Cutting peat: The historical ecology and dissection of the Chat Moss ecosystem

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SUMMARY

Peatland is a biotope of international importance because of its unique flora and fauna and, when in good condition, the potential for globally significant carbon sequestration and storage. Chat Moss is a peatland on the edge of the Greater Manchester conurbation in the north-west of England, and the largest of a system of peatlands along the Mersey Valley. Peatland habitat on Chat Moss has been decimated over the past 200–300 years. However, it is now the site of a landscape scale ecosystem restoration programme. This investigation was conducted using historical written accounts, maps and biological recordings, supplemented by modern studies to examine the evidence for the original extent, landscape and species of the Chat Moss ecosystem, and define the mechanisms and timeframe of anthropogenic impacts on the landscape and ecology. The cartographic evidence shows that the maximum extent of Chat Moss was 36 square kilometres. Land use change with drainage, peat cutting and conversion to agriculture was most rapid between 1779 and 1897, resulting in complete loss of primaeval peatland habitat and associated flora and fauna by the middle of the 20th century. Chat Moss is located at the epicentre of the Industrial Revolution. During the 1800s Merseyside and south Lancashire were one of the UK's largest generators of sulphur pollution due to unregulated chemical works employing the Leblanc alkali process. The resulting acid rain (HCl, SO_2, H_2S) contributed to the habitat degradation and loss of *Sphagnum* moss on the neighbouring lowland peatlands. Having a clear understanding of an ecosystem's baseline condition, as well as the factors responsible for habitat degradation, is essential for informing habitat restoration efforts and species reintroduction programmes.

KEY WORDS: air pollution, habitat fragmentation, habitat restoration, Industrial Revolution, peatland

INTRODUCTION

Peatlands have traditionally been undervalued (Lindsay 1993), although their stark aesthetic qualities have long been appreciated (von Humboldt 1850) and their natural capital more widely valued in recent years (Costanza 2003, Rouquette *et al.* 2021). Peatlands have attracted international attention because of their potential to sequester and store atmospheric CO_2 in carbon-rich soils (Hawken 2018, Joosten 2024), with northern peatlands estimated to store 90 % of the total global peatland carbon pool (Yu 2011). Internationally, about 15 % of peatlands have been damaged by human activity, becoming a net source of greenhouse gases (Worrall *et al.* 2010, Evans *et al.* 2017). Only 1 % of deep peat (> 0.4 m thick) in England remains undamaged (Natural England 2010), with degraded UK peatlands contributing 3.5 % of the UK's greenhouse gas emissions (IUCN UK Peatland Programme 2021). The protection and rewetting of peatlands has been identified as one of the most cost-effective (Moxey & Moran 2014, Joosten 2024) and practical methods currently available for reducing greenhouse gas emissions and controlling atmospheric CO_2 levels by mid-century (Hawken 2018, Project Drawdown 2024).

Whilst most landscapes in Britain have been modified since the advent of farming about 6,000 years before the present day (BP) (Williamson 2019), lowland raised bog is a primaeval biotope (Lindsay 1993) and a habitat of principal importance in England (DEFRA & Natural England 2022). The unique assemblage of flora and fauna contributes to regional biodiversity (Rydin & Jeglum 2013, Bonn *et al.* 2016, Joosten 2024), having evolved to survive in the unusual and extreme conditions created by *Sphagnum* moss, the bog's keystone species (van Breemen 1995). Essential for peat formation, the structure of *Sphagnum* - which contains hyaline cells - retains water, promoting waterlogged anoxic conditions. The biosynthesis of large quantities of phenolic compounds binds nutrients and creates highly acidic, antimicrobial conditions which inhibit the decomposition of dead plant material (Freeman *et al.* 2012), leading to some of the contained carbon being permanently stored as peat. However, living *Sphagnum* is vulnerable to anthropogenic disturbances such as lowering of the water table, eutrophication and pollution (Rydin & Jeglum 2013).

The main objective of this study is to examine documentary evidence in first-hand descriptions of Chat Moss, to trace the destruction of the landscape and ecosystem with a focus on the period from the Industrial Revolution through to the current day. Specific objectives are to:

1. use historical descriptions and maps to define the extent of Chat Moss and the timeline of the loss of peatland;
2. identify biological recordings and documentary evidence for a functioning peatland biotope and ecosystem during this timeline; and
3. identify documentary evidence of human understanding of the peatland's natural processes and natural capital.

Historical data are corroborated with contemporary research to fully explore the mechanisms of habitat destruction and extend the timeline back to early human history and the late Holocene. This perspective informs habitat restoration efforts and species reintroduction programmes (IUCN 2013, Ritson & Lindsay 2023).

METHODS

Study area

Chat moss (53.45 °N, 2.45 °W) is an area of 2790 ha of peatland (DEFRA 2024d) lying 10–16 km to the west of Manchester (Figure 1). Currently, the landscape consists mainly of fields, transport infrastructure (two railway lines, the M62

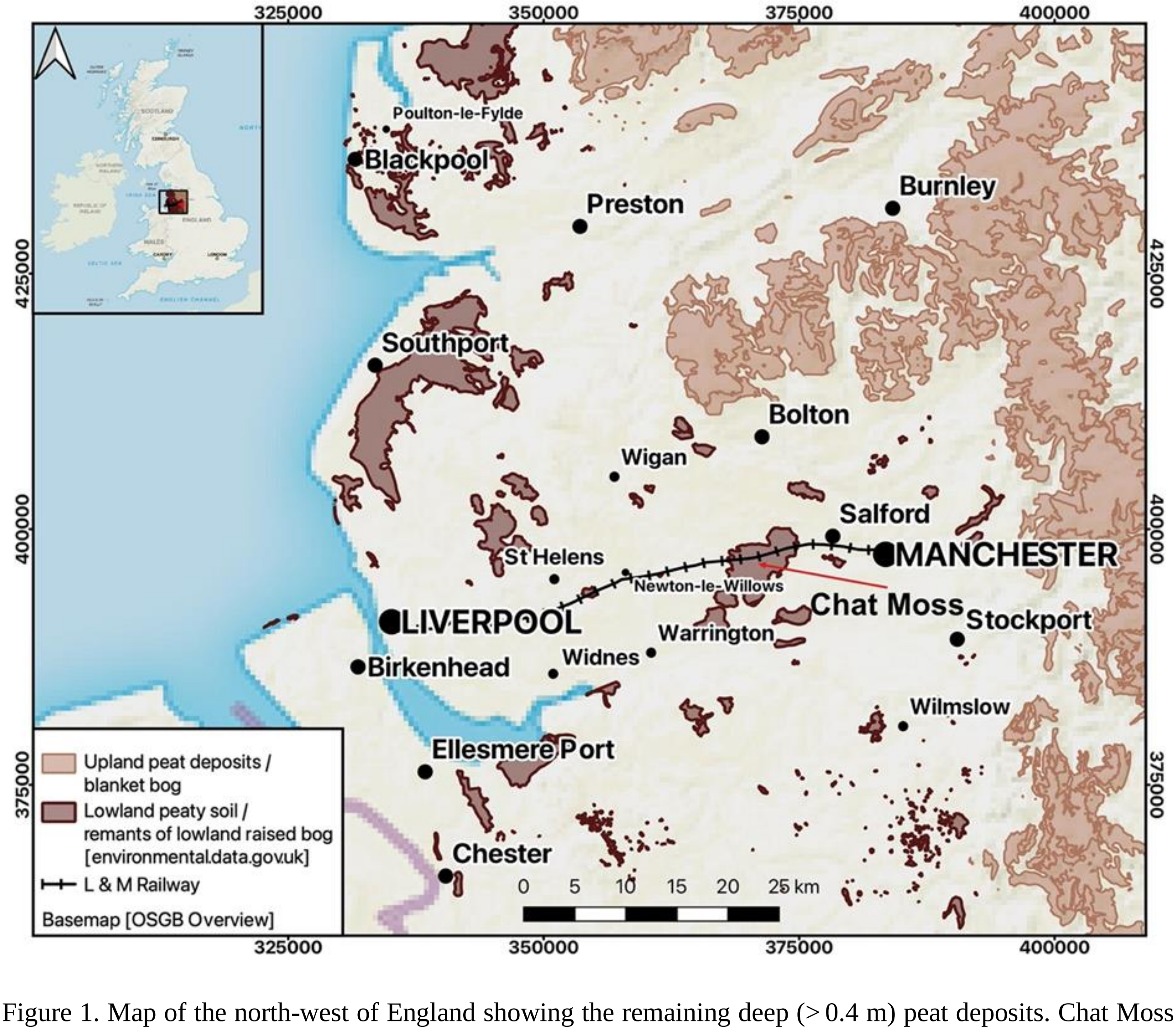

Figure 1. Map of the north-west of England showing the remaining deep (> 0.4 m) peat deposits. Chat Moss and closely related areas of the Manchester Mosslands are situated on the western outskirts of Greater Manchester, between the large urban areas of Wigan, Warrington and the City of Salford.

motorway and a regional airport) (Figure 2B), light industry and urban sprawl. Bragg *et al.* (1984) reported that by 1978 only 5 ha of Chat Moss remained intact. Industrial peat extraction on Chat Moss finally ceased in 2017 (DCLG 2012, Osborne *et al.* 2021), the only surviving area of uncut peat on the Manchester Mosslands being the neighbouring Holcroft Moss Nature Reserve Site of Special Scientific Interest (SSSI) (Garcés-Pastor *et al.* 2023). The remaining deep peat (> 0.4 m) on Chat Moss (DEFRA 2024d) is believed to be the remnant of a network of raised peat domes, with a 'skirtland' (essentially areas of former peat soils) consisting of mixed wetland habitats overlying clay and poorly draining alluvial sediments (Hall *et al.* 1995, British Geological Survey and Ordnance Survey 2024). According to peat core data and pollen analysis, wetland formation started at the end of the last ice age with the formation of fen and wet woodland within a large central hollow and neighbouring smaller depressions in the glacial clay (Birks 1964, Hall *et al.* 1995). A study of sub-fossil bog oak on the Little Woolden area of Chat Moss has documented mature oak - pine woodland growing from the mineral layer below the *Sphagnum*, dated to ca. 5,500 BP (Lageard *et al.* 2017), before the expansion of peatland during the mid-Holocene due to a change in climate to cooler and wetter conditions (Gallego-Sala *et al.* 2016) resulting in the vast Chat Moss raised bog complex.

Written descriptions

A library search was conducted for historical descriptions of south Lancashire's landscape, flora and fauna, visiting collections online and at Manchester Metropolitan University, Chetham's Library, the Lancashire Archives and Manchester Central Library. Relevant qualitative data were extracted and summarised to provide historical ecology evidence addressing our three research objectives.

Cartographic description

Maps of Lancashire were available from online collections curated by the British Library (https://www.bl.uk/), National Library of Scotland (https://maps.nls.uk/), Digimap (https://digimap.edina.ac.uk/), the Science Museum (https://www.sciencemuseum.org.uk/) and the British Geological

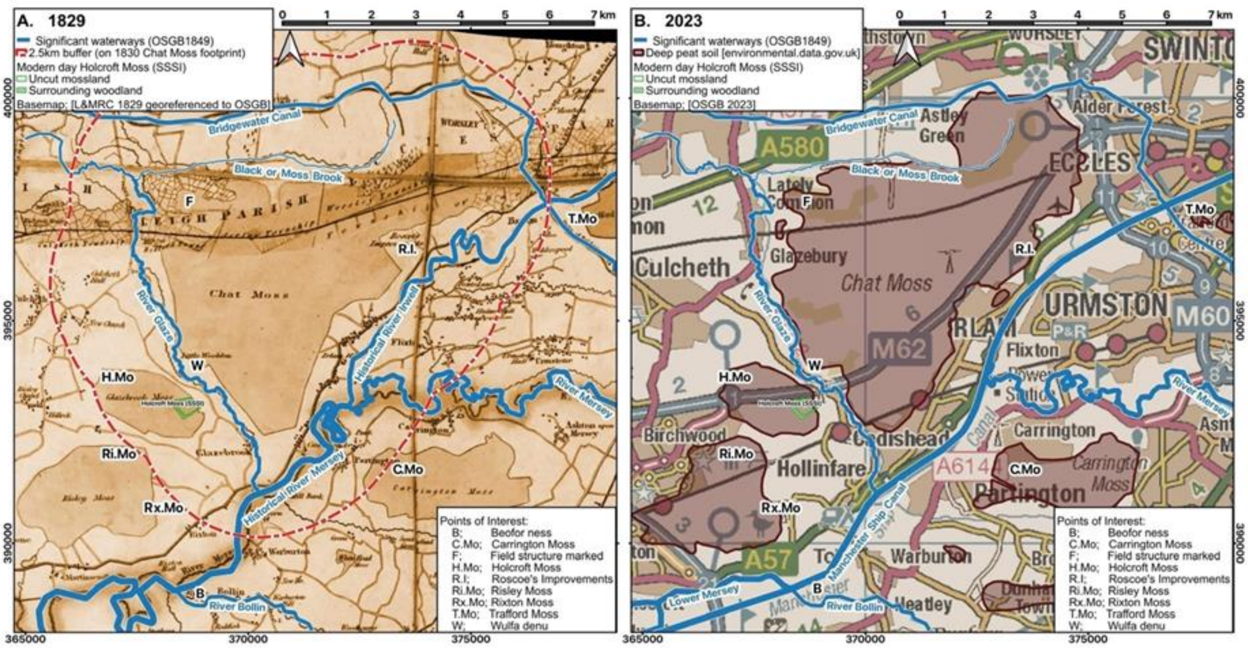

Figure 2. Maps of the Chat Moss area georeferenced to British National Grid. (A)1829 map showing the Liverpool to Manchester railway, which was then under construction. The field structure at the northern boundary of the peatland is visible and the meandering courses of the Rivers Irwell and Mersey are marked. (B) Modern-day map of the same area. The Chat Moss footprint is indicated by remaining deep peat soil. The canalised Irwell and Mersey are also marked. The M62 motorway was constructed adjacent to Holcroft Moss Nature Reserve (SSSI), the only remaining area of uncut peat on the Manchester Mosslands.

Survey (https://www.bgs.ac.uk/). Accurate maps by various cartographers, dating from the Elizabethan era (Saxton 1577) to the current UK Ordnance Survey edition at 1:25,000 scale (Ordnance Survey 2023) were analysed. Accuracy and detail improved significantly during the late 1700s with innovations in surveying technology (Harley 1965).

Maps were imported into QGIS (QGIS Development Team 2020) for analysis. County Series Ordnance Survey maps were acquired from Digimap as a 'Historic Data Download' pre-georeferenced to the British National Grid coordinate system. Early historical maps were georeferenced to British National Grid by using the QGIS raster georeferencing tool to pin recognisable landmarks to the corresponding landmarks on the First Edition County Series map (Ordnance Survey 1848–1849), then imported into QGIS using a thin plate spline, nearest neighbour, transformation. This First Edition Ordnance Survey map, published soon after the formation of the Ordnance Survey (UK Government 1841), provided an important link between the early historical maps and modern standards because it was surveyed before widespread urbanisation with re-routing of highways and additionally showed the original meandering configuration of the River Mersey and River Irwell before they were straightened and canalised between 1887 and 1894 (Moulton 1910).

Working in QGIS, 'patches' of the Chat Moss peatland that were marked as relatively intact 'mossland' were identified. On the detailed Ordnance Survey maps, post 1849 when the mossland was being dissected, parcels of land marked as wetland and not fully enclosed by drainage ditches, field margins or tracks (with associated drainage ditches) were included as patches of mossland. Patches marked as uncut mossland but less than 150 m across the shortest dimension were excluded, as they were well drained and hence likely to be ecologically poor and being prepared for peat cutting ('peat room' drainage systems were sometimes marked). Occasionally, patches of drained land appeared to have been abandoned and reverted to wetland or rough grassland. These, now semi-natural patches of secondary regeneration, were counted as mossland. Patches reverting to woodland were excluded from the analysis. Polygons were generated in new shapefiles, from which the area attribute could be extracted.

Areas of primary and secondary mossland were imported into R (v.4.0.4) (R Core Team 2021) and processed using RStudio (v.1.4.1106) (RStudio Team 2021). Areas were aggregated and a linear regression model was constructed to test the hypothesis that mossland area reduces over time. A localised regression was generated using the 'loess' function in base R and statistically significant inflection points on the loess curve were identified with segmented regression (Muggeo 2003) using the 'segmented' function in package 'segmented' (v2.0.0) (Muggeo 2017). The year when half of the earliest mapped area of Chat Moss had been lost was extracted from the predicted values of the loess curve.

Biological recording

To investigate historical species recordings, a preliminary spatial search of the National Biodiversity Network (NBN) Atlas (https://nbnatlas.org) (NBNT 2024) was conducted. The richest series of records within the Chat Moss area from the 1800s was for moth and butterfly presence, hence records of Lepidoptera presence were used for this investigation. The Hennet & Bingley (1830) map showed the last intact footprint of Chat Moss corresponding with the earliest biological recordings, so this footprint was used to define a 2.5 km wide hinterland using the 'Multi-distance Buffer' tool in QGIS. The resulting shapefile was imported into the NBN Atlas and used to define the area searched for all records of Lepidoptera presence that were 'accepted and considered correct'. The search was downloaded as a .csv file and imported into R for data extraction, dividing the 180 years between 1840 and 2019 into nine 20-year periods, and noting the total number of records for all Lepidoptera during each 20-year period. Five Lepidoptera species were identified as reliable biological indicators (Siddig *et al.* 2016) for specialist peatland plant species (Natural History Museum 2023) because of their highly specific (British) larval foodplant requirements (Table A1 in the Appendix). These species were *Arenostola phragmitidis* (fen wainscot), *Carisa sororiata* (Manchester treble-bar moth), *Coenonympha tulli*a (large heath butterfly), *Idaea muricata* (purple-bordered gold moth), and *Pasiphila debiliata* (bilberry pug). To ensure that all relevant records of these five indicator species had been identified, an additional spatial search was conducted within a 10 km radius of the Chat Moss centroid. Records logged as 'accepted and considered correct' were included along with one record logged as 'unconfirmed-plausible' which was judged likely to be correct. Because of the uncertainty in determining the exact location where specimens were originally collected, geolocation data (position and accuracy), descriptions of the County and Borough, and descriptions attached to pinned specimens, were considered in combination. The degree of certainty in location was graded as 'likely', 'probable' or 'possible'. Record locations that were clearly outside the hinterland area or whose certainty of location was judged to be only 'possible' were removed from the investigation. The area of peatland (Figure 2) where collection was most likely to have taken place was also identified.

The likely extinction date for Lepidoptera species was estimated using R script adapted from the 'fast re-sampling method' described by Brook *et al.* (2019). Records of presence at each site in each calendar year were used as input data, with the likelihood of correct identification of pinned specimens set at 0.99 and expert identification of live specimens set at 0.90. The median time of extinction (MTE) and upper 95 % confidence interval (UCI) were derived. For Lepidoptera species with only one or two records, it was not possible to calculate the MTE. The probability of extinction was, therefore, inferred using the method described by Roberts & Jarić (2020), whereby the probability of extinction was derived from the proportion of detection effort (i.e. the number of biological recordings for all Lepidoptera species) prior to the last record (of the species under investigation) divided by the detection effort during the whole collection period (1841–2019).

RESULTS

Written descriptions

Anthropocentric history

Early records are sparse. From the Medieval period, Harland (1861) refers to the 1322 survey of the Barony of Manchester, when 'Chatmos', "being undivided is not measured, because there is so small a goodness [or value, bonitatis] contained in so large an extent". 'Chat' has Saxon origins (Harland 1861) and local place names from the pre-medieval period speak to a world resembling modern-day Scandinavia or Canada, pushing the Chat Moss timeline back to the late Holocene. 'Woolden' (Figures 2A, 2B) is derived from Old English 'Wulfa denu' meaning 'wolves valley' (Eckwall 1922). 'Beofor ness', meaning 'beaver headland' in Anglo-Saxon era Old English (Aybes & Yalden 1995) referred to low-lying land at the confluence of the Rivers Bollin and Mersey, 3 km from Chat Moss (Figures 2A, 2B) (Dodgson 1970). Evidence from the archaeological excavation of a peatland site near Poulton-le-Fylde in North Lancashire (Figure 1) confirms the presence of *Castor fiber* (Eurasian beaver) from a beaver dam in a streambed underlying the peat, radiocarbon dated to 2,800–2,500 BP (Wells *et al.* 2000). *Castor fiber* was probably functionally extinct in England by the early Middle Ages (Aybes & Yalden 1995), although there is evidence of beaver presence in northern England as late as the 1300s (Manning *et al.* 2014).

The earliest known description of Chat Moss is given by the author Daniel Defoe (1724–1727), who documents cottagers cutting peat for fuel on the southern border of the moss close to the Manchester Road (Figure 2A). The first impact of the Industrial Revolution was drainage in the north-eastern part of Chat Moss from the 1770s (Gritt 2008) and the construction of the Bridgewater Canal (shown on the map from 1786 in Figure 3). This was followed by drainage and conversion to agriculture (by adding marl/clay and manure, fundamentally altering the chemistry of the *Sphagnum* peat) of a large area at the eastern end of Chat Moss (Roscoe's improvements, shown in Figure 2A) (Aiken 1795). This piecemeal approach to drainage of the periphery of the peatland was challenging as small parcels of agricultural land tended to revert to bog/heath because there was no systematic site-wide drainage system (Figure 3: 1818 and 1830).

The construction of the Liverpool to Manchester railway line (1826–1829) by a team of engineers led by George Stephenson (LMRC 1829, Booth 1830), across the widest part of "one of the most dangerous and treacherous bogs in the three kingdoms" (Redding 1842), was a milestone in disrupting the integrity of the central deep peat area of Chat Moss. In this central area, peat depth measurements with an iron boring-rod recorded up to 11 m of liquid peat overlying a further 1 m of soft clay and sand before a solid foundation was reached (Smiles 1858). One notable obstacle, probably at a depression in the underlying glacial clay, delayed progress for several months and threatened to derail the whole project. This was an area of deep liquid peat where "they could not find the bottom of the morass", which remained impassable despite approximately 48,000 m^3 of spoil being tipped and disappearing into the bog (Thomas 1980). The project was a formidable civil engineering challenge which was eventually completed by 'floating' the railway line across the most difficult section of Chat Moss (Smiles 1879, Thomas 1980).

A rapid phase of land enclosure (Hammond & Hammond 1911) and reclamation ensued (Baines 1867), with the expectation that all of the "barren heath" would be converted to "meadows, pastures and cornfields" within a few years. By the mid-1800s south Lancashire had become the epicentre of the Industrial Revolution (Douglas *et al.* 2002), a hub for coal mining and the early chemicals industry. The reclaimed peatland was fertilised with 'night soil' (human faeces) from Manchester (Lancet 1895, Douglas *et al*. 2002), yielding high-productivity farmland which helped feed the workers of the Industrial Revolution (Gritt 2008). The construction of the Manchester Ship Canal (1887–1894) (Moulton 1910) (Figure 2B) dramatically rearranged the topography of the Mersey and Irwell riparian corridors on the southern boundary of Chat Moss (Figure 2A), allowing industrial expansion and urbanisation of the southern edge of the peatland.

Landscape-scale change

In the earliest descriptions of Chat Moss, Defoe (1724–1727) describes a peatland measuring approximately 11.2 km north–south and 8 km east–west, with an unstable and impassable surface, extending southward close to the Manchester Road (Table A2). This seems exaggerated, but mapping techniques at the time were imprecise (Harley 1965) and the terrain difficult. The skirtland of Chat Moss may have merged with peatland farther north, for example Tyldesley Moss and Mossley Common, which are marked on the First Edition County Series Ordnance Survey map (1849).

Accounts of the construction of the railway during the 1820s suggest that Chat Moss covered approximately 2,000 ha (Thomas 1980) to 3,100 ha (Smiles 1879) with peat depths of 3–11 m (Smiles 1858, Thomas 1980). Smiles (1879) describes a semi-fluid mass rising up by 9–12 m above the

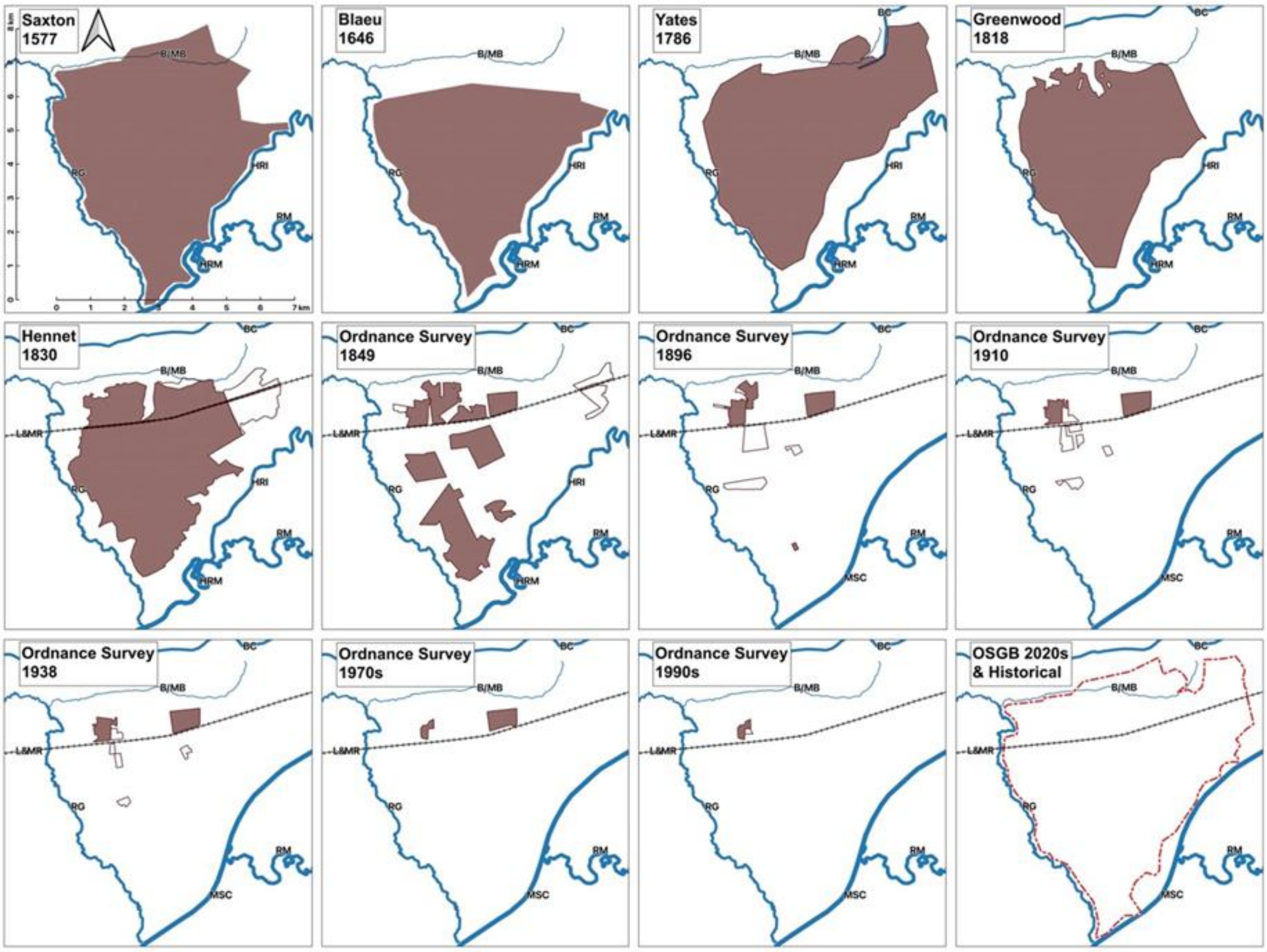

Figure 3. Map series showing footprints of viable peatland habitat recorded on maps dating from 1577 to the present day with progressive reduction and fragmentation of habitat. Primary undrained peatland is marked in brown, and areas of secondary regeneration are marked with brown boundary lines. The dotted red line defines the maximum extent of historical map footprints of Chat Moss. The evolution of the canal system is marked (waterways in blue), including the early Bridgewater Canal (BC) on Yates' 1786 map (intended to drain water off the north-eastern part of Chat Moss). The reconfiguration of the historical River Mersey (HRM) and historical River Irwell (HRI) riverine corridor, and the construction of the Manchester Ship Canal (MSC) is shown in the 1896 Ordnance Survey map. The 1829 Liverpool and Manchester Railway (L&MR) (black), Black or Moss Brook (B/MB), River Glaze (RG) and the upper part of the River Mersey (RM) are also marked.

surrounding country "like a turtle's back"; the course of the railway (Figure 2A) had been accurately surveyed using a theodolite (LMRC 1829, Smiles 1858, 1879). Baines (1867) states that half the former 2,500–2,900 ha area of the moss had been reclaimed, including land "on the central plain, which forms the highest part of the moss", and that the landscape was treeless although brushwood and heather had been gathered for construction of the railway (Thomas 1980).

The Victoria County History of Lancashire (VCH) (Farrer & Brownbill 1906) documents the remaining area of peatland at 124 ha of a former 415 ha (Table A2). It is possible that this incongruity reflects human memory of Chat Moss from the previous generation rather than examination of contemporary maps, and is thus an early example of shifting baseline syndrome (Pauly 1995).

Flora and fauna

Descriptions of species are rare in the early written accounts. Defoe (1724–1727) describes acrotelm peat with rhizomes, probably of *Eriophorum angustifolium* (common cotton-sedge). The first British account of the large heath butterfly (*Coenonympha tullia*) is given by Lewin (1795), the butterfly being found "in a moorish and swampy situation, near Manchester".

The VCH (Farrer & Brownbill 1906) states that *Drosera anglica* (large leaf sundew) was recorded on Chat Moss in 1868, and notes that *Rhynchospora alba* (white beak-sedge) is very rare. Travis's Flora of South Lancashire (Savidge *et al.* 1963) catalogues plant records on Chat Moss, "Until drainage operations started in 1805 … a typical wet fen carr and *Sphagnum* bog". The previous presence of multiple *Sphagnum* species and specialist bog plants (markers of good quality habitat) is noted - *Sphagnum rubellum* (1871) as well as the extinction of *Drosera anglica* (greater sundew) (1868) and *Rhynchospora alba* (white beak-sedge) (1900). The cotton-sedges *Eriophorum angustiofolium* and *Eriophorum vaginatum* were still present, along with *Myrica gale* (bog myrtle) at a single site. Birks' (1964) survey did not find any living *Sphagnum* on Chat Moss, an observation supported by biological recording data (NBNT 2024) - the first records of *Sphagnum* species in the area were for *S. balticum* and *S. pulchrum* on Carrington Moss in 1863–1866, with no further recordings until 1989.

Baines (1867) describes birds on the mossland, noting the presence of grouse that were "very wild and difficult to shoot" (most likely black grouse; *Lyrurus tetrix*), diminishing numbers of snipe and occasional wild ducks. Bittern were formerly found on the edge of the mossland. Large flocks of migratory geese from 'the Highlands' or Scandinavia rested or overwintered. The presence of 'windhover hawk' (common kestrel; *Falco tinnunculus*) and "hawkes in pursuit of grouse and other birds" is also noted (Baines 1867). By the mid-1900s Oakes (1953) notes that *Circus aeruginosus* (marsh harrier) on Rixton Moss and *Circus cyaneus* (hen harrier) on 'southern mosslands' were rarities. Currently Red Listed British birds (Stanbury *et al.* 2021) that were noted to be present on Chat Moss by Oakes (1953) include *Linaria flavirostris* (twite) 'breeding last occurred … 1940', *Emberiza calandra* (corn bunting) 'widespread as a breeder', *Passer montanus* (tree sparrow) 'abundant', *Motacilla flava* (yellow wagtail) 'particularly numerous', *Muscicapa striata* (spotted flycatcher) 'locally common', *Locustella naevia* (grasshopper warbler) 'a few pairs nest', *Dryobates minor* (lesser spotted woodpecker), *Streptopelia turtur* (turtle dove) (Oakes 1953). Of the wetland birds, Oakes lists only *Ixobrychus minutus* (little bittern) and *Vanellus vanellus* (lapwing).

Natural processes and natural capital

Defoe (1724–1727) appeared to have no clear understanding of the peatland - "What nature meant by such a useless production, 'tis hard to imagine", speculating that 'fir trees' (probably referring to Scots pine; *Pinus sylvestris*) found under the moss grew and 'encreased' underground. In contrast, by the mid-1800s there was a good understanding of the physical geography of peatlands. Baines (1867) and Smiles (1879) give well-informed discussions; peat formation is initiated in deep hollows in the "marl beds" (clay) and, unlike peat in the fens, Chat Moss peat is not mineral based, the "spongy vegetable pulp" resulting primarily from *Sphagnum* growing upwards over millennia, the previous year's growth being preserved by the antiseptic properties of the peat. The peat contained masses of roots and submerged birch (*Betula* sp.) and alder (*Alnus glutinosa*) rooted in sand and clay underlying the peat (Baines 1867). Smiles was aware that the peat body stored water, swelling in rainy weather. Baines goes into greater detail about the functioning of ombrotrophic raised bog, quoting from von Humboldt's 'Views of Nature' (1850) that British peat mosses are an extension of heathland in northern Europe "extending on the Continent from the extremity of Jutland". Baines also quotes from Lyell's 'Principles of Geology' (1837) that peat mosses hold water within pore spaces and that peat formation is favoured in cooler northern latitudes, going on to explain that in the tropics there is rapid oxidation of peat to CO_2 released to the atmosphere -

"vegetable matter, or humic acid, being converted into carbonic acid, rises and is absorbed into the atmosphere". The 'Account of the Liverpool and Manchester Railway' estimated that "at a very moderate calculation, Chat Moss comprises sixty millions of tons of vegetable matter … drawn from the clouds and the air" (Booth 1830). Baines also references Ormerod presenting papers to the British Association for the Advancement of Science describing a series of 'levellings' which documented subsidence of the surface of Chat Moss north of the railway line, after cutting drains - 1.7 m in the first nine months (Ormerod 1849), then 0.3 m per annum (Ormerod 1851).

The loss of natural capital resulting from the Industrial Revolution was felt amongst local people. Smiles (1879) documented hostility to the proposed railway line during the 1820s, with assaults on surveyors and destruction of the theodolite - resistance to land use change appearing to be the motivation, although vested interests also opposed the railway (Thomas 1980). A chemical works using the highly polluting Leblanc chemical process for manufacturing sodium hydroxide (Reed 2013) operated between 1828 and 1850 in Newton-le-Willows (Figure 4) (Dowd 2010). Unregulated release of hydrogen chloride (HCl), hydrogen sulphide (H_2S) and sulphur dioxide (SO_2) directly into the atmosphere (Smith 1872) damaged crops and created "noxious and injurious" living conditions. Protests and civil litigation (Tucker 2019) eventually forced the industry to relocate, moving 12 km to Widnes (Figure 1) (Dowd 2010). Proctor (1874) documents the industrial expansion of Manchester, but self-consciously devotes a chapter to his "juvenile reminiscences" of "the verdant, tree-decked bank of the Irwell" in the early 1800s, the river frequently overflowing onto floodplain meadows before levees were constructed. Contemporaneous illustrations graphically document the degree of environmental destruction (Whitworth 1734, Lowry 1924). The VCH (Farrer & Brownbill 1906) notes that Chat Moss had been significantly reduced with ongoing destruction - "the greater part of this remnant is being yearly dissipated as 'peat-moss litter' over the entire kingdom".

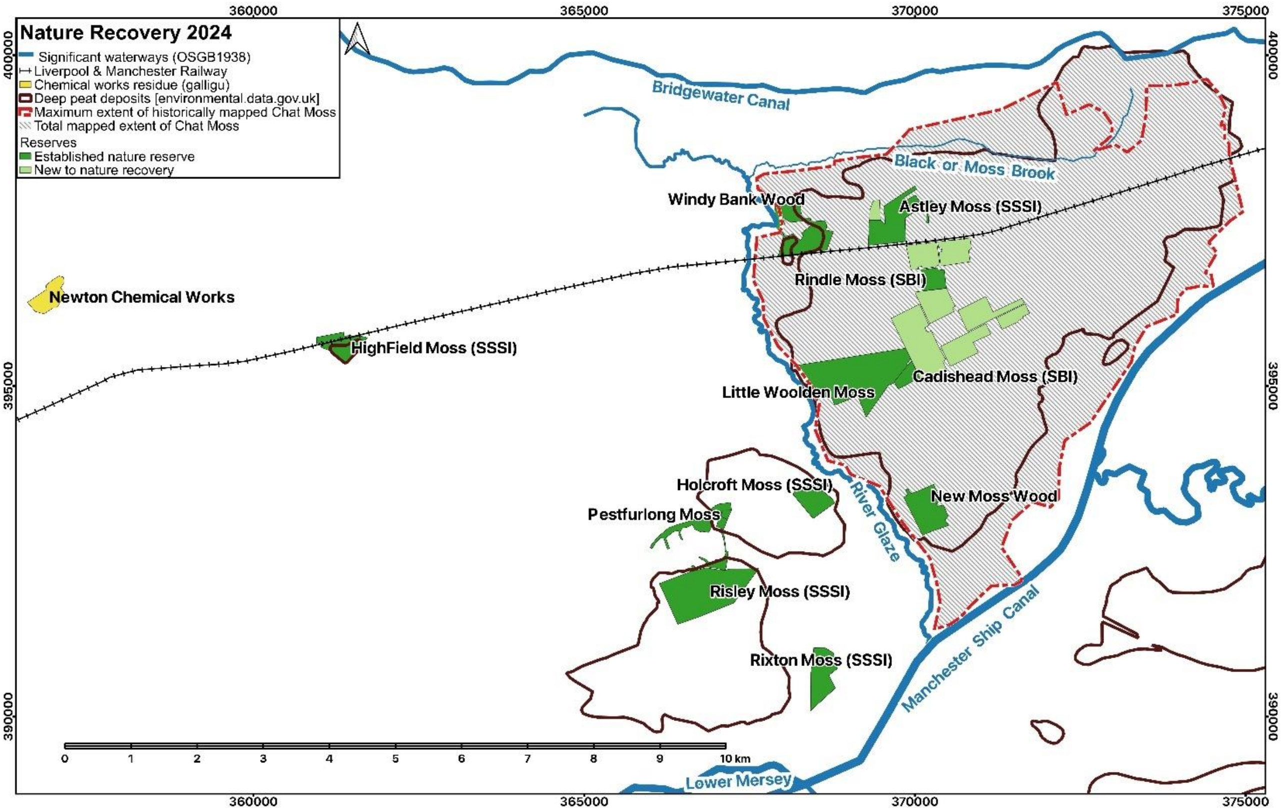

Figure 4. Nature reserves in the proposed National Nature Reserve (total area 545 ha), with a large area of closely connected habitat patches across the centre of Chat Moss. Stephenson's railway (L&MR) is marked close to nature reserves. The footprint of the galligu (sulphur residue) from the Leblanc alkali process at the Newton Chemical Works near Newton-le-Willows is also marked. 'SBI' indicates a local designation for nature conservation - Site of Biological Importance.

Heavy industry and pollution

Metal smelting was one of the major sources of sulphur pollution affecting plant communities and *Sphagnum* moss on south Pennine blanket bogs (Lee 1998) (Figure 1). In addition to this, because of its proximity to the south Lancashire coalfield and Cheshire salt production, Merseyside became a major centre for chemical production (Tucker 2019) and one of the UK's largest generators of sulphur pollution during the Industrial Revolution. Millions of tons of sulphur residue, a by-product of the Leblanc alkali process known locally as 'galligu', was dumped adjacent to chemical plants (Tucker 2019), the residue reacting exothermically with rainwater to release H_2S and setting the waste on fire, generating SO_2 (Reed 2012, 2013). One of the first of these chemical works was situated near Newton-le-Willows, 10 km west of Chat Moss and 3 km from Highfield Moss (SSSI) (Figure 4) (Dowd 2010) - the galligu remains as a local landmark, the 'Mucky Mountains' rising to a height of 30 m above ground level (Ordnance Survey 2023) (Figure 4). The sulphur pollution was additional to the unmitigated release of HCl vapour into the atmosphere - a 120 m high chimney was built to reduce local precipitation but disseminated the acid over a wider area (Dowd 2010). The 'acid rain', first described by R.A. Smith (1872), harmed local crops "St Helens was a good county for fruit - now all gone" (Figure 1) and can be presumed to have had a devastating effect on the local peatland vegetation. The human cost of the industry in Merseyside was tragic, precipitating the 1863 British Alkali Act and Alkali Inspectorate, headed by R.A. Smith, to enforce this new health and environmental regulation (Reed 2012, Tucker 2019).

Evidence of heavy industry, peaking around 1900, persists as legacy pollutants in local pond mud (Power & Worsley 2009) and peat cores (Keightley 2015, Garcés-Pastor *et al.* 2023). Chat Moss soils have high levels of industrial metal deposition (Rawlins *et al.* 2012) and Highfield Moss (SSSI), situated 4 km from the Newton chemical works (Figure 4) has twice the concentration of sulphur compared to other peatlands in the industrial north-west (Keightley 2015).

Improvements in air quality

UK air quality has improved over the last century. Coal consumption in Britain decreased gradually as heavy industry declined after the First World War, then more rapidly from the 1950s as natural gas, oil and nuclear power replaced coal for electricity generation (Minchinton 1990). By 2022, annual SO_2 emissions in the UK had reduced to 1.8 % and NOx emissions to 22 % of their 1970 levels (DEFRA 2024a). In the late twentieth century, Fiddler's Ferry coal-fired power station in Warrington (Figure 1) was identified as the largest single source of SO_2 in the Manchester region (Lee & Longhurst 1993), although it had been retrofitted to reduce NOx and HCl emissions, hence other coal-fired power stations made a more significant contribution to these pollutants. Fiddler's Ferry, the last operational coal-fired power station in the north-west of England, was finally shut down in 2020, having become loss-making due to cheap renewables (Ambrose 2020). Nitrogen deposition remained high during the 1900s (Fowler *et al.* 2004), with vehicle exhaust emissions becoming the major source of NOx (Lee & Longhurst 1993). Nitrogen deposition on peatland ecosystems results in loss of species richness and change in species composition to grass-dominated vegetation (Field *et al.* 2014), although exhaust emissions have reduced in recent years (Sykes 2020, Krecl *et al.* 2021) with evidence of benefit to plant communities (Berendse *et al.* 2021). Air quality measurements at automated testing stations on the western (DEFRA 2024b) and eastern (DEFRA 2024c) edges of Chat Moss show continued improvement in levels of NOx over recent decades. Agricultural ammonia release remains a significant problem (Lee & Longhurst 1993, Sykes 2020, APIS 2024), with emissions in 2022 at 83.7 % of their 1980 levels (DEFRA 2024a).

Cartographic analysis

Twelve maps of sufficient quality were identified for use in this part of the analysis (Figure 3) (Saxton 1577, Blaeu 1646, Yates 1786, Greenwood & Creighton 1818, Hennet & Bingley 1830, Ordnance Survey 1848–1849, Ordnance Survey 1894–96, Ordnance Survey 1909–1911, Ordnance Survey 1938, Ordnance Survey 1970–1981, Ordnance Survey 1990–1996, Ordnance Survey 2023), providing data from the late Middle Ages through to the present day.

There is a steady reduction in the Chat Moss footprint up until 1818, with a brief pause until 1830, after which the Moss is rapidly dissected leaving no primary or secondary peatland habitat by the present day. Area attributes extracted from the maps are shown in Figure 5.

The largest area (2,949 ha) was mapped in 1577. There is a significant trend in the reduction in area over time ($F = 40.96$ on 1 and 10 DF, Adj $R^2 = 0.78$, $p < 0.001$), the most rapid phase of peatland habitat loss occurring over 118 years between 1779 and 1897, and half of the 1577 area lost by 1832. The composite maximum extent of historically mapped Chat Moss (Figure 3: 2023) is 3,405 ha.

Biological recording

The search of the NBN Atlas revealed a total of 49,156 biological records for all Lepidoptera species from Chat Moss between 1841 and 2019. There is a steady increase in the volume of biological recording data during the twentieth century (Table A1), with less than 100 Lepidoptera records in each 20-year period prior to 1939, increasing to 38,579 during the period 2000–2019.

In total, 47 records for (five) lepidopteran indicator species are included, of which 26 verify the presence of peatland indicator species on individual peatland sites between 1841 and 1919. After this time the number of indicator species observations is reduced, with just three during the period from 1920 until 2019 (Figure 5, Table A1) ($\chi^2 = 11.59$, df = 1, $p < 0.001$).

Analysis for the estimated date of extinction returns extinction dates for all five of the lepidopteran indicator species. For the Manchester treble-bar moth (n = 15; last recording (LR) = 1912), the median time of extinction (MTE) is 1915 (95 % UCI = 1918). For the large heath butterfly (n = 6; LR = 1926) the MTE is 1977 (95 % UCI = 2006). For the purple-bordered gold moth (n = 8; LR = 1964) the MTE is 2004 (95 % UCI = 2010). For the fen wainscot (n = 2; LR = 1940) there are insufficient data to estimate the MTE, but the probability of extinction by 2019 is p = 0.005. For the bilberry pug (n = 1; LR = 1862), again there are insufficient data to estimate the MTE and the probability of extinction by 2019 is p = 0.002.

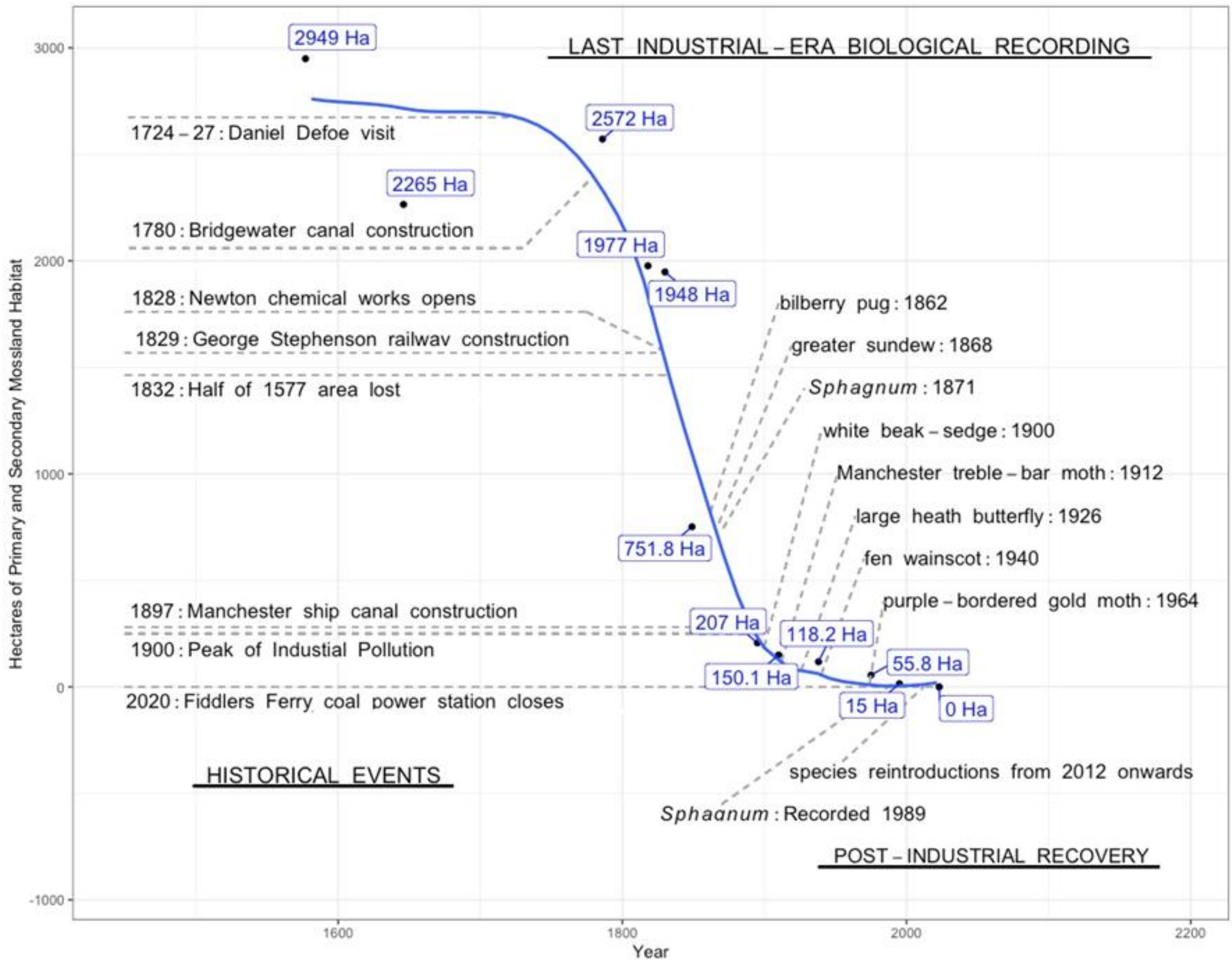

Figure 5. The area of primary and secondary peatland habitat on Chat Moss, as marked on historical maps from the Elizabethan era through to the present day. The local regression (loess) curve, key historical events, industrial-era biological recordings and species recovery milestones are also shown. There appears to have been a brief pause in habitat loss during the early 1800s, before the construction of the railway in 1829 facilitated access to the deep peat area in the centre of the Moss.

DISCUSSION

Our approach to data collection focused predominantly on three sources of historical data. The review of old written descriptions is mostly anecdotal but gives a rich picture of the landscape, as well as human attitudes and understanding of the environment. The cartographic analysis gives quantitative land area data. Historical biological recording data gives semi-quantitative data for species presence since the mid-1800s.

Evidence for the original size of Chat Moss is corroborated by geological, cartographic and documentary evidence. The remaining area of deep peat is co-located with pre-1830 maps showing a contiguous Chat Moss, although the north-eastern part of the peat body was not included in these maps. The composite footprint (Figure 4) suggests a roughly elliptical peat body extending to 3,597 ha, which is somewhat larger than Victorian-era estimates of the original area of Chat Moss (Table A2). In early maps (Figure 3), Chat Moss is shown extending to the banks of the Glaze, Mersey and Irwell and north of the Black or Moss Brook, although the land starts to climb northwards from the Bridgewater canal which would have constrained the northern boundary of the peat body (Ordnance Survey 1848–1849). The measurements taken by George Stephenson during the 1820s give direct evidence that Chat Moss was a raised bog with its surface 9–12 m above the surrounding land (Smiles 1879). The rapid collapse of the peat body after drainage was subsequently reported to the scientific community by Ormerod (1849, 1851). The time sequence in Figure 3 demonstrates the gradual loss of the periphery of Chat Moss from the late Middle Ages until the early 1800s. Stephenson's large-scale and determined civil engineering project facilitated access to the deep peat in the central area of the peat body, allowing rapid dissection of the peatland over a few decades. The remaining scraps of primary and secondary mossland were converted to agriculture during the twentieth century, completing the destruction of the 36 square kilometres of wilderness that had been present when Daniel Defoe visited Chat Moss 300 years previously (Figures 2 and 4).

Our geospatial analysis yields an objective assessment of habitat loss due to land use change (Figure 3) and attempts to track the loss of the area's biodiversity during successive decades (Figure 5). The historical 1:10,560 County Series maps are detailed and accurate but, beyond indicating wet ground, rough grassland or scrub/woodland, they do not give detailed insight into the dominant vegetation type. However, our strict assessment criteria of compartment width and distance from drainage is a quantitative indicator of the intensity of land use and lowering of the water table.

In assessing the transition from *Sphagnum*-dominated peatland to grassland habitat, areas of land that appeared to represent borderline-quality habitat were excluded from this analysis, hence our estimates are more conservative than those of previous studies (Bragg *et al.*1984).

The most rapid phase of dissection and dissipation of the peatland habitat occurred during the decades following construction of the railway (Figure 3: 1849 and 1896) while the botanical records indicate that the specialist flora was in decline from the mid-1800s onwards (Farrer & Brownbill 1906, Savidge *et al.*1963). Peatland-specialist Lepidoptera species were present at multiple locations until the early 1900s, indicating that islands of peatland vegetation were surviving as small remnants of primary or secondary habitat. Our analysis of the estimated date of extinction supports the hypothesis that these populations became locally extinct.

Chat Moss had lost half of its original area by about 1832 (Figure 5), shortly after the railway was completed, then became increasingly fragmented, impacting habitat continuity (Fahrig 1997, Chase *et al.* 2020). Frequent drainage ditches were required to lower the water table, maximising the edge effect on habitat islands and impacting the bog vegetation and primary production of larval food plant resources. Access roads and firming up of the liquid bog surface may well have facilitated access for biological recording, even as the species of interest were in decline, and there are few recordings of specialist Lepidoptera presence after 1920. Of the bird species present by the mid-1900s (Oakes 1953), there were few waders, the landscape having been converted from open wetland to a mixture of agriculture and woodland. Evidence from recent bird recording suggests that most of the species abundant 70 years ago are now uncommon or absent (Dave Steel; verbal report).

Sphagnum moss, the peatland's keystone species, was completely absent in Birks' detailed mid-1900s survey (Birks 1964). The addition of clay and fertiliser to the peat made it suitable for agriculture but permanently altered the nature of the bog's chemistry, rendering the regeneration of *Sphagnum*-dominated bog difficult. It is surprising, however, that there was no *Sphagnum* to be found in ditches and wet hollows, raising the possibility that factors other than land use change also played a significant part. *Sphagnum* is vulnerable to atmospheric pollution (Ferguson *et al.* 1978, Press 1983, Lee *et al.* 1990, Lee 1998); SO_2 deposition injures *Sphagnum* and deposition of nitrogen oxides (NOx) above the critical load is toxic. NOx deposition also impacts dwarf shrub communities (Lee 1998) and fertilises grasses, resulting in a shift away from bog plant communities. Most *Sphagnum* species were virtually eliminated from blanket bog in the uplands east of Manchester by the twentieth century (Caporn *et al.* 2006, Ritson & Lindsay 2023), with a transition to *Molinia caerulea* (purple moor grass) dominance (Caporn *et al.* 2015). The impact of air pollution on the lowland bogs west of Manchester has been largely overlooked. However, the proximity of the Newton chemical works (Figure 4) (Dowd 2010) would have concentrated HCl and SO_2 deposition onto Chat Moss and neighbouring peatlands (Keightley 2015) to a much greater degree than onto the uplands, situated tens of kilometres away from the industry (Figures 1 and 5).

Coinciding with a reduction in coal burning and improvements in air quality during the past century (Minchinton 1990, DEFRA 2024a), multiple *Sphagnum* species were recorded on Holcroft Moss in 1989 and on Carrington Moss in 1996, along with *S. fimbriatum* on Chat Moss in 1989 (NBNT 2024). These are the first records of *Sphagnum* moss in the area since ca. 1870. Despite these improvements, ammonia emissions remain high (DEFRA 2024a) and nitrogen deposition continues to exceed the critical load (5–10 N kg ha^{-1} year^{-1} for lowland bogs) across Chat Moss (25–28 N kg ha^{-1} year^{-1}) (APIS 2024).

Factors controlling peat bog hydrology, initiating bog formation and constraining expansion, have been viewed in purely geophysical terms (Clymo 1984, Hall *et al.* 1995, Comas *et al.* 2004). There is historical evidence of *Castor fiber* presence across England until the Middle ages (Aybes & Yalden 1995, Raye 2015). There is also archaeological evidence from North Lancashire suggesting a role for beaver in the initiation of lowland raised bog formation (Wells *et al.* 2000), and some local place-names indicate the historical presence of *C. fiber* on the River Mersey (Aybes & Yalden 1995). It is, therefore, probable that *C. fiber* colonised local riparian corridors and wooded lakes at the centre of Chat Moss in the post-glacial period and was present until the Middle Ages. Beaver dams raise the water table in fens, expanding and deepening wetland in the early stages of peatland formation (Karran *et al.* 2018), support the edges of peatlands (Karran 2018, Swift & Kennedy 2022), and create open water within peatlands (Turetsky & St. Louis 2006). The introduction (Elliott *et al.* 2017) or removal (Green & Westbrook 2009) of this keystone species and ecosystem engineer results in significant modification to streamflow and the riparian landscape. Black or Moss Brook would have been suitable for (beaver) damming, possibly explaining the extension of the wetland to the north of Black or Moss Brook observed in the earliest map of the area (Figure 3: 1577). In the context of descriptions of the Irwell and Mersey as meandering rivers (Figure 2A) connected with their floodplains (Proctor 1874), beaver activity on small entrant streams and side channels of these rivers would have promoted lagg fen, carr woodland and reedbed formation bridging the skirtland of Chat Moss between the peat body and the river, as shown in the earlier maps (Figure 3).

We have attempted to give context to the present-day Chat Moss in terms of its historical ecology by reviewing the evidence that, until less than 200 years ago, Chat Moss was not simply an area of peat soil marked on maps, but also an 'impenetrable wilderness' (Defoe 1724–1727). Well-known figures from modern history, Daniel Defoe and George Stephenson, whose work is still relevant to current-day life, culture and education (Nikoleishvili 2007, Science and Industry Museum 2018) witnessed and documented this remarkable peatland complex. Indeed, the Liverpool to Manchester railway was the world's first intercity passenger rail service and is still in use today. Through a combination of anthropogenic factors, the 36 km^2 of raised bog has not just been degraded, but all trace of original primary bog habitat has been completely lost - an unusual degree of habitat destruction (Laurance 2010). Very little attention was paid to this destruction until the mid-1900s (Oakes 1953, Dormer *et al.* 1962, Savidge *et al.*1963). It is difficult to conceptualise the magnitude of this process because it occurred over three human lifespans and almost all evidence of the primaeval baseline has been lost (Pauly 1995).

Chat Moss peatland restoration

A peatland restoration project is currently being undertaken across Chat Moss (Lancashire Wildlife Trust 2023) with the objective of improving the natural capital of the area (Ashby *et al.* 2021) and, most urgently, protecting the carbon stored in the remaining peat (Smart *et al.* 2020). It is not possible to restore contiguous habitat because of human infrastructure on Chat Moss. Nevertheless, some restoration sites are over 100 ha in size and drainage ditches can be removed or re-routed to merge parcels of land into larger patches of habitat, mitigating edge effects and optimising connectivity.

Astley Moss Nature Reserve (SSSI) (Figure 4) has been in restoration since the 1980s. Also, the Little Woolden Moss peat extraction site is now being restored to lowland raised bog; after only ten years of habitat restoration it has become a functioning nature reserve with multiple trophic levels, breeding wetland birds, the re-establishment of *Sphagnum* moss (Osborne *et al*. 2021), plant species reintroductions (Hartley 2023) and sequestration of carbon (Keightley *et al*. 2023). In 2020, Astley Moss became the site of a large heath butterfly (*Coenonympha tullia)* species reintroduction programme (Weston 2020, Osborne & Coulthard 2022, Osborne *et al*. 2024a), returning this endangered butterfly (Fox *et al*. 2022) to the region after a century of absence (Table A1). This research has stimulated interest in plant species reintroductions, specifically with a view to re-establishing habitat suitable for specialist peatland lepidoptera - bilberry and cranberry (*Vaccinium* sp.), which are the larval foodplants for the Manchester treble-bar moth (*Carsia sororiata*), and marsh cinquefoil (*Comarum palustre*) as the larval foodplant for the purple-bordered gold moth (*Idaea muricata*) (Natural History Museum 2023).

These reserves form part of a landscape-scale habitat restoration programme (Lancashire Wildlife Trust 2023) comprising multiple closely related or adjoining parcels of land (Figure 4) owned by a consortium of governmental and charitable landowners. The possibility of establishing a National Nature Reserve consisting of a mosaic of habitats (bog, fen, wet acid grassland, wet woodland) across the Manchester Mosslands is currently under discussion (Figure 4).

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AUTHOR CONTRIBUTIONS

AWO, SM, SJMC and EC conceived the ideas and designed the methodology; AWO collected and analysed the data, and led writing of the manuscript. SM, SJMC and EC contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data and R scripts are available from Manchester Metropolitan University e-space (Osborne *et al*. 2024b).

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Appendix

Table A1. Year of biological recording of the presence of specialist Lepidoptera species (shown with habitat and food plant) on Chat Moss and neighbouring peatlands, grouped into 20-year periods from 1840 to 2020. Records of these species were reduced after 1920, when habitat loss and fragmentation were almost complete. Records for Chat Moss are shown in bold. Key to site name abbreviations: CM = Chat Moss; CM(N) = CM north of railway; CM(S) = CM south of railway; C.Mo = Carrington Moss; H.Mo = Holcroft Moss; Ri.Mo = Risley Moss; R.Mo = Rixton Moss; T.Mo = Trafford Moss.

Area	Moss (site)	Twenty-year time periods									Total
		1841–1859	1860–1879	1880–1899	1900–1919	1920–1939	1940–1959	1960–1979	1980–1999	2000–2019	
Arenostola phragmitidis (fen wainscot): Fen/Reed Bed; *Phragmites australis*											
Carrington	C.Mo				1903						
Trafford	T.Mo						1940				
Carsia sororiata (Manchester treble-bar moth): Bog/Heath; *Vaccinium myrtilllus, Vaccinium vitis-idaea*											
Astley	**CM(N)**	1846									
Partington	C.Mo		1862								
Partington	C.Mo		1875								
Cadishead	**CM(S)**			1882							
Urmston	T.Mo			1882							
Rixton	Rx.Mo			1894/7/8							
Rixton	Rx.Mo				1908/10						
Irlam	**CM**				1910						
Rixton	Rx.Mo				1912						
Coenonympha tullia (large heath): Bog/Wet Heath; *Eriophorum vaginatum* (*Rhynchospora alba, Carex sp*.)											
Urmston	T.Mo	1857									
Urmston	T.Mo			1896							
Culcheth	H.Mo			1896							
Rixton	Rx.mo			1897							
Astley	CM(N)			1899							
Culcheth	H.Mo					1926					
Idaea muricata (purple-bordered gold moth): Fen; *Comarum palustre*											
Astley	**CM(N)**	1846									
Risley	Ri.Mo	1859									
Rixton	Rx.Mo	1859									
Urmston	T.Mo	1859									
Culcheth	H.Mo			1886							
Partington	C.Mo			1890							
Culcheth	H.Mo				1900						
Urmston	T.Mo							1964			
Pasiphila debiliata (bilberry pug): Open Woodland; *Vaccinium myrtillus*											
Trafford	T.Mo		1862								
Number of Records: Number of Lepidoptera records in the automated area search of CM and hinterland											
All	All	81	6	37	66	46	226	426	9701	38579	49156

Table A2. Summary of various historical authors' reports of the original area, area at time of description, and peat depth of Chat Moss.

Citation	Original area (ha)	Year of description	Area (ha)	Peat depth (m)
Defoe (1724–1727)	5900	1720s	5900	2.4–2.7
Baines (1867)	2,500–2,900	1867	1400	-
Smiles (1879)	-	1828	3100	6–9
Thomas (1980)	-	1825	2100	3–10.5
Farrer & Brownbill (1906)	415	1906	128	-