**SUPPORTING INFORMATION TEXT S1: Dalmatian Pelican spatiotemporal distribution in the British Holocene record**

### *East Anglian Fens*

The first pelican bone reported in Britain was a left humerus from Burwell Fen in the North Cambridgeshire Fens (Newton 1868, 1871), described by Milne-Edwards (1868a, 1868b). Milne-Edwards (1868a, p. 166) noted it represented a young individual which must have originated from a local breeding population. The bone was 'of very considerable dimensions' (Milne-Edwards 1868a, p. 166), and larger than comparative available modern humeri from several pelican species, including Dalmatian Pelican and Great White Pelican, the two living European species; Milne-Edwards (1868a) concluded it was referable to *Pelecanus* but not attributable to species. Its stratigraphic position was unknown, but Milne-Edwards (1868b, p. 364) thought its 'colour and nature' indicated it came from a peat horizon also containing a diverse vertebrate assemblage. A direct date of 3920±60 BP (GrA-27417) was obtained on Red Deer antler from this horizon by Loveday *et al*. (2007), but these authors suggested that low collagen yield and $\delta^{13}C$ values indicated possible contamination, recommending caution over this date. More recent direct AMS dates spanning 5210-4247 cal BP (OxA-11088, 11090, 11093, 11218, 33529) were reported on beaver bones from Burwell Fen (Marr *et al*. 2018).

An adult left humerus was unearthed in 1870 at Feltwell Fen, Norfolk (Newton 1871). No within-site location or context was recorded. Newton noted that, although large, the Burwell and Feltwell Fen specimens were comparable in size to a modern specimen (probably *P. crispus*) from Romania. Two dates (material unreported, probably plant macrofossils) are available for Feltwell Fen: 4135±70 BP (Q-2548) for

the transition from freshwater peat to marine-deposited clay, and 3815±70 BP (Q-2551) for return to freshwater peat deposition (Waller 1988). Dalmatian Pelicans are typically associated with freshwater rather than marine environments (Catsadorakis & Portolou 2018), so the specimen is probably older than the earlier date or younger than the later date.

Harmer (1897) reported a pelican distal humerus and proximal radius and ulna discovered several years previously at Burnt Fen, Cambridgeshire. The specimens were found alongside beaver, pig, swan, goose and pike, with no further context reported. The humerus closely resembled previously discovered specimens, and were similar to Newton's (1871) *P. crispus* reference specimen.

Newton (1901) discovered an additional pelican distal tarsometatarsus within the original Burwell Fen collection, probably from the same peat horizon based upon colour and condition. Comparison with Newton's (1871) reference specimen suggested it was probably Dalmatian Pelican.

Forbes *et al*. (1958) described three fused thoracic vertebrae from a flood relief channel half a mile north of Saddle Bow, near King's Lynn, Norfolk, which they assigned only to *Pelecanus*. It was probably from the site's peat bed, although precise location or context are lacking. Pollen analysis of peat scrapings from the bone placed it within a period of saltmarsh replacement by freshwater fen but prior to growth of fen woodland ('Godwin's pollen zone VII-VIII'), correlated with the Iron Age by Forbes *et al*. (1958). These authors re-examined all known East Anglian pelican bones and compared them with several *P. crispus* and *P. onocrotalus* skeletons, revealing they all overlapped in size with *P. crispus* and two probably male *P. onocrotalus* skeletons. They suggested most East Anglian pelican wing bones represent '*Pelecanus* of uncertain species' (Forbes *et al*. 1958, p. 154), but noted the Burwell Fen tarsometatarsus had a projecting hypotarsus

and small posterior face that matched the morphology of *P. crispus*, supporting its identification as Dalmatian Pelican.

Three bones (carpometacarpus, two first phalanges) were unearthed at the Cat's Water subsite, Fengate, near Peterborough (Biddick 1984, Pryor 1984), apparently from Iron Age and/or Romano-British levels. The largest set of remains from the Fens was discovered at the Haddenham V archaeological site, Cambridgeshire (Evans & Hodder 2006). Serjeantson (2006) described 18 bones from the Iron Age part of the site, which is radiocarbon dated to between c. 350 cal BC and AD 130 (Evans & Hodder 2006). No juvenile bones were found, although the large sample suggests pelicans may have bred nearby. Cut-marks on several bones suggest feather removal and butchery (Evans & Hodder 2006). Bones at both sites were assigned to *P. crispus*, with Haddenham V specimens compared with *P. crispus* reference specimens.

A right tarsometatarsus and scapula were unearthed alongside numerous faunal remains showing signs of breakage and butchery, from an Iron Age midden-platform feature at Godwin Ridge, Over, Cambridgeshire (Evans 2013, Evans *et al*. 2016). Direct dates on human bone associated with this feature span the Iron Age, with adjacent human remains providing even younger direct dates (Evans *et al.* 2016).

The youngest finds from the Fens are a distal right humerus and radius from a Romano-British settlement (the 'Camp-Ground', a major inland barge-port) at Colne Fen, Earith (Regan *et al*. 2004, Evans 2013), with one associated with Phase III (AD 270-350) and one with Phase IV (AD 350-410) of the Roman Period (Regan *et al*. 2004). Species identification was uncertain, but comparison with biometric data in Bulleid and Gray (1917) suggested the humerus was probably *P. crispus*. We have revisited the Colne Fen collection and found an additional likely fragmentary pelican digit associated with other bone fragments (Supplementary Information Table S1).

***Somerset Levels and Moors***

At least 48 pelican bones were discovered at the Iron Age Glastonbury Lake Village, alongside a diverse wetland mammal and bird assemblage (Bulleid 1894, Andrews 1899, Bulleid and Gray 1917; Table 1). Andrews (1899) reported at least five individuals; reanalysis of material by the authors indicates at least seven individuals are represented based upon number of left humeri. Many bones were from young birds, indicating pelicans bred locally and were used for food (Andrews 1899). Andrews (1899) compared bones with modern *P. crispus* and *P. onocrotalus* specimens, reporting they resembled *P. crispus* and were longer and more robust than *P. onocrotalus*. Forbes *et al*. (1958) re-examined eight tarsometatarsi, finding that five retained the taxonomically diagnostic hypotarsus and were all *P. crispus*.

Information on the context of animal bones from Glastonbury is limited. Pelican bones were recorded from south of the Mound 5 palisade (excavated 1897; spans the site's Early, Middle and Late phases), and from Mound 85 (excavated 1907) (Bulleid & Gray, 1911, 1917, Coles & Minnitt 1995). This latter feature is a possible animal enclosure from the site's Late Phase, raising the possibility that pelicans might have been corralled within the structure; however, bones were reportedly recovered under rather than within the mound, making their association with this feature uncertain (Coles & Minnitt 1995). The site is radiometrically constrained to between 180 cal BC and 20 cal BC (Marshall *et al*. 2020). However, the imprecise recorded context of pelican specimens makes it difficult to reconstruct whether they were locally present throughout the site's occupation history.

A distal tibiotarsus was found in 1971 at a nearby site, the Mound at Wirral Park Farm, Glastonbury (Darvill & Coy 1985). The specimen was found in a horizon (Area 1,

F24) that also yielded bones of red deer, beaver and swan, as well as domestic fowl, goose, horse, cattle, pig, sheep/goat and cat. The Mound site was occupied from Roman to Early Medieval times, with evidence of earlier Neolithic and early Bronze Age habitation (Carr 1985). Species-level identity was not determined, although comparison with *P. crispus* and *P. onocrotalus* specimens indicated the tibiotarsus had thicker bone walls than modern specimens, suggesting the larger Dalmatian Pelican. Its context was assigned to Medieval layers (10th-12th century AD) based on overlying pottery sherds (Carr 1985), making it possibly the most recent British pelican specimen by about a thousand years. However, Serjeantson (2010, p. 150) considered that "without confirmation from a radiocarbon date, it is best regarded as reworked from the Iron Age".

***Humber Valley***

A distal femur was unearthed during excavations at King George Dock, Hull (Newton 1928). Its stratigraphic context is uncertain, but its colour and condition resembled bones from the site's peat bed; no information is available for this layer's age. Unfortunately, the specimen was probably lost during an air raid in World War II, when the Albion Street Museum was destroyed (Sheppard 1929; P. Gentil, pers. comm., 14 September 2020).

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**SUPPORTING INFORMATION TEXT S2: Modelling methods**

***Climatic niche modelling***

Holocene and current-day (1979-2013) climate data were downloaded from PaleoClim (Brown *et al*. 2018), which subdivides the Holocene into the Greenlandian, Northgrippian and Meghalayan. Downscaled future climate data from CMIP6 were downloaded from WorldClim (Eyring *et al*. 2016). Five General Circulation Models (GCMs) from different model families (CNRM-CM6-1; FIO-ESM-2-0; HadGEM3-GC31-LL; INM-CM4-8; MPI-ESM1-2-HR) were selected for each future period, representing a range of uncertainty and excluding models considered unsuitable for Europe (McSweeney *et al*. 2015, Sanderson *et al*. 2015). Model selection was conducted using the Shared Socioeconomic Pathway 2 (Riahi *et al*. 2017). All five GCMs were averaged to produce a single climatic projection for each future period.

As all available indirect dates associated with pelican records fell partially or wholly within the Meghalayan period, climate data for all pelican localities were extracted specifically from this climatic period using the *dismo* package (Hijmans *et al*. 2011) in R v.4.1.0 (R Development Core Team 2021).

The 'maxent' command in the *dismo* package was used to model the association between localities and climatic variables. Maxent is a machine-learning method suitable for modelling species distributions using presence-only data (Elith *et al.* 2011), and is robust to relatively small sample sizes (Pearson *et al*. 2007, Wisz *et al*. 2008). Default settings were used due to low sample size (Elith *et al*. 2011) and five-fold cross-validation was used to train and test the model. Model fit was assessed using the receiver operator characteristic (ROC) curve, with area under the curve (AUC) values.

***Optimal linear estimation***

OLE was implemented following Solow (2005) in R v.4.1.0 (R Development Core Team 2021). A single date was used for each site to represent a temporal 'sighting event'. Estimated date intervals were obtained for each 'sighting', from associated calibrated radiocarbon dates (e.g. 4840–4444 cal BP for Feltwell Fen) or from estimated dates of British archaeological periods (e.g. Iron Age: 800 BC–AD 43) based upon Historic England's Periods List (http://heritage-standards.org.uk/wp-content/uploads/2015/08/Periods-List-HE-FISH-WP.pdf). Where multiple associated dates were available, oldest and youngest dates were used. All dates were converted to years BP for analysis. Two sites of unknown age (Burnt Fen, King George Dock) were excluded from analysis.

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**Supplementary Information Table S1.** Measurements of pelican bones (mm) at various UK insitutional collectio
*archaeological sites. Peabody Museum Bulletin I* . In cases where there is a partial fracture, only the available m
= Medial length; Bb = Basal breadth; Bp = Breadth of the proximal end; Dp = Depth of the proximal end; SC = Sm
end; Did = Diagonal of the distal end; Bpacr = Breadth across the Processus articulares craniales; Bpacd = Bread
Processus articulares caudales; BA = Breadth in the middle ; AA = Breadth between the borders of the acetabula

| Institutional collection | Site | Latitude | Longitude |
|---|---|---|---|
| Sedgwick Museum of Earth Sciences, Un | Burwell Fen, North Cambridge Fens | 52.303589 | 0.287558 |
| Sedgwick Museum of Earth Sciences, Un | Burwell Fen, North Cambridge Fens | 52.303589 | 0.287558 |
| Sedgwick Museum of Earth Sciences, Un | Great Ouse (Flood Relief Channel), 1/2 mile nc | 52.72315 | 0.379525 |
| Museum of Zoology, University of Cambı | Burnt Fen, Littleport, Cambridgeshire | 52.441478 | 0.377853 |
| Museum of Zoology, University of Cambı | Burnt Fen, Littleport, Cambridgeshire | 52.441478 | 0.377853 |
| Museum of Zoology, University of Cambı | Burnt Fen, Littleport, Cambridgeshire | 52.441478 | 0.377853 |
| Museum of Zoology, University of Cambı | Feltwell Fen, near Brandon, Norfolk | 52.487997 | 0.448736 |
| Cambridgeshire County Council Archaeo | Colne Fen, Camp Ground, Earith, Cambridgesh | 52.385561 | 0.024261 |
| Cambridgeshire County Council Archaeo | Colne Fen, Camp Ground, Earith, Cambridgesh | 52.385561 | 0.024261 |
| Cambridgeshire County Council Archaeo | Haddenham V, Haddenham, Cambridgeshire | 52.339586 | 0.072611 |
| Cambridgeshire County Council Archaeo | Haddenham V, Haddenham, Cambridgeshire | 52.339586 | 0.072611 |
| Taunton Heritage Trust | Lake Dwellings, Glastonbury | 51.163611 | 2.725833 |
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| Taunton Heritage Trust | Lake Dwellings, Glastonbury | 51.163611 | 2.725833 |

ns in accordance with methods published by: *von den Driesch, A. I97*
easuring points were recorded. P & D denotes proximal and distal en
allest breadth of the corpus; Bd = Breadth of the distal end; Dd = De
th across the Processus articulares caudales; GLPa = Greatest length
, measured at narrowest part

| **Specimen number** | **Element** |
|---|---|
| D.5760 | left humerus (young individual) |
| D.5761 | right tarsometatarsus |
| D.5762 | 3rd, 4th, 5th fused thoracic / synsacral verte |
| UMZC 258.D | partial left humerus |
| UMZC 258.D | radius |
| UMZC 258.D | ulna |
| UMZC 260.a | left humerus |
| 7240/7242 | right humerus (distal), radius |
| 7287 | possible digit (probably same individual as 7 |
| 22161 | radius |
| 22161 | ulna |
| 252/1987/1019 F10 | left tarsometatarsus |
| 252/1987/1435 BB5 | left humerus |
| 252/1987/1021 AA2 | left tarsometatarsus |
| 252/1987/1018 K15 | right femur |
| 6 | left femur |
| 252/1989/1437 I29 | left tibiotarsus |
| 252/1987/1450 AA24 | right radius |
| 252/1987/1438 K14 | left femur |
| 252/1987/1445 | left tibiotarsus |
| 252/1987/1443 K2 | right coracoid |
| 252/1987/1447 K5 | left coracoid |
| 252/1987/1452 BB33 | left femur |
| AA14 | right tarsometatarsus |
| 252/1987/1023 F5 | right tarsometatarsus |
| Unlabelled | right tarsometatarsus |
| 252/1987/1436 F6 | right tarsometatarsus |
| 252/1987/1436 K12 | left tibiotarsus |
| 252/1987/1434 AA16 | left humerus |
| 252/1987/1451 BB20 | left tibiotarsus |
| 252/1987/1433 AA18 | left humerus |
| 252/1987/1440 BB7 | right ulna |
| 252/1987/1446 I7 | right carpometacarpus |
| 252/1987/1444 K13 | left femur |
| 252/1987/1448 BB29 | right femur |
| Unlabelled | left humerus |
| 252/1987/1449 BB10 | left tibiotarsus |
| 252/1987/1430 AA17 | right humerus |
| 252/1987/1447 BB11 | left ulna |
| 252/1987/1439 BB2 | left humerus |
| 252/1987/1431 BB3 | right humerus |
| 252/1987/1441 I17 | right tibiotarsus |
| 252/1987/1424 K17 | left femur |
| Unlabelled | pelvis |
| 252/19871022 F7 | left tarsometatarsus |
| 252/1987/1025 AA15 | left tarsometatarsus |
| 252/1987/1024 K19 | left tarsometatarsus |
| 252/1987/1026 | large unidentified fragment (sternum?) |
| GG | pelvis |
| Unlabelled | three fragments: one possible ulna (based o |
| Unlabelled | likely digit based on modern pelican skeleto |

*'6. A guide to the measurement of animal bones from*
ıds of bones. GL = Greatest length; La = Axial length; Lm
pth of the distal end; Dip = Diagonal of the proximal
from the Processus articulares craniales to the

| Condition | GL | La | Lm | Bb | Bp |
|---|---|---|---|---|---|
| eroded entire | 363.14 | | | | 62.85 |
| good condition, hypotarsus intact | 131.54 | | | | 26.31 |
| ebrae | | | | | |
| fractured in P | | | | | |
| fractured in P | | | | | |
| fractured in P | | | | | |
| very well preserved with little erosion | 364.91 | | | | 63.85 |
| fractured and only D remaining. There was no obvious evidence of the reported radius, but within the specimen bag | | | | | |
| fractured and eroded | | | | | |
| eroded and fractured in D but pieces clearly fit | 410.64 | | | | |
| fracture to shaft in P and cracked entire length | 425.65 | | | | 32.51 |
| eroded D and P, particularly trochlea and hypotarsus | 122.32 | | | | 22.54 |
| fragmented in both D and P | | | | | |
| intact with only slight erosion | 125.92 | | | | 26.83 |
| erosion in D and P, crack to shaft towards D | 119.08 | | 115.09 | | 27.98 |
| intact with only slight erosion | 125.25 | | 119.25 | | 32.52 |
| erosion in P | 184.02 | | | | |
| fractured in D but eroded in P | | | | | |
| erosion to P and D | 132.33 | | 127.51 | | 29.33 |
| fractured in P, erosion to fibular crest | | | | | |
| fractured at sternal, erosion to entire | 125.46 | | | | |
| erosion on entire | 139.14 | | 131.03 | 63.52 | |
| probable juvenile, fragmented and no measurements available as lateral condyle and entire P missing | | | | | |
| slight erosion only | 121.44 | | | | 23.14 |
| slight erosion, more so in P | 122.55 | | | | 24.57 |
| very little erosion or damage | 124.13 | | | | 25.64 |
| heavily eroded in P, hypotarsus missing | 125.93 | | | | 25.63 |
| fractured in P, eroded in D | | | | | |
| eroded in P and D | 320.34 | | | | 46.45 |
| juvenile, heavily eroded | 155.94 | | | | |
| fractured at P, small fracture to D | | | | | |
| fractured in D and P | | | | | |
| slight erosion, missing metacarpal III | 176.33 | | 172.58 | | 37.01 |
| heavily eroded | 121.31 | | 119.18 | | 24.3 |
| fractured in P, heavily eroded in D | 16.39 | | | | |
| slight erosion, more so in P | 363.02 | | | | 66.01 |
| probable juvenile, heavily eroded, cracked in D | 128.99 | | | | |
| fractured in P, heavily eroded in D | | | | | |
| fractured in D and P | | | | | |
| fractured in D and P | | | | | |
| fractured in D and P | | | | | |
| erosion especially in P, fracture to shaft at P end | 195.37 | 189.7 | | | |
| eroded and partial fracture to D, internal and external condyle missing | | | | 24.8 | 19.48 |
| slight erosion and fractured at waist | | | | | |
| only slight erosion | 123.07 | | | | 24.97 |
| fractured at P | | | | | |
| fracture on D, external condyle missing, erosion on enti | 103.26 | | | | 26.87 |
| probable *Pelecanus crispus* no measurements taken | | | | | |
| fragmented therefore no measurements taken | | | | | |
| ın presence of nutrient hole), one large fragment of possible coracoid, final a leg or wing bone fragment (possibly par | | | | | |
| eroded in P and D, no measurements taken | | | | | |

| Dp | SC | Bd | Dd | Dip | Did | Bpacr | GLPa | Bpacd | BA |
|---|---|---|---|---|---|---|---|---|---|
| | | 22.39 | 46.78 | | | | | | |
| | | 11.91 | 27.31 | | | | | | |
| | | | | | | 31.86 | 31.03 | 26.5 | |
| | | 23.84 | 51.34 | | | | | | |
| | | 11.02 | | | | | | | |
| | | 25.29 | 37.69 | | 40.08 | | | | |
| | | 24.34 | 52.74 | | | | | | |
| ; were multiple additiona | | | 53.34 | | | | | | |
| | | 10.85 | 19.79 | | | | | | |
| | | 15.56 | | 38.14 | 30.03 | | | | |
| | | 11.85 | 26 | | | | | | |
| | | 19.89 | | | | | | | |
| | | 11.97 | 26.74 | | | | | | |
| | 19.06 | 14.2 | 31.05 | 19.62 | | | | | |
| | 22.79 | 14.81 | 33.89 | 22.82 | | | | | |
| | | 13.62 | 25.9 | 28.57 | | | | | |
| | | 11.71 | | | | | | | |
| | 24.31 | 16.13 | 34.06 | 19.13 | | | | | |
| | | 14.58 | 23.58 | 6.4 | | | | | |
| | | 11.21 | 23.82 | | | | | | |
| | | 11.54 | 24.59 | | | | | | |
| | | 11.94 | 26.76 | | | | | | |
| | | 13.29 | 27.64 | | | | | | |
| | | 14.63 | 24.27 | 25.75 | | | | | |
| | | 19.95 | 39.9 | | | | | | |
| | | 12.49 | 23.7 | 14.14 | | | | | |
| | | 20.25 | 45.45 | | | | | | |
| | | 13.14 | | | | | | | |
| | | | | | 27.32 | | | | |
| | 21.94 | 13.95 | 30.97 | 17.05 | | | | | |
| | | | 34.3 | 22.94 | | | | | |
| | | 23.82 | 49.5 | | | | | | |
| | | 10.79 | 19.27 | 11.14 | | | | | |
| | | 22.04 | 42.72 | | | | | | |
| | | 13.72 | | | | | | | |
| | | 20.72 | | | | | | | |
| | | 20.24 | | | | | | | |
| | | 14.59 | 25.83 | 25.81 | 30.76 | | | | |
| | | 13.71 | 27.45 | | | | | | |
| | | | | | | | | | 55.47 |
| | | 12.43 | 26.61 | | | | | | |
| | | | 25.85 | | | | | | |
| | 19.46 | 12.95 | | | | | | | |

ɾt of the aforementioned ulna)

**AA**

46.82