarely exposed. This is suggested by the fact that it has not previously been documented in existing Irish records of sea-level indicators (e.g. Edwards and Brooks 2006) and intertidal peats (e.g. Westley and Edwards 2017) or reported in the official description of the Streedagh Point Dunes Special Area of Conservation (NPWS 2006) within which the beach lies.

If Category 1 indentations are ancient footprints, then which animal do they represent? The double nature of the indentations suggests the paired cleats of an artiodactyl. Given a *terminus post quem* of ~7200–7300 cal BP from the oldest radiocarbon date, and excluding 19th and 20th century introduced species (on the basis of the firmness of the footprint-bearing surface and its rare exposure), this limits the range of artiodactyls known from the Irish fossil record to wild boar, red deer, fallow deer, domesticates (cattle, sheep, pig) and feral goat (Montgomery et al. 2014).

Of these, wild boar/domestic pig and cattle are the least likely candidates. With regard to the former, there are no clear traces of dew claws (often used as an identifier of boar/pig tracks), and the fused mass of toe pad at the rear end of the print is also not evident (Olsen 2013; Rhyder 2021). The elongated nature of the cleats of the Category 1 indentations also does not match the more rounded examples of boar footprint-tracks from the literature (e.g. Burns 2019: Fig. 5.97). Similarly, this elongation also fits less well with cattle prints which tend to appear more blocky or rounded (Barr and Bell 2017: Fig. 6; Rhyder 2021) and are also often larger than the indentations here (e.g. >10cm: Olson 2013). This leaves the two deer and ovicaprid species as more likely candidates.

Of the two deer species, fallow deer tend to have straighter hoof walls less in keeping with the curvature visible on the Area A Category 1 indentation (Rhyder 2021). Moreover, this species is also a much later introduction to Ireland (13th century AD) compared to red deer which have been present since at least the mid-Holocene (Montgomery et al. 2014; Monaghan 2017). Given the likely timing of footprint deposition (see below) coupled with a longer presence in Ireland, we favour red deer as the more likely of the two species. However, there are features of the Category 1 prints which could be argued to fit less well an attribution to red deer. Firstly, the wide spacing between the cleats and their variable shape. Secondly, the small size of the Area B Category 1 indentations.

This can be countered by evidence from the Severn Estuary where similar footprint-tracks have been identified as red deer. These exbibit a variety of shapes (see Scales 2007: CD 12.53) including blurred, connected and separated indentations. This has been attributed to variations in the animal's movement, weight distribution, slight differences in sediment and preservation (Scales 2007). Examples of wide spacing between cleats in deer footprint-tracks – indicating very splayed toes – also exist in the literature (Allen 1997: Fig. 22; Scales 2007: CD12.53; Barr 2019: Fig. 9.16). In terms of size, all but one of the Category 1 prints fall within or close to the range measured at the Severn Estuary sites, albeit towards the small end of the size range (Table 2). At the Severn Estuary sites, the small prints have been identified as either juvenile red deer, or roe deer (Scales 2007). Nevertheless, given the small sample size and variation in shape and footprint-track size the attribution to red deer is not definitive. Ovicaprids also produce elongated cleats with rounded to pointed tips (Barr and Bell 2017:

Fig. 6; Rhyder 2021) and with a size range which fits the Area B examples (Olsen 2013). That said, the degree of curvature on the Area A indentations are more deer- than ovicaprid-like. Consequently, we interpret the Category 1 indentations as artiodactyl footprint tracks, possibly red deer, but not excluding ovicaprids. The implications of this with regard to Irish faunal history will be discussed below.

Interpretation of the Category 2 indentations as footprint tracks is less certain. These too have indications of double indentations and are similar to the size range of Severn Estuary red deer (Fig. 7A–I). Their size, location, elevation and alignment relative to the Category 1 prints does hint that they are part of the same set of tracks and this is further supported by the absence of such features elsewhere on the clay. However, their highly variable morphology prevents their interpretation as animal footprint-tracks. There is even less certainty over the Category 3 indentations (e.g., Fig. 7J–I). If they were created by modern processes such as gouging by gravel/cobbles during storms, they might be expected to occur randomly across the entire clay surface and not in association with the Category 1 and 2 examples. Nevertheless, without clear indications of foot/hoof shape, they cannot presently be interpreted as animal footprint-tracks.

PALAEOENVIRONMENTAL CONTEXT

No palaeo-environmental analysis was done as part of this study, thus the precise environment represented by the clay is unclear. The assessment of a bulk sample from the eroding edge of the deposit identified only a single foraminifera test lining (which may have been intrusive given the exposed location of the sample) and some charcoal which, while not conclusive, suggests that this was not an intertidal or saltmarsh environment. This is supported by the absence of banded sediments indicative of tidal fluctuations, as observed at footprint-bearing sites such as the Severn Estuary and Formby Point (Bell 2007b; Burns 2021).

Additional evidence that the clay was not laid down under coastal/marine conditions comes from extant evidence of Holocene sea-level change. The closest terrestrial limiting date (Culleenamore: 16km to the south) indicates that Relative Sea Level (RSL) was at least -1m below present by ~4300–4800 cal BP whilst Sea Level Index Points (SLIPs) from West Donegal (50km to the north) suggest that present mean sea level elevation was reached by ~4800–4200 cal BP (Brooks and Edwards 2006; Shennan *et al.* 2018). Given that the trend for this area during the early- to mid-Holocene was one of steadily rising RSL, this suggests that RSL was a few metres below present when the clay was deposited. This is substantiated by modelled RSL from Glacio Isostatic Adjustment (GIA) models which give an RSL elevation of ~-2 to -4m between 6000–7500 cal BP (Bradley *et al.* 2011). High resolution bathymetric data is not available for the adjacent inshore waters but, based on nautical charts, this would place the contemporary palaeo-coastline in the vicinity of the present bay mouth; ~300–400m seaward of the study site.

Beyond this, we cannot speculate further on the precise environment of deposition for the clay other than it was inland and waterlain; for instance on a lake margin or a backwater basin or channel, possibly associated with the Grange River which runs east of the dunes that back the present-day beach (Fig. 1).

WIDER SIGNIFICANCE

As mentioned above, we favour red deer as the likely candidate species for the Category 1 footprint tracks, but do not exclude ovicaprids. At present, the available evidence suggests that red deer were introduced to Ireland after the Early Neolithic: ~5800 cal BP, with the earliest faunal remains dated by association to ~5400 cal BP and by radiocarbon to ~4900–4500 cal BP (Carden *et al.* 2012). Ovicaprids also appear in the Irish record at roughly the same time: ~5400 and 4500 cal BP for sheep and goat respectively (Montgomery *et al.* 2014).

If the Trawgar prints are contemporary with obtained radiocarbon dates (~7300-6300 cal BP), this would make them ~1500–500 years older than the presumed earliest of these introductions: that of red deer at ~5800 cal BP (Carden *et al.* 2012). If this is the case, then it implies the early introduction of red deer (or even sheep/goat) during the Mesolithic. This is not a totally inconceivable suggestion. There is evidence that Irish Mesolithic hunter-gatherers actively modified their surrounding landscape, including the deliberate introduction of large mammals such as wild boar, dog and, possibly, bear (Warren *et al.* 2014; Warren and Westley 2020; Warren 2022). There are also early dates for domesticates in Ireland in the form of cattle bones from Ferriter's Cove dated to 6400–6300 cal BP (Whitehouse *et al.* 2014).

However, we consider this an unlikely scenario for two main reasons. Firstly, it is at odds with the total absence of red deer or ovicaprids from Irish Mesolithic archaeological sites (Carden *et al.* 2012; Warren 2022). Secondly, the nature of the depositional environment, in particular the fact that deposition of a relatively thick clay layer implies standing water. Freshly-deposited clay surfaces (i.e. co-eval with the obtained radiocarbon dates) have a high water content, and therefore do not retain well the shape of footprints, such as the Category 1 examples here (Allen 1997; Marty et al. 2009; Bell 2020). De-watering of the sediment is necessary to produce a surface more conducive to print preservation (e.g. moist but not waterlogged: Marty et al. 2009; stiff mud with moderate moisture content: Allen 1997). This can be done soon after deposition by surface exposure and drying. However, this produces desiccation cracks, none of which are visible at Trawgar. Consequently, in this case, the mechanism may have been de-watering via burial and consolidation. Subsequent exhumation of the clay sometime after its deposition then revealed a surface better-suited to footprint retention. After footprint formation, burial occurred a second time, resulting in further consolidation and the very firm clay surface which exists today.

This poses the question though, of how long after deposition this occurred. In other words, could the footprints be as young as 500 years or old as 5000 years? The evidence at hand prevents a definitive answer. Nevertheless, it could be argued circumstantially that an older rather than a younger age is more likely. The present context – an exposed sandy beach – is considered an unlikely environment for either deer, sheep, or goat to roam. There is no grazing and the beach does not lie on a route between grazing areas. This beach has existed since the early 1830s at least, based on 1st Edition Ordnance Survey maps (OSI 2023). Moreover, as stated previously, a very recent age for the prints also rendered unlikely by the present firmness of the substrate.

The earliest date for which a beach could have existed in this area is sometime from ~4500–4000 cal BP. This is suggested by the closest available evidence for Holocene sea-level rise. SLIPs from West Donegal (~50 km to the north) show that present mean sea level elevation was reached by ~4800–4200 cal BP while the aforementioned terrestrial limit from Culleenamore shows that RSL was at least -1 m below present by 4800–4300 cal BP (Shennan et al. 2018). Sand dune accumulation accompanying slowly rising sea level (observed elsewhere in the mid- to late-Holocene in the north of Ireland: Wilson *et al.* 2004), could also provide the mechanism for the second burial of the clay deposit after the footprints were emplaced. In summary, the circumstantial evidence allows us to consider a window for the footprints of between ~5800 cal BP (after the earliest introduction of red deer) to ~4000 cal BP (when this area was transformed from an inland to a coastal environment by RSL rise). Nevertheless, we stress that this a tentative hypothesis which would require further data to test.

More generally, these tracks highlight that Holocene palaeo-ecological evidence can be preserved even on high-energy exposed coastlines such as the west of Ireland. Taphonomy and, ultimately, preservation, in these cases, are heavily dependent on local geomorphology and coastal processes (see Flemming *et al.* 2017 for a full overview). In this case, the location of the site tucked into the angle between the beach and a rocky peninsula has meant that the site is protected from all directions with the exception of waves coming directly from the southwest. Moreover, proximity to the bedrock cliffs has probably resulted in further protection as a result of armouring by boulders and cobbles eroding from the cliffs to the north.

This has implications both for sites presently located in the intertidal zone or fully underwater. Unlike other areas in the British Isles or North Sea where extensive tracts of submerged or intertidal

Quaternary landscapes are preserved (Bell 2007a; Fitch *et al.* 2007; Cohen *et al.* 2017; Farr *et al.* 2017; Missiaen *et al.* 2021), along the Irish coast, remnants of these landscape more likely exist in smaller 'pockets' of preservation where local conditions have conspired to ensure site survival (see also Westley 2015, Westley and Edwards 2017; Westley and Woodman 2020). This means that it is difficult to write off large areas as having low to no archaeological potential (Goodwin *et al.* 2010; Westley *et al.* 2011) without considering in detail local taphonomic controls. It also simultaneously highlights the vulnerability of these sites. Once exposed to storms, fragile and unique evidence can be very rapidly destroyed or re-buried (Wiseman and De Groote 2018). Mitigating this requires trained eyes on the coast, either in the form of citizen science monitoring initiatives supported by professionals (Wiseman *et al.* 2022) – exemplified by the Shorewatch and CitiZan programmes in the UK (Sherman 2015; Dawson *et al.* 2020) – or active monitoring by professionals. This latter is now in place in Ireland in the form of the Cherish programme (Barker *et al.* 2019), but at present is only active on the southwest and east coasts.

CONCLUSION

Human and animal tracks from Pleistocene and Holocene deposits have been previously documented from the intertidal zone of Great Britain, including both its North Sea and Irish Sea coasts. However, despite the existence of exposures of Holocene sediments and organic deposits (e.g. peat) around the shores of Ireland, until now, no similar tracks have been reported. The footprints described and discussed here were most probably created by artiodactyls - possibly red deer, but not excluding sheep/goat - during the mid-Holocene and walking on a clay surface which was originally deposited in a wet inland environment. Radiocarbon dating of the footprint-bearing organic clay surface places it between ~7300–6300 cal BP. However, the footprints are estimated to be younger than this, firstly on the basis that the clay, when originally deposited, would have been too waterlogged to preserve good footprint-track impressions and secondly, that the Irish fossil record does not contain any evidence of the aforementioned artiodactyl species until at least ~5800 cal BP. As such, a tentative window of footprint deposition of ~5800–4000 cal BP is assigned based this earliest date of introduction coupled with the likely time at which RSL reached present levels in this area and transformed the formerly inland area into an coastal one. More generally, the footprints provide a good example of fine-grained ephemeral palaeo-ecological evidence which can occur in submerged or intertidal contexts, even in high-energy settings such as the west coast of Ireland. It remains to be seen whether this is truly an exceptional example of fortuitous preservation in an Irish context or whether further intertidal footprint tracks will come to light. It is hoped that the latter will be the case now that proof of preservation has been demonstrated for Ireland.

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FIGURES

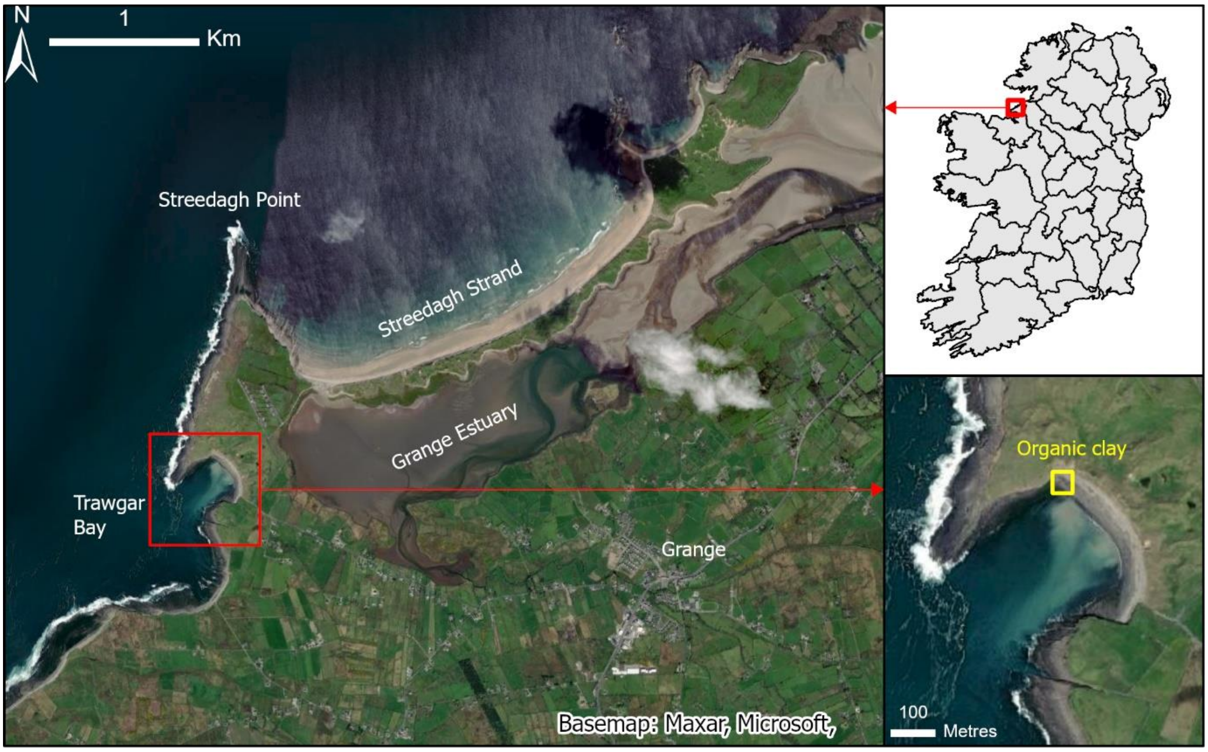

Fig. 1. Satellite image showing the study area of Trawgar Bay (Co. Sligo) on the west coast of Ireland.

Fig. 2. A) Viewing looking south over the organic-rich clay, partly water-covered during the falling tide, photograph: 11/3/2019. B) View looking northwest over the organic-rich clay after exposure at low tide. Yellow lines indicate where the clay is exposed, photograph: 11/3/2019. C) Area A: Category 1 indentation, photograph: 06/03/2019. D) View looking northeast over Area A showing the clearest Category 1 indentation and surrounding Category 2 and 3 indentations, photograph: 06/03/2019.

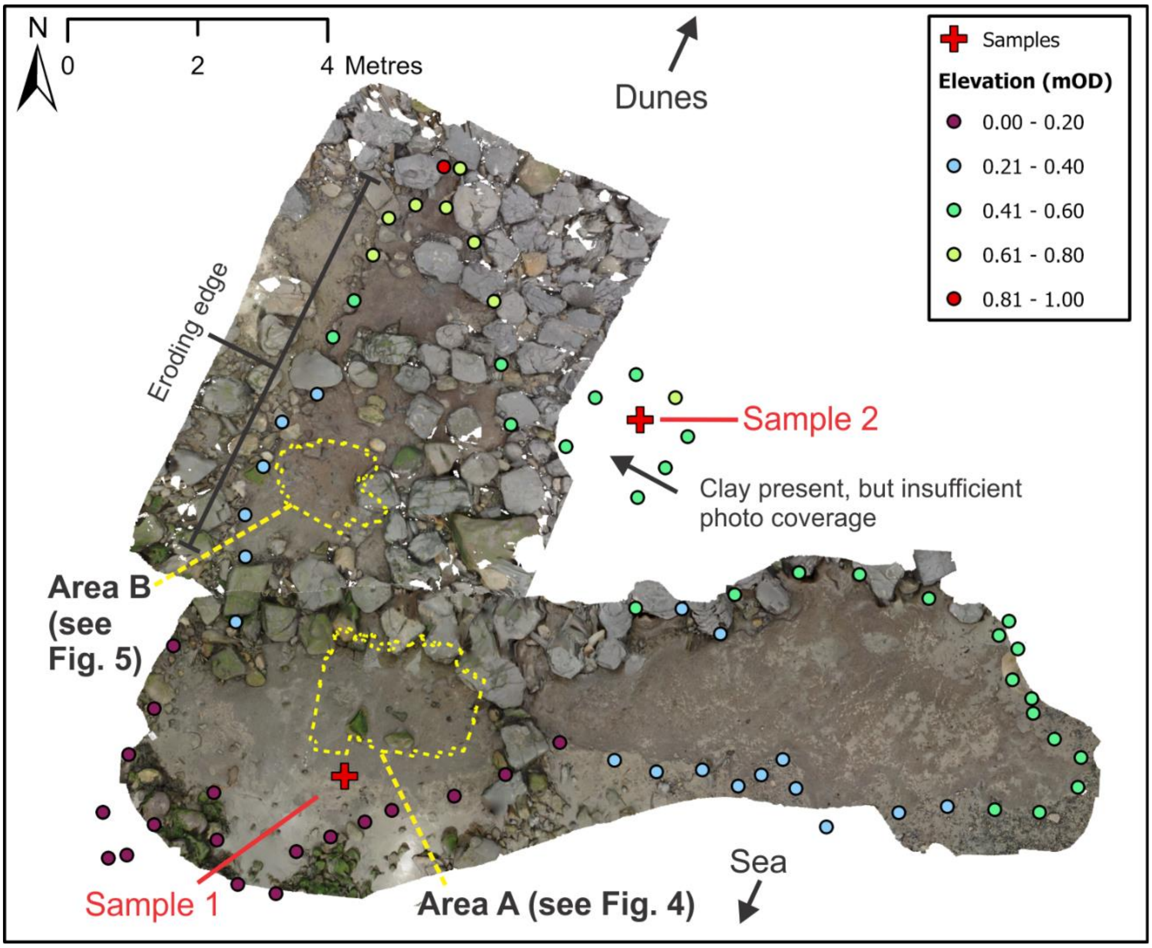

Fig. 3. Orthomosaic showing the exposed extent of the organic-rich clay annotated with location of indentations, RTK-GPS positions and elevations for deposit's edge and ^{14}C sample locations.

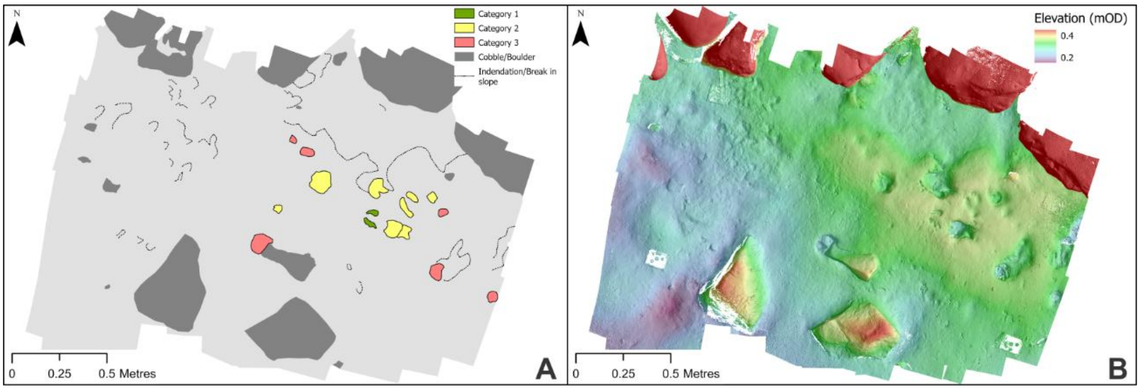

Fig. 4. Overview of Area A presented as A) line drawing showing indentations classified by interpretation category; B) Digital Elevation Model (DEM).

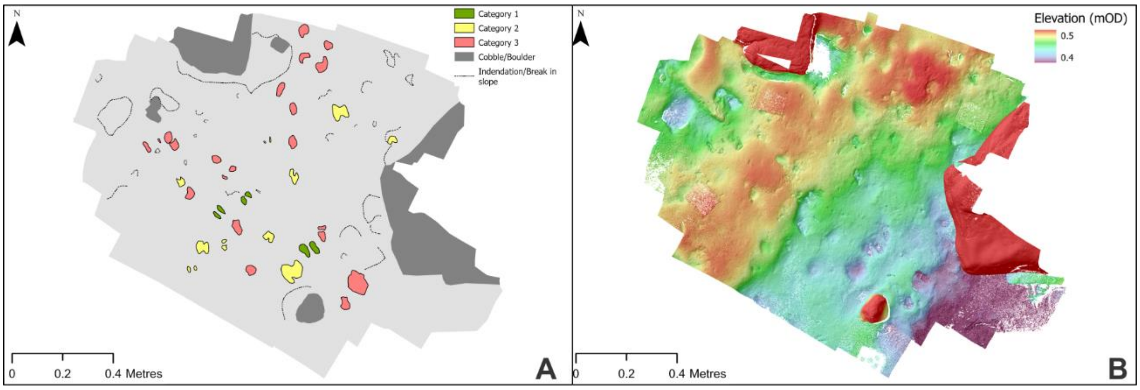

Fig. 5. Overview of Area B presented as A) line drawing showing indentations classified by interpretation category; B) Digital Elevation Model (DEM).

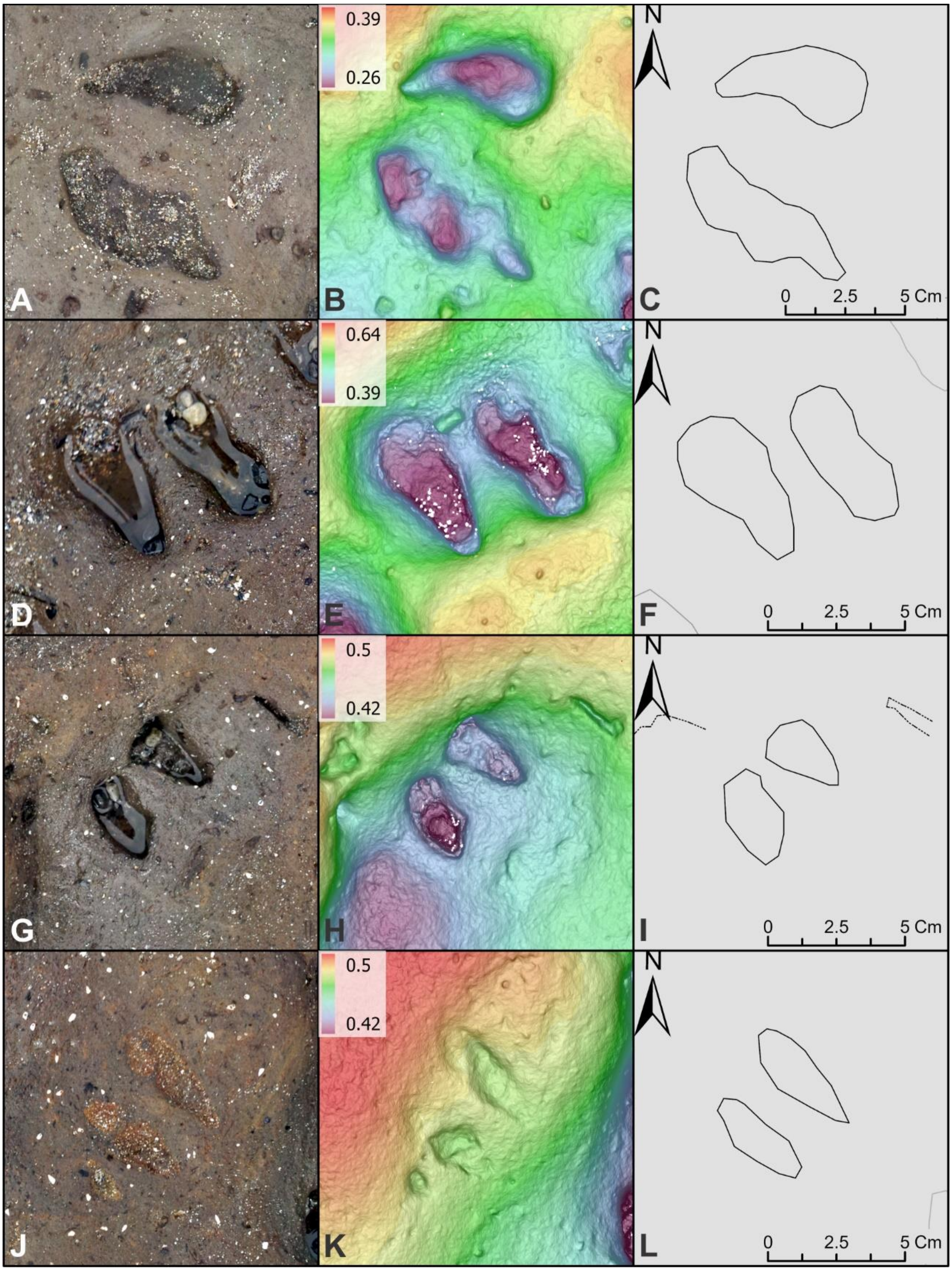

Fig. 6. Category 1 indentations. Each row shows the same indentation presented as an orthophoto, a DEM (elevations in metres relative to OD) and a line drawing. A–C) Area A indentation. D–L) Area B indentations. Note that the example shown in J is stilly partly infilled by beach sand and therefore does not clearly show on the DEM; the line drawing traces the outline visible on the corresponding orthophoto.

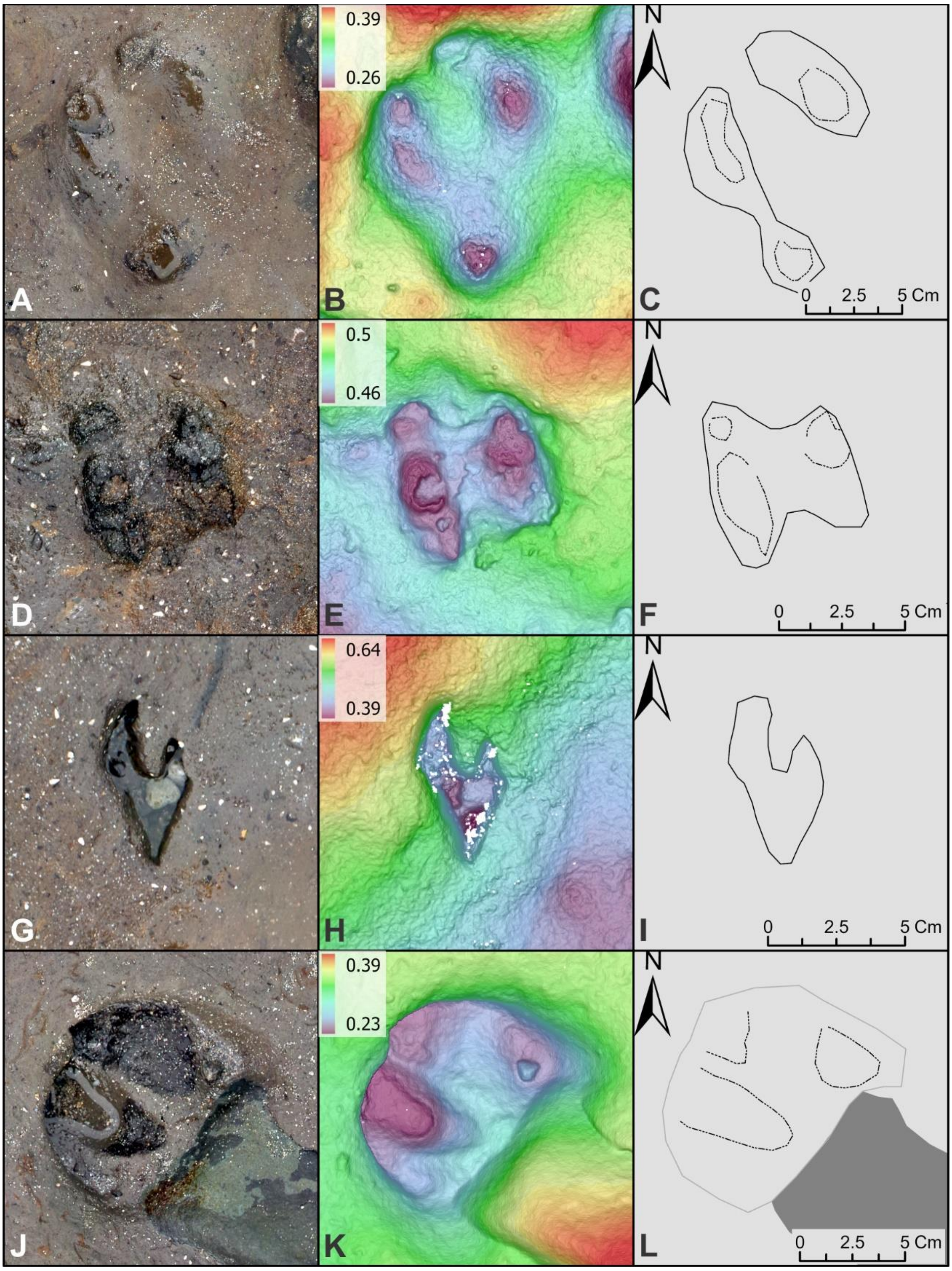

Fig. 7. Examples of the Category 2 and 3 indentations. Each row shows the same indentation presented as an orthophoto, a DEM (elevations in metres relative to OD) and a line drawing. A–C) Area A, Category 2 indentation. D–I) Area B, Category 2 indentations. J–L) Area A, Category 3 indentations.

TABLES

Table 1. Radiocarbon dated samples from Trawgar Bay. Calibration performed with Calib 8.2 software and the Intcal20 calibration curve (Reimer et al. 2020).

UBA number	Sample no.	Elevation (m OD)	^{14}C Age (BP)	Cal BP (2 sd)
UBA-46583	Sample 1	0.22	6329 ± 33	7165 – 7226 7233 – 7319
UBA-46584	Sample 2	0.61	5609 ± 29	6306 – 6447

Table 2. Comparative measurements of the prints from Trawgar and red deer prints from the Severn Estuary sites (data from Scales 2007: CD12.49)

	Severn (Cervus sp.)		Trawgar Cat 1		Trawgar Cat 2		Trawgar Cat 3	
	Length (mm)	**Width (mm)**	**Length (mm)**	**Width (mm)**	**Length (mm)**	**Width (mm)**	**Length (mm)**	**Width (mm)**
Max	140	90	82	93	112	121	107	100
Min	44	35	35	40	21	27	19	5
Average	78	63	56	62	59	59	51	35