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Neolithic track sites from Formby Point, England: New data and insights

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ABSTRACT

Formby Point, England is a well-documented exposure site in which marine erosion has regularly exposed Neolithic human trackways along the coastline since the 1980s. We report here the discovery of an additional 17 trackways and 61 isolated tracks (181 human footprints in total) discovered during four field seasons of natural site exposure at four localities in the Formby Point region, recorded in 2016–2018. This adds substantially to the existing ichnological and palaeoecological body of data available for this site. The footprints belong to adults and children, in association with a large collection of other animal prints (>700), and are typically preserved in sandy-silts. The human trackways show a bimodal direction, with most of the trackmakers travelling in a south-west direction, towards the palaeo-coastline, with fewer trackmakers travelling in a north east direction, inland. Some trackmakers were either walking side by side or were following one another hours/days later as indicated by parallel trackways, whilst one trackway shows an individual running, eventually coming to a stop with both feet together on the ground. The trackmakers made repeated visits to the site, whereby some trackways were made hours/days earlier than others, evidenced by the impressions' depth. We present the data here to: (1) add to literature of Neolithic footprints discovered around the world; and (2) make all three dimensional models and associated metadata publicly and freely available for use by other researchers. Most importantly, Formby is an exposure site in which we exclusively rely upon erosion to expose the footprints. Therefore, researchers can only understand the true dynamics of the site via the reporting of each successive exposure. We encourage local researchers to work with the public to aid in future documentation of the site to add to the continuously-growing database of Formby discoveries.

1. Introduction

The recovery of human and animal footprints from the geological record provides a rare glimpse into past life. This snapshot in time is often unparalleled when compared to other evidence, such as archaeological (e.g., tools) or skeletal material. Footprints can offer an insight to group demographics (e.g., Ashton et al. 2014; Hatala et al., 2017; Roach et al. 2016; Duveau et al. 2019), behavioural ecology (e.g., Bennett et al. 2020), and human-animal interactions (Leakey and Hay 1979; Altamura et al. 2018; Wiseman and De Groote 2018; Bustos et al. 2018). The number of publications reporting human fossil footprint discoveries has increased rapidly in recent years (e.g., Helm et al. 2018; Bustos et al. 2018; Duveau et al. 2019; Bennett et al. 2020; Hatala et al. 2020; Bennett et al., 2021; Mayoral et al., 2019; McNutt et al., 2021), leading to new ways of understanding past life.

For the past 40 years, coastal erosion at Formby Point on the Sefton Coast, England (Fig. 1) (53.5639° N, 3.1003° W) has regularly exposed an abundant collection of human and other animal footprints along a 4 km stretch of coastline (Tooley 1978; Huddart et al. 1999; Roberts 2009; Wiseman and De Groote 2018; Burns 2021). The footprint-bearing sediments were probably buried rapidly by sand avalanching from the active faces of nearby dunes after track formation (Roberts 2009). This led to the preservation of these footprints which are regularly exposed and subsequently destroyed by the submersive tide (Wiseman and De Groote 2018). The footprints appear along the beach much to the delight of the local community, but have been documented by ichnologists only sporadically (e.g., Tooley 1978; Pye et al., 1995; Huddart et al. 1999; Roberts 2009), although have received renewed attention in recent

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years (Wiseman and De Groote 2018; Wiseman et al. 2020a; Burns 2021). Formby is thus best characterised as an exposure site in which ichnologists rely on erosion to reveal more trackways.

As of 2018, 146 human trackways associated with animal tracks have been interpreted with varying degrees of reliability as red deer, roe deer, auroch and wolf have been documented in the literature at Formby Point (Roberts 2009; Wiseman and De Groote 2018), although here we refer to the former collectively as artiodactyl until further experimentation can refine ichno-identification. The number of actual footprints is likely to be much higher due to regular reports from local residents of unmapped trackways appearing at low tide, following storms. The sediments containing the footprints are mainly composed of silty sands (Gonzales et al., 1997), which are soft, sometimes deformable, and quickly eroded once exposed to the elements (Wiseman and De Groote 2018). Unfortunately, once these sediment beds are exposed then they are quickly destroyed within days by marine action. This often impedes data recording by ichnologists, and so we encourage researchers to work with the public as 'citizen scientists' to record and share their findings. Here, we shall discuss the benefits of such tasks.

We report four new field seasons in which we documented new trackways,. We report the general ages and heights of the human trackmakers (provided as Supplementary Information), including behavioural changes in movement. We are also providing open-access to all 3D models created of the human footprints collected at Formby Point (accordingly to Falkingham et al., 2018). We do not identify nor speculate on the other animal tracks here.

2. Geological context

All track-bearing surfaces within the intertidal environment are composed of silty, fine-grained sands and peat sediments with nearby sand dunes to the east and the Irish Sea to the west (Roberts et al., 1996). The trackways are preserved in unlithified, soft-sediments which are sometimes deformable (Huddart et al. 1999; Roberts, 2009; Wiseman and De Groote 2018), and are regularly trampled by the public (Wiseman et al. 2020b). The sediment beds are twice daily immersed by the tide, leading to their destruction, but also often leading to the exposure of underlying prehistoric beds (Wiseman and De Groote 2018).

Previously dated beds obtained from alder root samples have yielded dates of 3649 ± 109 years BP (Gonzalez et al. 1997) ~ 3230 ± 80 years BP (Pye et al., 1995), indicating the footprints date to the Neolithic. Direct dating of Blundell Path C (see below) was conducted in another study using radiocarbon dating of plant macrofossils extracted from the sediments (see: Burns 2021), which yielded dates of 4331–4050 years calBC (5363 ± 59 years BP, UBA-32242). A lack of organic material of the lower sediments has resulted in these dates being an absolute minimum (Roberts 2009), indicating that some of the footprint-bearing beds may be geologically older (Burns 2021). No associated archaeological material has been discovered in the vicinity (Roberts 2009) which might assist in dating of the footprints and/or improve our understanding of life on the Neolithic coast.

Similar to the study of Wiseman and De Groote (2018; see also: Ashton et al. 2014 for other marine exposure sites), the trackways reported here were exposed by marine erosion. Whilst wind speeds were often quite high and caused difficulty in recording (see below), the footprint-bearing sediments were firm enough to withstand short term wind erosion during the few days of exposure prior to destruction by tidal immersion. The footprint surfaces were relatively consistent in composition between each of the localities. All beds had a high-water saturation, as expected for repeated immersion in salt water. The material is a browny-grey, with an orange hue, silty sand with few to no inclusions. The beds are mostly flat, not inclined, although the Gypsy Path and Cornerstone beds have a slight undulating ripple.

2.1. Field season descriptions

Footprints were mostly easy to identify due to their stereotypical outline (Bennett and Morse 2014). Other footprints resembled elongate hollows measuring 113 mm – 271 mm in length, similar to hollow morphotypes reported by Ashton et al. (2014). Similar elongate hollows have previously been demonstrated to be "footprint-like depressions" which are either inadvertently man-made or the result of erosional processes (Panarello et al., 2018), instead of a foot impression. Some of the Formby hollows are contained within a trackway whereby other footprints are more identifiable as human. These particular hollows were more identifiably human, but other such isolated hollows are questionable, especially those from Gypsy Path. Hollows were included here based upon the following criteria: evidence of heel tapering, potential impression of a longitudinal arch on one side of the impression, or a wider forefoot region (anterior print) than that of the heel (posterior region). Nevertheless, the inadvertent inclusion of anthropic pseudo-footprints within our dataset is a possibility, and as such we place more emphasis on the importance of the well-defined trackways.

Because the surfaces were located on the coastline, they were repeatedly immersed by the high tide, leading to their destruction in a matter of days after exposure (Wiseman and De Groote 2018; Burns 2021). Therefore, it was challenging to record the footprints prior to their destruction, which was further hindered by time constraints of the incoming tide. Most of the beds were exposed after stormy weather during winter months, which further challenged data collection. Most of

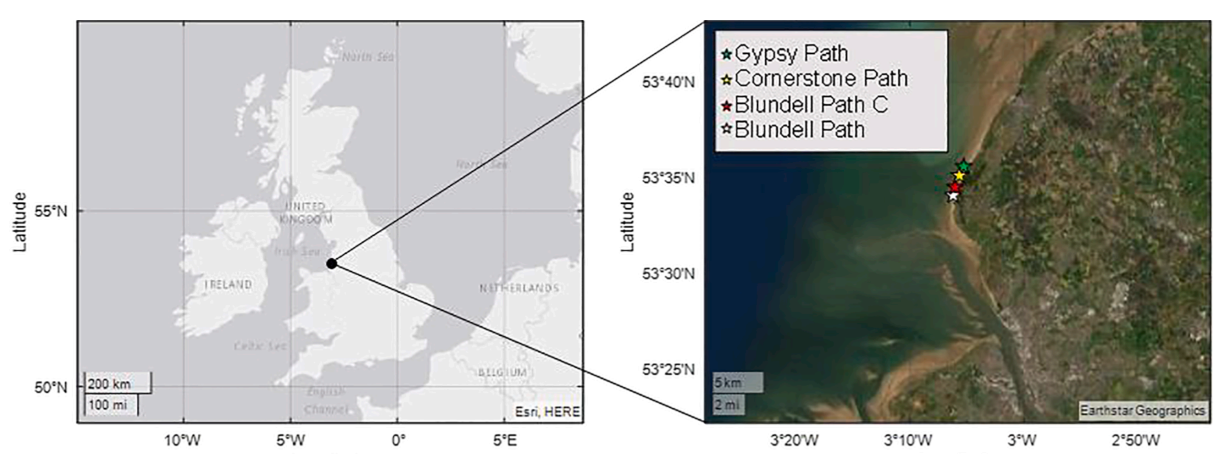

Fig. 1. Location of Formby Point, England with four locations marked detailing the location of new discoveries during 2016–2018. Image was created in MATLAB 2021a.

the beds were firm and compact, affirming that the footprints could not have been made by recent human and/or animal activity because the sediments are too firm to leave deep impressions. However, one bed (Gypsy Path; see below) was easily deformable (Fig. 2C). We assume that these barefoot impressions are prehistoric and not modern based upon two assumptions: (1) the footprints were discovered alongside medium to large-sized artiodactyl prints whose probable trackmaker are no longer native to the area, and (2) this bed was uncovered in December in the UK along the coastline. The daily temperatures were around 0 °C and it seems unlikely (although arguably not entirely implausible) that any adult and their child would be walking around barefoot on wet and cold, slippery silts.

We report four field seasons:

(1) In June 2016 three human trackways were discovered immersed in a collection of over 700 animal tracks at the Blundell Path locality (Fig. 1). The animal tracks were identified as belonging to medium to larger-sized artiodactyls and birds. We do not make any inference as to non-human species identification here and urge further experimental studies to refine ichno-species assignment. Whilst these particular trackways have been reported previously (Wiseman and De Groote 2018; Burns 2021), we include them here to provide information on the behavioural ecology of the trackways but to also now provide open-access to the 3D models. Our previous study (Wiseman and De Groote 2018) focused solely on a select few footprints from Blundell Path to assess the rate of daily erosion caused by the tide, but here we provide a comprehensive overview of all prints from this locality. The Blundell Path trackways were excavated by staff and students of The University of Manchester, UK and by staff of Liverpool John Moores University, UK. These footprints are well preserved, showing clear anatomical definitions such as individual digit impressions.

(2) In December 2016, 29 footprints were discovered at Gypsy Path (Fig. 1). Only three short trackways were identified, whereas all other footprints were single impressions not associated with a trackway. The footprints were of a poorer preservation quality than those from Blundell Path, and exhibit some over-trampling by modern humans owing to the beds location on public land. These footprints are best described as elongated hollows. The Gypsy Path trackways were excavated by staff and students of Liverpool John Moores University during unfavourable winter weather conditions. Therefore, the 3D models from Gypsy Path were captured in limited visibility, wet and windy conditions resulting in poor quality 3D models. Unfortunately, when returning to the site the following the day, the trackways had been destroyed by the tide and stormy conditions during the previous night (Fig. 2D). Consequently, inferences regarding the Gypsy Path trackways are limited.

(3) In February 2017 two long, parallel trackways in Bed II were discovered at Blundell Path C (Fig. 1), which are the longest trackways discovered at Formby Point to date. Trackway 4 measured 13.2 m long (n = 35 footprints) and trackway 5 measured 12.6 m long (n = 24 footprints). The Blundell Path C trackways – so called because the trackways were discovered midway between Blundell Path and Cornerstone Path (Fig. 1) – were excavated by staff and students of Liverpool John Moores University during windy weather conditions, which unfortunately created a large uplift of sand from the nearby sand dunes which consistently blew into the trackways during 3D model creation. Unfortunately, the 3D models are of a lower quality than what would normally be expected during data collection (Falkingham et al. 2018), but track dimensions and behaviour are fortunately still visible from the models, and the prints are of a good preservation quality with clear anatomical definitions. A few days later an adjacent bed (Bed III) was uncovered by tidal action which partially overlay the north-west corner of Bed II. Bed III consists of an intermix of single footprints (Fig. 2C) which are of a poorer preservation quality than Bed II (i.e., only some anatomical definitions are present, with much border collapse).

(4) In later February 2017 six trackways were discovered at Cornerstone Path (Fig. 1). There were two sets of double trackways (Fig. 2A), and two separate trackways. The Cornerstone Path trackways were excavated by staff and students of Liverpool John Moores University during good weather conditions. These footprints had good preservation quality.

2.2. Methods

All beds were discovered on land managed by the National Trust UK,

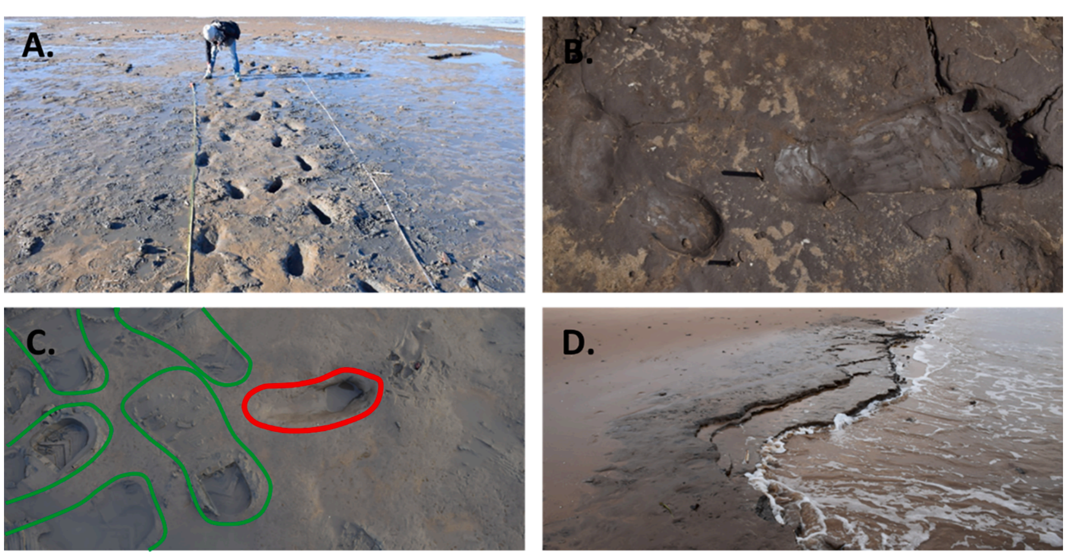

Fig. 2. Selection of photographs from each of the prehistoric beds included in this study. (A) Excavation of the double trackway at Cornerstone Path. (B) Example of two trackways from Blundell Path. (C) Example of the deformable sediment which can be sometimes deformed by the excavators and/or the public if the bed is highly saturated. The prehistoric print is highlighted in red. Modern prints are highlighted in green. (D) Example of the destructive nature of the high tide at Gypsy Path which destroyed the sediment bed overnight, prohibiting further data collection. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

who gave permission for research to be conducted. All trackways were exposed naturally by tidal action (see: Wiseman and De Groote 2018; Burns 2021). Excess sediment (i.e., sand and other debris) that infilled the prints was gently removed with a soft bristle brush or a small wooden spatula measuring 2 cm in diameter. Excess water which infilled the prints (e.g., Fig. 2C) was removed using a sponge. A handheld DSLR D3300 Nikon camera with a macro 60 mm lens of fixed zoom was used to photograph all the trackways documented here using a circular path to optimise 3D model resolution (Wiseman et al. 2020b). Due to sporadic weather conditions (a mix of cloud cover, rain, and bright sunlight) camera settings were consistently altered to accommodate weather. Photogrammetry was applied to create 3D models of each track daily on the licensed software Pix4Dmapper (v.4.327 Pix4D).

Depth maps and contour-lines were generated with DigTrace Pro (v 1.8.1, Bennett and Budka, 2018; Budka et al. 2016) all measurements were taken on 3D models using Dig Trace Pro, although the poor quality of some of the 3D models (see below) might have influenced measurements and this should be appropriately acknowledged as a potential source of error in this study. We defined footprint length as the distance between the heel and hallux following the mid-line of the footprint, following the best practice outlined in Bennett and Morse (2014) and Wiseman and De Groote (2021). Poor preservation quality of some of the prints made it difficult to identify homologous landmarks for measuring length (i.e., such as the tip of the hallux), but such error is expected to be minimal and is discussed in Section 2.3.

Stature was predicted from footprint lengths (Wiseman and De Groote 2021), in which a foot length to stature ratio has repeatedly been found to positively predict stature in modern habitually unshod populations (Martin, 1914; Hrdlička, 1935; Dingwall et al., 2013) and is commonly applied in palaeoanthropology to predict stature from fossil footprints (e.g., Tuttle, 1987; Ashton et al., 2014; Wiseman et al. 2020a; Bennett et al. 2020). However, the previous experimental methods which forms the basis of the protocol used here (see: Wiseman and De Groote 2021), were performed with modern, shod individuals, which is not the case for these Neolithic footprints that exhibit traces of unshod feet (although see below). Therefore, there is the possibility that slight error will be present in our stature estimations. Consideration must also be given to slight changes in substrate characteristics between previous experiments (sands with medium sized inclusions) with the Formby sediments (sandy-silts). Substrate changes can effect track dimensions (Milan and Bromley, 2006; Morse et al. 2013), and can result in over- or under-estimates of stature (Wiseman and De Groote 2021). Nevertheless, potential discrepancies are expected to be minor, and the methods employed are considered to be the current 'best practise' based upon the rigorousness of the previous experiments (Wiseman and De Groote 2021).

Direction of travel is reported for all trackways and footprints, although direction of travel for isolated footprints should be cautiously interpreted because an isolated track may not be representative of the direction of travel, but could instead be 'non-directional' (i.e., perhaps the individual was not travelling to a specified location). Speed was calculated following well-established methods (see: Alexander, 1976; Alexander, 1984; Raichlen et al. 2008; Bennett et al. 2021) and the best practise established by Bennett and Morse (2014). Speed was only calculated for 'complete' trackways (i.e., $n > 4$ footprints within a trackway).

Age estimates of the trackmakers was tentatively assumed based on data from UMTRI/CPSC Child Anthropometry Study (Snyder et al. 1977; Bennett et al. 2021). For each whole number foot length in this dataset the associated subject ages were extracted and a mean age, with standard errors, was calculated for that length. Track lengths > 200 mm were considered to be sexually dimorphic (Snyder et al. 1977) and we report predicted sex categorisation and associated age for trackways which had an average track length above this threshold. A modern 14 year old can have the same foot length as an adult (Snyder et al. 1977), and so here for this prehistoric population at all Formby localities we have considered a child print as belonging to a trackmaker with an estimated age of < 12 years old (after which, foot length becomes sexually dimorphic; Snyder et al. 1977). We acknowledge that estimated ages > 12 years old might belong to a juvenile or an adult, of which further research is required to refine age predictions from footprints. With this approach designed by Snyder et al. (1977), age can be estimated to be up to 19 years of age of which we do report here solely to incorporate potential sexual dimorphism, but we acknowledge that such age estimates > 12 years old are superfluous and should be interpreted as 'adult'. All age estimates are extracted from Q75 (see: Bennett et al. 2021) which are considered most accurate because these predictions take nutritional differences between modern populations into consideration and thus accounts for potential sources of error in estimating age using modern growth curves for prehistoric populations. It should be noted that this approach does not consider the effect that substrate will have on length (see: Wiseman and De Groote 2021) and that further experimentation is required to refine age estimation from dynamic prints made in a range of substrates. The age/sex predictions are considered here as a 'best informed estimate'.

Finally, we also calculated the minimum number of individuals (MNI) per site. MNI was estimated upon track length measurements only and by assuming that footprint impressions per trackmaker did not vary by > 5% in length (see: Belvedere et al. 2021), although see Duveau et al. (2019) in which it was demonstrated that print length could instead vary by up to 12.8% per individual. Therefore, our liberal approach in MNI determination may have over-estimated the number of trackmakers present, but with such a small sample size in some localities (i.e., isolated footprints at Gypsy Path or partial trackways consisting of just two footprints), such predictions should be interpreted with caution regardless of the margin used (Belvedere et al. 2021).

Due to the poor quality of some of the trackway 3D models, we did not conduct any morphological analyses here.

2.3. *Sensitivity analyses of print measurements*

We performed sensitivity analyses of measuring footprint length. To test measurement error, foot length was changed up to 10 mm (229 mm ± 10 mm; range 219–239 mm) and age and stature was predicted for each new measurement. Predicted age varied by just 1.25 years (range 13.58 to 14.83 years), but stature varied more substantially by 135 mm (range 1479 to 1615 mm). However, inaccuracy of identifying homologous landmarks by up to 10 mm seems quite liberal, and it is more likely that error in identifying landmarks (i.e., see: Wiseman et al. 2020b) was likely more conservatively between 1 and 5 mm. If so, then age predictions would be within 0.17 years (range 14.25 to 14.67 years) and stature predictions would be within 34 mm (range 1534 to 1568 mm). Due to already highlighted potential issues of substrate influencing length measurements, such possible measurement error can be deemed negligible and thus our length measurements of poorly defined prints are likely accurate representations.

2.4. *Experimentally generated footprints*

A selection of footprints from Cornerstone were quite deep, with some evidence of slippage in which it was difficult to ascertain if the individual was walking or running (see below). To determine if the individuals were walking (i.e., if speed estimates are influenced by slippery substrate inflating track length; Wiseman and De Groote 2021) or running, we compared the data to modern human trackways and footprints moving across a similar substrate at a walk, a fast walk and a jog/run. Data collection has previously been described by Wiseman and De Groote (2021) but is described here in brief. Data was collected with ethical permission from Liverpool John Moores University from which a trackway was constructed measuring 12 m long by 0.6 m wide and filled with fine-grained homogenous sand composed of rounded to sub-angular particles measuring ~ 0.06–0.7 mm in diameter, with a standardised depth of 44 mm. A high-water content of 10–12% was used, following Raichlen et al. (2010). Similar sand/hydration levels have been used in other studies (e.g., Crompton et al. 2012), and are considered here as a proxy for the Formby Point trackways. One participant is used here as a proxy because their biometric dimensions match those from trackway 10 (25 years old; right foot length is 280 mm; stature is 1820 mm). The participant was instructed to walk, then walk briskly, then jog/run across each of the substrates at a steady speed. Between each individual trial the experimental trackways were flattened and levelled using a screed to ensure that all steps were conducted on a flat, even surface. Speed was controlled for each repeated movement via the use of timing gaits (Browser TCi Timing System).

Experimental trackways were digitized and measured according to the methods explained above. Averaged footprints (i.e., all those belonging to a walk versus those belonging to a jog) were created following Bennett et al. (2016) and Belvedere et al. (2018). The averaged surfaces were then compared in DigTrace Pro to the footprints from Cornerstone trackway 10.

3. Results and discussion

We report a total of 181 human footprints, composing 17 trackways (n = 137 footprints across the trackways) and a mix of isolated footprints (n = 44 footprints) from four different localities at Formby Point, UK: Blundell Path (n = 16 footprints in total; n = 4 trackways; n = 0 isolated prints), Blundell Path C (n = 76 footprints in total; n = 3 trackways; n = 22 isolated prints), Gypsy Path (n = 29 footprints in total; n = 3 trackways; n = 18 isolated prints) and Cornerstone (n = 58 footprints in total; n = 7 trackways; n = 0 isolated prints). An overview of the direction of travel for all trackways from all localities and the estimated ages for each trackway are provided in Fig. 3 and reported for each trackway in Table 1. All metadata including track lengths and stature predictions can be found in Supplementary Information 1.

We found that five trackmakers were travelling in a south-west direction, with three of the trackmakers travelling in a north-east direction. The trackmakers from Blundell Path C were both travelling north-east, whereas the additional trackways from the same path found the following day after sediment removal were mostly headed north, apart from two shorter trackways (one belonging to an adult, another to a child aged ~ 9.00 ± 2.86 years; Table 1) which were headed west, towards the coast. The adult trackmakers from Cornerstone were travelling south-west, with one adult trackmaker and one child trackmaker (aged ~ 7.50 ± 2.01 years; Table 1) travelling north-west. Only one trackmaker from Gypsy Path was travelling in a consistent pattern (west), with all other prints exhibiting an intermix of directions. The trackway belonged to a child aged ~ 7.25 ± 2.04 years (Table 1); all other prints were singularly impressed, disassociated from any trackway. 29 footprints were found in this locality, of which eight were adult and the rest belonged to children, the youngest estimated to be ~ 1.5 years of age based upon modern shoe sizes (note: foot sizes this small are not present in the Snyder et al. 1977 dataset for comparison). Trackways from Blundell Path were travelling south-west and north. An additional track-bearing bed was also discovered at Blundell Path during the same field season, but is not reported here (see: Burns 2021). This previous study found additional child prints in the same locality, with no clear direction of travel.

Overall, most trackways (51%) were estimated to belong to adults (+12 years of age), with a predilection for most trackways to be travelling either south-west (34%) or north-east (25%), suggesting an inward and outward journey towards a common area for all four localities.

Each of the sediment beds and their associated trackways are described in detail below.

3.1. Blundell Path

During the first field season, three human trackways were discovered, immersed in a collection of animal tracks (>700) identified to belong to a range of artiodactyl species and bird (Wiseman and De Groote, 2018; Burns 2021). We describe three human trackways:

Trackway one: This adult trackway (♂ = 17.29 ± 1.85; ♀ = 15.83 ± 0.56; Table 1) shows an individual presumably travelling at quickened speeds, before coming to a stop with both feet side by side left impressed on the ground. We are careful about reporting speed as we do not wish to make speed inferences based upon a singular stride length, in which intermittent prints are presumed missing – this is identifiable in Fig. 4B. Overlaying sediments crosscut the trackway, as visible in Fig. 4B, further hindering precise speed estimations. No active excavation was permitted on site, rather just natural exposure – this was to minimise hazards to the public. Therefore, we could not remove the overlaying sediment which transects trackway one to reveal any possible underlying footprints which may have belonged to this trackway. We assume that additional footprints belonging to this trackway lay beneath this overlaying sediment. Nevertheless, this is the first known ichnological record to show a person coming to a stop with both feet placed side by side in a standing position, and we can only speculate as to why, although we cannot ascertain if the trackmaker was walking or running. Over 700 animal tracks were discovered in the surrounding region, so perhaps we can presume that the individual stopped to monitor animal movements. Any inference is entirely speculative.

Each print within the trackway has different grades of preservation, although all footprints exhibit digit impressions and a clear border. Track 1272 (Fig. 4C) is clearly defined and all features are identifiable (i.

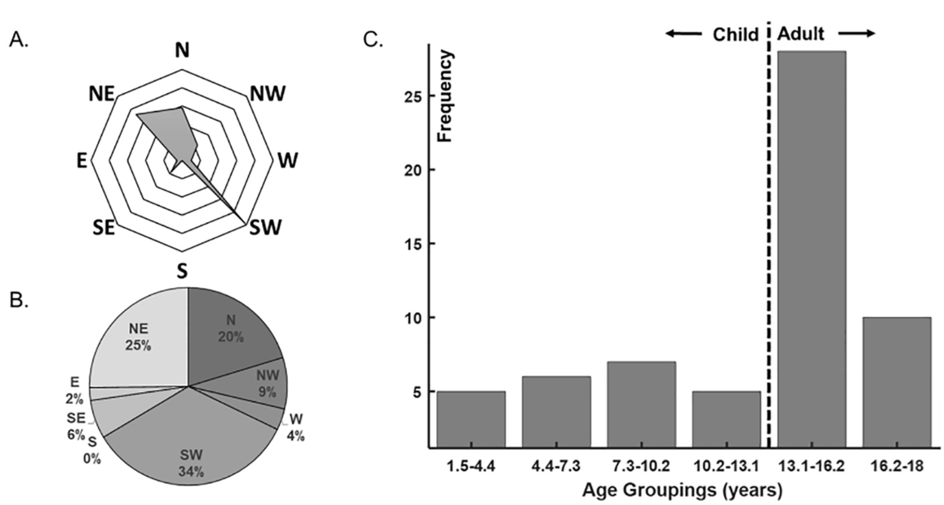

Fig. 3. All footprints (single and within a trackway) from all localities are included for determining direction of travel (A) Rose diagram demonstrating the direction of travel from each locality, with most footprints (34%) travelling in a south-west direction. (B) The frequency of total footprints travelling in each direction (i.e., 25% of trackmakers were travelling in a north-east direction). (C) Frequency of estimated ages from all localities – this data includes single prints which were not associated with any trackway. We cautiously estimated age here, whereby any predicted age above 12 (indicated on the graph by a dashed black line; no trackmaker ages were within the age bracket 12–13.1) was assumed to be an adult. Age predictions for trackways correspond to Table 1.

Table 1
Predicted ages of each trackway-maker (individually impressed footprints are not reported here) following Snyder et al. (1977) and Bennett et al. (2021). Track lengths which were > 220 mm are sexually dimorphic and we report both the estimated male and female age predictions. We do not report any sex determination for track lengths < 200 mm. Trackways 1–3 are from Blundell Path. Trackways 4–6 and 14 are from Blundell Path C. Trackways 7–13 are from Cornerstone. Trackways 16–17 are from Gypsy Path. Estimated ages from Q75 (marked by *) are considered most accurate because these predictions take nutritional differences between modern populations into consideration and thus accounts for potential sources of error in estimating age using modern growth curves for prehistoric populations.

Trackway	Mean Length (mm)	Sex	Predicted Ages Mean	SE	Min	Q25	Q50	Q75*	Max
1	278	Male	16.22	0.16	13.00	15.21	16.17	17.29	18.83
		Female	15.42	0.59	14.58	15.00	15.42	15.83	16.25
2	228	Male	12.08	0.13	6.75	10.92	12.17	13.42	17.92
		Female	13.64	0.15	7.92	11.92	13.58	15.33	18.50
3	214		11.13	0.12	5.75	9.50	10.83	13.17	17.75
4	235	Male	12.57	0.14	8.67	11.35	12.67	13.73	17.33
		Female	13.92	0.13	8.67	12.54	13.67	15.42	18.67
5	257	Male	14.76	0.15	11.00	13.58	14.58	16.17	18.75
		Female	14.43	0.32	9.42	13.21	14.42	15.96	17.58
6	225	Male	11.79	0.13	6.75	10.75	11.67	13.33	15.42
		Female	13.26	0.15	6.92	11.50	13.42	14.75	18.67
7	308	Male	18.36	0.22	17.83	18.21	18.58	18.63	18.67
		Female							
8	253	Male	14.28	0.15	10.17	13.00	14.00	15.25	18.75
		Female	14.09	0.25	9.42	12.81	13.92	15.50	18.00
9	252	Male	14.15	0.15	10.17	13.00	13.88	15.10	18.50
		Female	14.27	0.25	9.42	12.83	14.33	15.75	18.00
10	280	Male	16.37	0.16	13.67	15.42	16.67	17.29	18.83
		Female							
11	278	Male	16.22	0.16	13.00	15.21	16.17	17.29	18.83
		Female	15.42	0.59	14.58	15.00	15.42	15.83	16.25
12	230	Male	12.11	0.14	6.75	10.92	12.25	13.42	17.92
		Female	13.78	0.14	7.92	12.17	13.75	15.33	18.50
13	185		6.90	0.09	3.92	6.08	6.83	7.50	10.67
14	194		8.18	0.10	4.58	7.25	7.96	9.00	14.08
15	122								
16	219		11.98	0.13	7.42	10.17	11.50	13.67	18.67
17	183		6.54	0.09	3.92	5.75	6.42	7.25	10.67

SE = standard error.

e., digits, ball of foot, arch and heel), whereas track 1366 is infilled by debris hindering feature identification. Attempts were made to remove excess material, but removal destroyed the underlying impressions and thus this action was stopped. Nevertheless, the print has clearly defined borders and a hallucal impression. A ridge between the hallux and digit II was also present, suggesting an easily deformable underlying substrate causing an uplift of material upon impression. This impression is also identifiable in other footprints from this trackmaker (Fig. 4C). The other footprints within trackway one had greater preservation quality than 1366, by exhibiting all digit impressions and a clearly defined longitudinal arch (Fig. 4B).

Trackway two: This adult trackway (if ♂ = 13.42 ± 3.34; if ♀ = 15.33 ± 3.29; Table 1) is the deepest of the three trackways from Blundell Path, travelling at a walking pace of $\overline{x} = 1.061$ m.s^{-1} (S.Dev = 0.046 m.s^{-1}). The footprints are firmly impressed into the ground, with trackway three cross-cutting this trackway. Trackway three (age estimate:13.17 ± 3.70; Table 1) is contrastingly very lightly impressed and, consequently, all footprint features are clearly defined (i.e., digit impressions). The differences in footprint formation between these two cross-cutting trackways implies that the trackways were likely formed at different times of the day (although this could also be over a few days), suggesting repeated visits to the site whilst the sediment bed dried and became firmer. We can assume that trackway two was created at a time when the substrate was much wetter and more compliant. As the trackway began to dry and harden, another individual traversed the area, leaving footprints which were more lightly impressed, but also showing clearer morphology. One track from trackway two has been trampled by a larger artiodactyl print, implying that the human trackway was made before the passing of large body-sized artiodactyl (Fig. 4A).

Trackway three: This individual moved in a northerly direction, cross-cutting (i.e., passing successively) other human trackways, but also a medium body-sized artiodactyl trackway that is heavily impressed. The heel border of the human trackway has pushed the ridges of an artiodactyl track laterally away from the foot, indicating that the animal trackway was made prior to the human trackway. The frequency of human and animal prints from Blundell Path implies that the area was densely populated by animals (>700 prints in this area; see also: Burns 2021), with humans regularly moving in the same environment within a short snapshot of time (Fig. 4).

Trackway three is very lightly impressed and, as such, the digit impression is not as clear as the other trackways. However, it is still possible to see digit impressions alongside clear arch and heel imprints (i.e., see track 1303 in Fig. 4C). There is some damage to the bed which cross-cuts one track (1301), but this damage is likely modern owing to damage developing into a crack with a lack of infilled sediment.

Clear definition of digit impressions for all three trackways implies unshod trackmakers, with an estimated MNI of three. There is no evidence of slippage in any of the trackways.

3.2. Blundell Path C

The trackways from Blundell Path C are the longest trackways recovered from Formby Point, measuring 13.151 m (trackway 4; n = 35 footprints) and 12.550 m (trackway 5; n = 24 footprints) long. The trackways are ~ 1.5 m apart in distance, with both individuals travelling in the same direction (north-east). Trackway 4 was travelling at a slow walking pace, $\overline{x}$=0.899 m.s^{-1} (S.Dev = 0.276 m.s^{-1}). Trackway 5 was travelling at a slightly brisker walking speed, $\overline{x}$=1.205 m.s^{-1} (S.Dev = 0.103 m.s^{-1}). The discrepancy in walking speeds implies that the two trackmakers were not walking along side by side, but rather that one was likely following the other, or perhaps walking hours/days apart and following the trail of previous footprints. It is not possible to establish which trackmaker was leading, but both individuals were moving away from the coastline and travelling inland, and both trackways exhibit

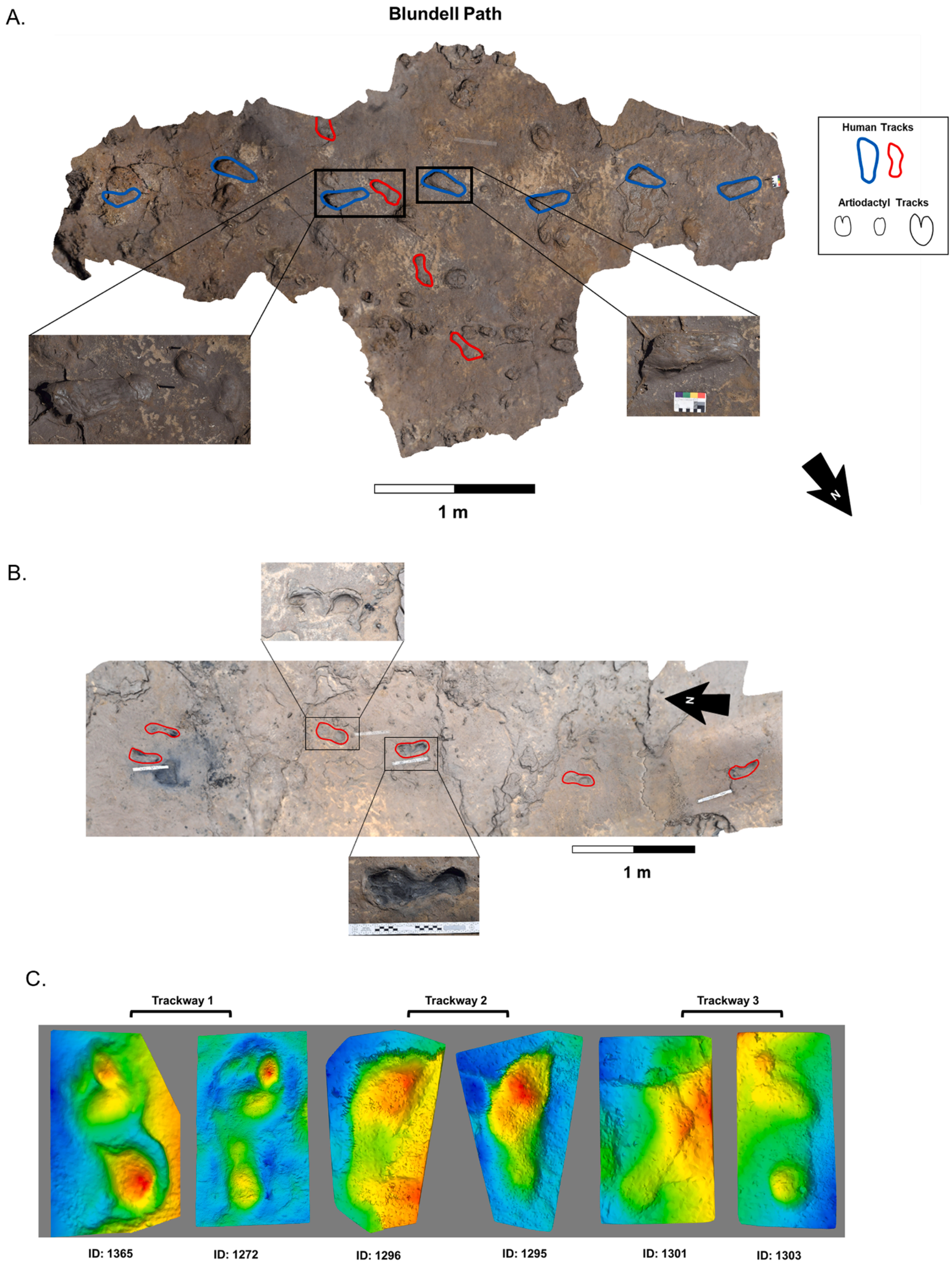

Fig. 4. 3D models of human trackways from Blundell Path, with high resolution orthogonal photographs of select footprints shown. (A) Trackways 1 and 2 are shown, immersed in a collection of animal tracks. Human footprints have been outlined in red and blue, colour associated with each trackway. Numerous animal tracks are visible in the bed. The outlines of the medium and large body-sized artiodactyl tracks have been provided in the figure legend, corresponding to the track outline shapes on the model. (B) Human footprints have been outlined in red. This bed was not excavated by hand, rather it was naturally exposed by tidal action. It is possible to see an overlaying sediment bed cross-cutting the trackway multiple times. It was decided to allow the tide to naturally expose the remaining footprints, but unfortunately after five days the entire bed was destroyed by tidal action (as reported by Wiseman and De Groote 2018), rather than just the overlying sediment. (C) Select footprints with best preservation are shown. Red regions show the deepest parts of each track. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

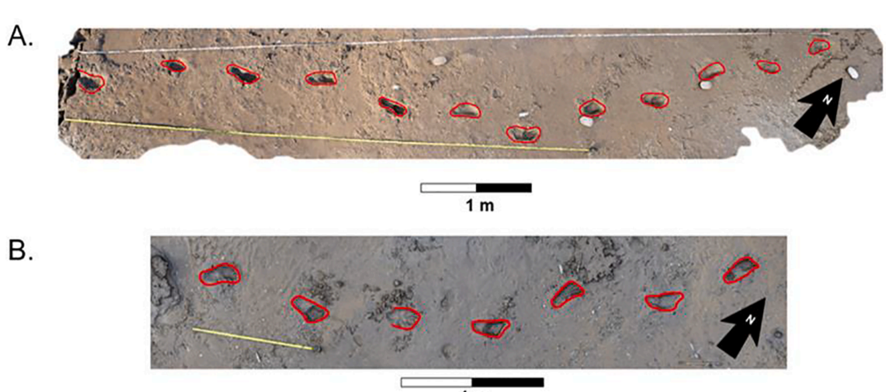

Fig. 5. 3D models of a human trackways from Blundell Path C. Each trackway is outlined in red. Trackway 4 (A), trackway 5 (B). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

similar morphology indicating that the trackways were impressed in similar substrate conditions. There is no evidence of heel slippage, but a deeper forefoot than heel region indicates that the substrates was easily deformable, and potentially slippery. Nevertheless, there are no clear indications of slipping which may have affected biological predictions (see: Wiseman and De Groote 2021). Clear definition of digit impressions for both trackways implies unshod trackmakers, with an estimated MNI of two.

Unfortunately, the trackways were exposed during a spell of very windy weather. Attempts at recording and 3D model creation were made but proved to be difficult and impeded by weather conditions. Wind speeds were quite high the day after natural bed exposure by the high tide, which created an uplift of sand from the nearby sand dunes. Sand was repeatedly blown across the footprints, refilling them with material almost instantaneously after removing other debris. The area was mapped by hand measurements and by few photographs intended for photogrammetric reconstructions (Fig. 5).

3.3. Gypsy Path

The bed was heavily eroded, with much trampling by modern individuals owing to the bed's location on a public beach (Fig. 6). Therefore, the borders of many prehistoric prints were destroyed by overlaying modern footprints, whilst other prints were of poor definition, with few prints tentatively assumed to be human based upon similar characteristics with other footprints but can be best described as elongated hollows.

The Gypsy Path bed has 29 prints in total, of which ~ six form the longest trackway from this locality (age 13.67 ± 3.49), whereas other partial trackways are formed of just two prints each belonging to children < 12 years old (Table 1). However, there is possibly an additional trackway located next to the longer trackway (highlighted in blue in Fig. 6), but upon inspection of the data, both footprints belonged to the right foot, with no clear sign of a left impression. Whilst one might postulate that the individual (which very likely belongs to a child; print length < 220 mm) might be 'hopping' on one foot, as modern children

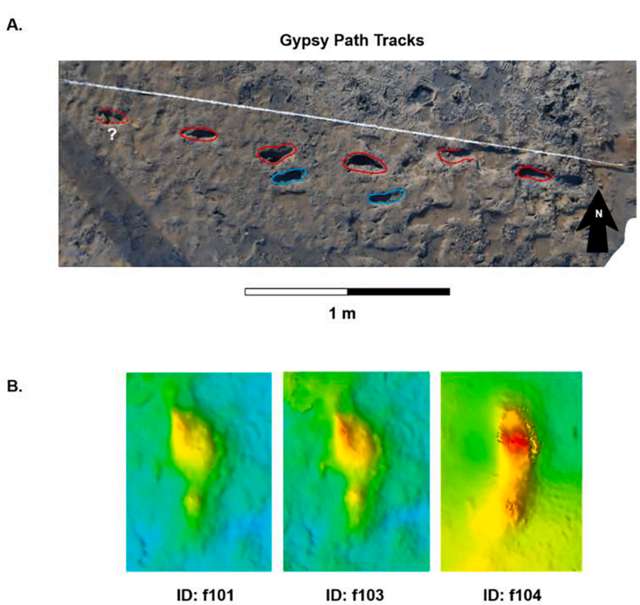

Fig. 6. (A) 3D model of two human trackways from Gypsy Path. One trackway is outlined in red and another in blue. In the top right corner of the 3D model it is possible to see modern footwear impressions made by the excavators and/or members of the public. (B) Select single trackways from Gypsy Path bed which were not associated with any trackway. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

occasionally do, or playing, without additional impressions this remains subjective, and so we tentatively claim that the prints may not belong within the same trackway. There are a mix of trackmaker ages from this bed, although this should be interpreted with caution due to all age estimates being performed on individual prints (see: Belvedere et al. 2021) of which may have succumbed to erosion (thereby making the print borders less defined, leading to a presumed over-estimation in track length) or slippage during footprint creation (thus making the footprint longer than the actual foot). Nevertheless, 21 prints belong to children ranging in age from ~ 1.5 years to > 12 years (Table 1). Assuming that footprint impressions per person did not vary by > 5% in length, there is an estimated MNI of 16 (n = 1 adult; n = 15 children), although see Duveau et al. (2019). This figure should be interpreted with caution due to (1) the poor definition of many of the prints likely introducing slight measurement error and (2) potential traces of slippage in six footprints that could have inflated biological predictions (i.e., Wiseman and De Groote 2021).

Only 11 footprints exhibited partial digit definition which was only the hallucal impression (i.e., see print f101 in Fig. 6B). The other 18 footprints have poor anatomical definition with a cone-shaped impression around the digits (i.e., see track f104 in Fig. 6B). Similar shapes have been reported from Cussac in France, dated to 28–31 ka cal BP (Ledoux et al. 2021). It was postulated that these footprints may have exhibited traces of shod trackmakers. To test this, the Cussac footprints were compared to experimentally generated footprints which were clad with various types of footwear, ranging from straw-stuffed clad leather to simple leather binding. It was concluded that the Cussac trackmakers were likely wearing footwear whilst moving through the cave (Ledoux et al. 2021). Similarities in track shape in the proximal foot impression region between Cussac and some of the Gypsy Path footprints might indicate the presence of footwear at this locality, but this will require further experimentation of similar substrates, hydrology and also of trackmaker age (i.e., are there any distinct differences in impression shape in children versus adults?) to confirm.

3.4. Cornerstone Path

There were a total of seven trackways from Cornerstone Path (trackways 7–13). This locality also produced a double trackway (trackways 10 and 11; Supplementary Information 1), composed of two individuals walking in the same direction on a slippery substrate (Fig. 7). The footprints are quite deep (>22 cm deep), with trace evidence of slipping around the heel borders. Trackways 7, 9–13 are all 'true' footprints. They do not penetrate into the underlying layer. This was evident via damage to the bed borders which cross-cuts through one print, demonstrating just a single print-bearing layer. Three footprints from trackway 8 are instead 'under-prints' (also known as 'transmitted prints'), in which these traces are preserved in the underlying level.

Despite the slippery substrate, the estimated speed for trackway 10 (red in Fig. 8) was $\bar{x}$ = 2.672 m.s^{-1} (S.Dev = 0.615 m.s^{-1}) and for trackway 11 was $\bar{x}$ = 1.991 m.s^{-1} (S.Dev = 0.144 m.s^{-1}), which are both a steady running speed. We present two scenarios: the first is that the individuals were indeed running across this substrate, or that the slipperiness of the substrate has over-emphasised the heel borders of each individual print, resulting in 'longer' footprints causing over-estimation of stature ($\bar{x}$ = 1870 mm in trackway 10; $\bar{x}$ = 1830 mm in trackway 11; see Supplementary Information 1) and, subsequently, of stride length.

We compared these trackways to those of experimental footprints. In the experimental data, the heel is typically the deepest portion of the trackway from all speeds, although the digits are deeply impressed in walking speeds. In a fast walk, this becomes more medially impressed than in a slower walk. In the jog, the lateral digits are almost 'missing', with a deeply impressed heel and well-defined mid-foot arch. A noticeable trend is also apparent whereby as speed increases, then the mid-foot arch increases in prominence.

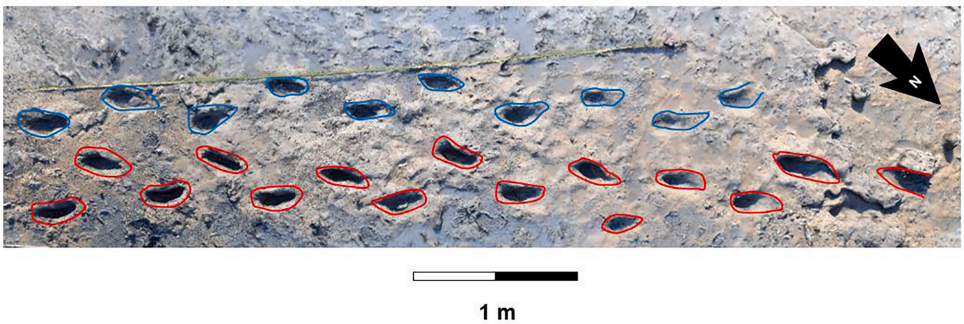

Fig. 7. 3D model of two human trackways from Cornerstone. Trackway 10 is outlined in red and trackway 11 in blue. The footprints were particularly deep (>22 cm deep) with uneven track borders, resulting in difficulty in 3D modelling of the trackways – unfortunately it was not possible to build accurate 3D models with the track bases full present without some interpolation of the meshes (e.g., Larsen et al. 2021). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

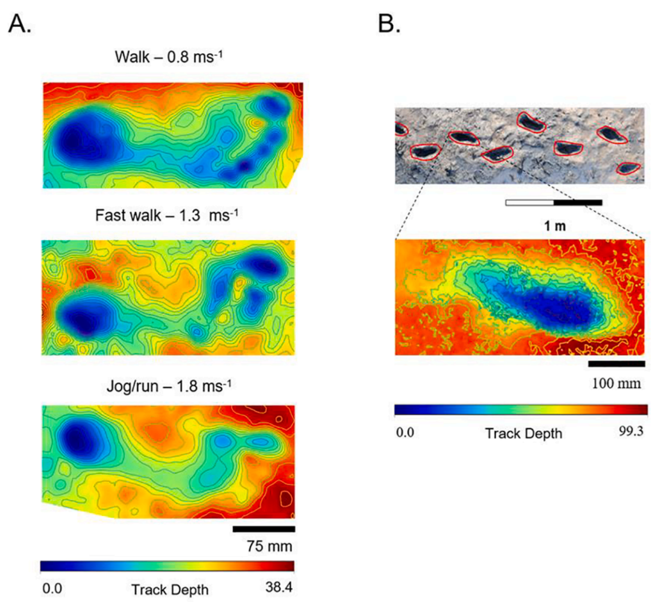

Fig. 8. Morphological comparisons of modern example data (A) to that of an example track from Cornerstone trackway 10 (B). Modern data was collected from an individual whom had the same foot length and stature as the predicted measurements from the prehistoric trackmaker. For all footprints, the posterior region (heel) is towards the left and the anterior region (digits) is towards the right.

Upon comparison with the Cornerstone footprints (one example is provided in Fig. 8B), It is possible to establish that the prints are deeper, likely influencing the walls of the prints. We can assume that as the foot hit the ground, it slid backwards during stance and into push-off, thereby influencing the depth distribution of the prints. Nevertheless, it is possible to note that the digits are not clearly defined and that the deepest part of the print is in the (medial) ball of the foot. Therefore, we can assume that the individual was not moving at a slow speed if we use the modern data as a benchmark (i.e., the modern print is well-defined on the lateral border at a slow walk, but not for the Formby Point print). Generally speaking, morphological comparisons suggest that the Formby Point print most closely resembles an individual fast walking. However, this conclusion does not take into consideration how kinematics of the limb may influence print shape (e.g., Hatala et al. 2018), nor the effect that slippage traces likely had on overall print definition (e.g., Wiseman and De Groote 2021).

We infer that the trackmakers were walking briskly (perhaps jogging/slow running) in a north-east direction, with one individual moving ahead of the other, and the other trailing behind. The trackways are often < 10 cm apart, which would suggest that the individuals were not walking side by side. At such close proximities, the two individuals would likely be bumping into each other, implying one individual was leading the way inland.

Three additional trackways were also discovered at Cornerstone on the same bed, but these were located in different level (Fig. 9). Trackway 8 (in yellow; Fig. 9) is visible across both levels of Bed I (i.e., three prints are present in Bed I level I in which trackways 10–11 are located in, but the remainder of the trackway is in level II). The first three prints in the lower level (level I) are under-prints rather than 'true' tracks. It is not possible to know the time period between different level formation without sampling the sediments, but it does permit an insight into repeated visits of the same area by this Neolithic population over a prolonged period.

A partial trackway consisting of just ~ two poorly defined footprints (shown in purple in trackway 7; Supplementary Information 1) was determined to belong to an adult, moving south-east. The other two trackways (trackways 8 and 9) are parallel to each other, but are moving in opposite directions, similar to trackways discovered at White Sands National Park, USA (Bennett et al. 2020). Trackway 7 had the largest track length and was likely impressed by an adult male (Table 1) and travelling south-east (leading inland). Trackways 8 and 9 were instead travelling north-west (which would at some point eventually lead to the coast). Perhaps one individual was following the impressions left by the other to lead back to a desired location. Trackways 8 and 9 were much more deeply impressed than those of trackway 7, indicating that they were likely made first on the sediment (travelling towards the coast), with the other individual following the trackways sometime later when the bed had begun to dry and somewhat harden (travelling inland). Trackways 8 and 9 were of a good preservation quality, with all footprints exhibiting defined hallucal impressions and tapering of the heel. Other digit impressions were not evident.

Due to time pressures of the incoming tide, trackways 12 (adult) and 13 (child) were not digitally recorded and, unfortunately, the following day the tide had destroyed the bed. Only simple linear measurements were captured for these two trackways (Supplementary Information 1; Table 1), and speed estimates were not possible. The individuals were both travelling south-west. Overall, the estimated MNI of the Cornerstone locality was seven.

4. Future directions: Community science

There are two types of footprint sites: integrity sites and exposure sites. Integrity sites are typically within a small area, with comparatively fewer discoveries in which every footprint is important and must be documented. Such examples can be found at Laetoli in Tanzania (e.g., Leakey and Hay 1979). Preservation attempts are possible in such sites, and are often successful. The Laetoli footprints which were discovered in 1976 were successfully protected and are still available today, >40 years later (Masao et al. 2016). Exposure sites, on the other hand, can be extensive in which serendipity plays an important role in the natural exposure of track-bearing sediments. Such sites can yield many footprints, although it can be challenging to record every footprint prior to its destruction. Unfortunately, exposure sites cannot be preserved *in situ*

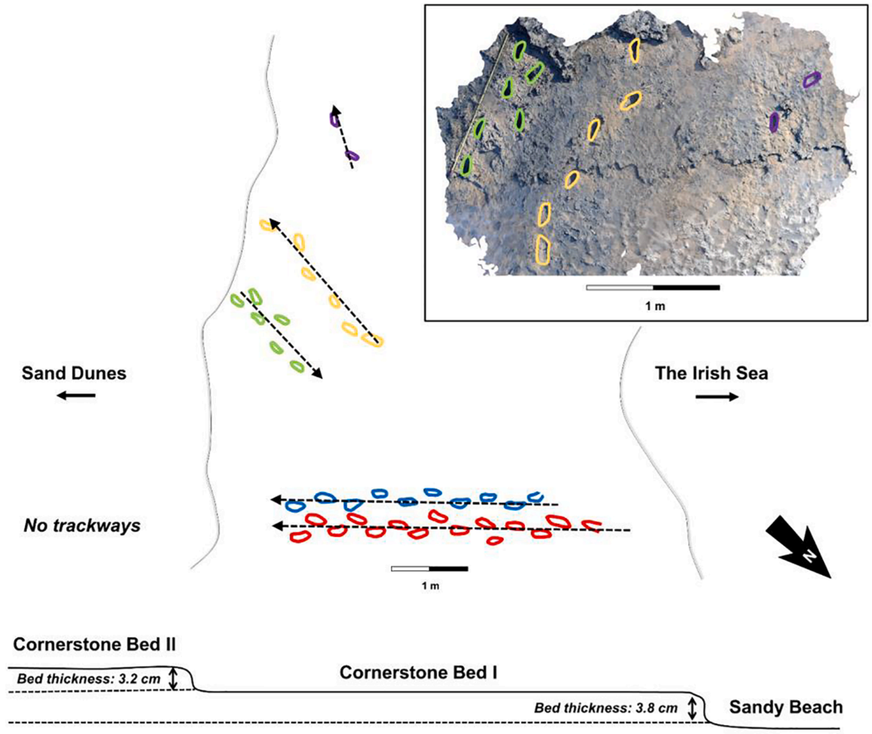

Fig. 9. Diagram of all trackways from Cornerstone, alongside arrows indicating direction of travel. Trackway colour-coding corresponds to the outlined footprints in Fig. 8 and the 3D model example shown in the cut-out box here in which one trackway is outlined in green, one in yellow and another in purple. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and attempts at removal can be costly, and so we must focus our efforts towards *digital preservation* (i.e., Falkingham et al. 2018). An example of this is the site of Happisburgh, England in which the track-bearing sediments were destroyed within weeks of their exposure but digital representations of the footprints exist (Ashton et al. 2014; Wiseman et al. 2020a). Exposure sites which repeatedly reveal footprints over time, require long-term discussion and recording to expose the true dynamics of the site. We must aim to continue to document ongoing discoveries at such sites.

Formby Point is as an exposure site in which natural erosion is beneficial to the history and public enjoyment of the site. The latter point here is of great importance: the public actively engage with the footprints and regularly enjoy National Trust led tours along the beach to go ‘fossil footprint hunting’ (in summer, these tours are weekly). The natural erosion of the sediment beds continuously exposes more and more footprints, and the public have already shown a keen interest to engage with the site. The Blundell Path discovery in summer 2016 was reported in local newspapers to the great delight of the public – many of whom came to visit the site. Children and adults alike were keen to learn about the footprints and the methods ichnologists use for analysis. Evidently, public engagement at Formby is an ‘untapped resource’. Those of us who research these footprints – and also for future exposure site discoveries – should be encouraging the public to participate as ‘citizen scientists’ (i.e., Bonney et al. 2014) to maximise our collective knowledge about the site. We should train the public how to record the footprints, which is easily achieved using a smartphone with an in-built camera to capture photographs (e.g., Larsen et al. 2021) and easy-to-use freeware (e.g., DigTrace Pro) to create 3D models of the footprints. Student-led projects could be readily implemented in local schools which could involve a morning on the beach searching and recording the footprints, followed by an afternoon in the classroom quickly and easily using photographs from a smartphone to generate a 3D model and then learning about the prehistory of the local area. These 3D models could be uploaded to a range of free online repositories (copyright permitting with the National Trust), or emailed to the National Trust and/or any expert in ichnology, such as the authors of this paper so that specialists and non-specialists can work together to advance our knowledge of the area.

The frequency of discoveries at Formby will eventually reveal the dynamics of the site over time, but to achieve this goal we must work together with the public to record the footprints.

4.1. Conclusion

The prevalence of the sediment beds that are continually appearing with the tide suggests that further footprints will be uncovered in the future to add to the ever-growing database of the Formby Point trackways. We discuss here additional discoveries from Formby Point and report on the prevalence of human footprints, immersed in a large collection of animal prints. We also highlight that most prints were travelling south-west towards the coastline, followed by a large selection of prints travelling north-east inland. We can only speculate on these behaviours, gathered from four sites and representing at least 12 trackways. Perhaps the individuals were heading towards the coastline for hunting/foraging activities, and then moving back inland towards shelter. Unfortunately, no material culture has ever been found in this vicinity, so this assumption remains unverified. Nevertheless, so many trackways travelling consistently in the same directions does offer credence to our hypothesis of a potential shelter/base nearby.

The presence of adult and child footprints adds to the ever-growing discovery of such interactions discovered in coastal locations (e.g., Ashton et al. 2014; Duveau et al. 2019; Mayoral et al. 2021). Child trackways were determined to be mostly travelling in specified directions, but other footprints, such as those from Gypsy Path, follow no pattern, other than to provide us with an insight into the trace evidence of children during the Neolithic.

Overall, these field seasons at Formby Point have unearthed new trace prehistoric interactions, of which we see the following for the first time:

(1) Trace evidence of an individual presumably travelling at greater speeds, then coming to a stop with both feet side by side.
(2) Trace evidence of many individuals from four different localities travelling in the same directions, potentially embarking on inward (coastline-bound) and outward (inland-bound) journeys.

CRediT authorship contribution statement

Ashleigh L.A. Wiseman: Conceptualization, Data curation, Methodology, Data collection, Model Creation. **Deborah Vicari:** Data collection, Model Creation. **Matteo Belvedere:** Methodology. **Isabelle De Groote:** Conceptualization, Supervision, Funding acquisition. All authors contributed to writing the manuscript and approved the final draft

Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2022.103546. 3D models of the footprints are freely available for other research use and can be accessed via DOI: https://doi.org/10.17863/CAM.86283.

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