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A meta-database of peatland palaeoecology in Great Britain

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ABSTRACT

We present and appraise a large compilation of peatland palaeoecological research in Great Britain, and discuss the value of these data for secondary analysis. We identify 475 radiocarbon-dated palaeoecological records from British peatlands published since 1970. Peatland palaeoecological research has been widespread but with some clear spatial biases reflecting factors such as accessibility and the location and interests of active researchers. We show that basic details such as stratigraphic descriptions, site coordinates and details of radiocarbon dates are omitted from publications with surprising frequency and note the large quantity of data that only ever appears in PhD theses. To allow papers to remain concise while presenting essential background information we propose a system of standardised meta-data in online supplementary material. The extensive body of palaeoecological data for British peatlands has been relatively unexploited. The compilation we present will be a valuable aid in making better use of this data resource.

KEYWORDS: Database; Meta-database; Peat; Holocene; Carbon; Publishing

Introduction

Palaeoecology increasingly seeks to answer questions at larger spatial scales (Seddon et al., 2014) but most Holocene palaeoecological studies report data for a single core from a single site. Key to answering fundamental Holocene palaeoecological questions therefore are studies which bring together multiple individual records. However, there have been surprisingly few attempts to compile the published data, even for regions that have been intensively researched (Coles et al., 1998; Battarbee et al., 2011; Suggitt et al., 2015). Such compilations have an important role as a source of data for secondary analysis, a guide to the literature for future researchers and to highlight important trends and biases. Here we consider the palaeoecology of peatlands in Great Britain.

Peatlands have been widely used as repositories for palaeoenvironmental information, having the general advantages of:

1) Wide distribution.
2) Relatively easy coring with simple, manually-operated, equipment.
3) Good preservation of a wide range of micro- and macrofossils.
4) Relatively high accumulation rates, allowing studies to have good temporal resolution.
5) An organic medium that is easy to date by radiocarbon.
6) Minimal issues with post-depositional disturbance.

Peatland palaeoecology has a long history in Great Britain, dating back to pioneering researchers such as Sir Harry Godwin in the early decades of the twentieth century (Godwin and Godwin, 1933; Godwin et al., 1935). In more recent years British researchers have pioneered the use of peatland archives for climate reconstruction (Chambers and Charman, 2004; Chambers et al., 2012). However, there has been no systematic attempt to compile and synthesise the extensive literature. We believe that such a synthesis is overdue and that the data contained in these studies is a valuable resource that is currently under-exploited. Our goal here is to produce a new compilation of British peatland palaeoecology studies, use this to explore the changing nature of the research undertaken and make recommendations for the future.

Methods: Producing the compilation

1) Search approach

We used multiple data sources in producing this compilation:

First we exploited existing databases of palaeoecological studies. We found the most useful of these to be the English Core Record Meta-database (Suggitt et al., 2015), the Scottish Palaeoecological Archive Database (Coles et al., 1998) and the European Pollen Database (Fyfe et al., 2009). We inspected all records within our search region and extracted and examined those where details recorded in the database suggested studies that met our search criteria (see below). We also inspected publication lists in studies that have compiled basal radiocarbon dates in the context of peat initiation (Tallis, 1991; Tallis, 1998; Flitcroft, 2006; Gallego-Sala et al., 2015). Each of these data sources only provided a small proportion of the total, clearly demonstrating the need for a more focussed compilation.

Secondly, we conducted literature searches using the databases Scopus and Google Scholar during the period from October 2014 to November 2015. We used many combinations of search terms including the following keywords: Britain, England, Scotland, Wales, United Kingdom, fen, bog, peat, peatland, mire, Flandrian, Holocene, radiocarbon, palaeoecology, pollen, palynology, palaeo* and macrofossils. We typically examined the top 500 returns sorted by relevance and inspected the abstract before reading the paper in more detail if this suggested a study that met our search criteria. Our initial searches revealed a large quantity of relevant material in PhD theses so we also conducted searches of the UK's national thesis repository (EThOS) using many of the same search terms. As several UK universities do not subscribe to EThOS we conducted further searches of institutional thesis repositories.

Our main interest is in radiocarbon dated sites (see below) so we also searched for studies by identifying radiocarbon dates on peat. We examined radiocarbon date lists published in the journal Radiocarbon for the most active UK-based radiocarbon laboratories (including Glasgow, Belfast, Oxford, Cambridge and Birmingham). The main publicly-funded laboratory for the analysis of environmental samples in the UK is the NERC Radiocarbon Laboratory (NERC-RCL), East Kilbride, so we paid particular attention to identifying sites dated at this laboratory. We inspected the lists of older radiometrically-dated studies published by Harkness and Wilson (1973), Harkness and Wilson (1974), Harkness and Wilson (1979) and Harkness (1981) and data published in a CD accompanying Harkness et al. (1997). We also inspected the compilation of radiometric dates produced from 1996-2005 (Garnett et al., 2010) available on the NERC-RCL website (www.gla.ac.uk/centres/nercrcl/results.htm). Information for more recent AMS-dated sites was provided directly by laboratory staff. For all of these sources we identified dates from British sites where the dated material was peat, peat extracts (humin, humic acid) or peat components such as *Sphagnum* macrofossils. We used either publication details associated with the record, or searched by site and/or author name in an attempt to find full publications. We did not include some sites where we located radiocarbon data but not palaeoecological data.

2) Inclusion criteria

We established a number of criteria for inclusion in our compilation.

Our first criterion was that the site can be legitimately considered a peatland. There is no universally accepted definition of the terms ‘peat’ and ‘peatland’. Most definitions of peatland take the form ‘a site with a surficial layer greater than Xcm depth with more than Y% organic material’ but the actual values of ‘X’ and ‘Y’ vary considerably (Charman, 2002) and even differ between the soil surveys of the different nations of the UK (Chapman et al., 2009). In palaeoenvironmental studies the term ‘peat’ is occasionally used rather loosely, and information presented in published studies often does not include the organic content. We opted for a relatively conservative approach, excluding sites where the sediment was described using terms such as ‘silty peat’ or ‘peaty sediment’, sites where mineral sediment overlies peat, and sites with saline influence as these often have more complex stratigraphy.

Our second criterion was the adequacy of the chronology. We believe that palaeoecological records without any form of external chronological control are much less likely to be of interest for future comparison or re-analysis. The overwhelming majority of peatland palaeoecological studies have been dated by radiocarbon so we focus on studies with one or more radiocarbon dates. Preparation, analysis and interpretation methods for radiocarbon determinations have improved considerably since the invention of the method in the 1940s (Libby, 1946; Bronk Ramsey, 2008) and early radiocarbon dates should be treated with a degree of caution. We apply an arbitrary cut-off at 1970, that we suggest is a reasonable estimate for a point in time by which radiocarbon analysis had become a routine method and conventions for publication of radiocarbon data had become reasonably standardised (for instance, consistent use of the Libby half-life). We excluded studies with radiocarbon dates solely on archaeological materials, even where these were extracted from peat contexts, due to the additional complexity this imposes. Similarly, we were cautious of radiocarbon dates on wood, particularly wood macrofossils at the base of profiles as these may not be contemporaneous with surrounding peat. We only included records where dates on wood formed part of a coherent sequence with dates on peat, peat extracts or other plant macrofossils.

We confined our search to Great Britain and outlying islands, including the Isle of Man and Scottish Islands. We did not include sites in Ireland. We assigned each record to a location based on either published coordinates, or estimates of coordinates based on site location maps. In some instances we found published coordinates to be erroneous and in these instances we endeavoured to correct them.

3) Caveats

Total comprehensiveness is an unrealistic goal for a compilation of this type. Other databases are known to have gaps (e.g. Tooley, 2015) and this is very likely to be the case here. There is some material we were unable to access and undoubtedly there are further publications not recovered by our search criteria or overlooked in our searches. Most likely to be excluded are: i) Entirely unpublished records. ii) Records only presented in PhD theses or contract reports. iii) Records associated with archaeological studies, which are often harder to identify and locate. iv) Older material, which is less-likely to be included in journal databases. v) Very recent material not yet included in databases, or in PhD theses, which are not yet publicly accessible. vi) Sites where peat is incidental to the main focus of the study (for instance longer cores where the focus of the authors was on periods prior to the Holocene).

However, we went to considerable effort to identify as much material as possible and believe that our compilation does capture a substantial majority of all the work that has been undertaken. We welcome suggestions from readers for additional material and will endeavour to update the database in the future with both new publications and with material previously overlooked. Given the volume of material considered we cannot guarantee that the dataset is entirely free of errors and inconsistencies but aimed to minimise this by cross-checking between authors.

Results and Discussion

The state of the art

We identified 475 radiocarbon dated palaeoecological records from across Britain published since 1970 (Supplementary Material 1). The average duration of a record is around 4500 radiocarbon years and the records represent a total of 2299 radiocarbon dates (Fig. 1). More than a dozen palaeoecological methods have been applied with an average of 2.3 methods per study. Of these methods, pollen analysis has been by far the most popular (80% of all records), followed by charcoal analysis (37%). Of the methods used for reconstruction of peatland palaeo-wetness, alkali extraction humification analysis (Chambers et al., 2011) has been the most widely applied (19%).

Records are widely dispersed across Britain; there are very few regions with peat left unstudied (Fig. 2). The distribution of palaeoecological studies only loosely follows the distribution of peat. Similar numbers of studies have been conducted in Scotland (44% records) and England (39% records) despite Scottish peatland area being more than four times as great (Joint Nature Conservation Committee, 2011). The distribution map clearly highlights the contributions of individual researchers. The work of Prof. Frank Chambers in south Wales, Prof. Keith Barber in the Scottish borders and Dr. Richard Tipping in Glen Affric are particularly apparent when considering the distribution of studies (Glen Affric is a good contender for the most intensively researched peatland area in Britain). The high density of studies in the peatlands of Devon and Cornwall is clearly attributable to the long-history of palaeoecological research at the Universities of Exeter and Plymouth.

Seemingly the most under-researched area of extensive peat is the Monadhliath Mountains of the western Cairngorms (eastern Scotland). This is a relatively large area with extensive peatland but appears to be entirely unstudied, most likely due to its remoteness. Another notably under-researched peatland area is the Fenland region of eastern England. In this case the comparative lack of research is attributable to the very degraded condition of these agriculturally-utilised peatlands.

The number of palaeoecological records is, of course, a poor proxy for the quality of palaeoecological knowledge. For instance, our assessment is that the three most densely peat-covered regions of Britain (the Flow Country, the Isle of Lewis and Shetland Mainland) are considerably under-researched despite the reasonable number of core records identified in Fig. 2.

<u>Temporal trends in research</u>

In compiling the dataset we observed some notable temporal trends in the research undertaken (Fig. 3). The first is simply a large increase in the number of core records produced over time, with more than three times as many records published in the decade 2000-2010 as the decade 1970-1980. This result may be somewhat exaggerated by the greater accessibility of more recent material but the underlying trend is undoubtedly real, paralleling the increase in publication numbers observed across science (Larsen and von Ins, 2010). Assessing the changing motivations for palaeoecological studies is inherently difficult but it is clear that there has been a sharp decline in studies focused on patterns of vegetation history since the 1980s and a greater diversity of motivations over the last two decades (Supplementary Figure 1). There is a notable drop in the total number of records published since 2010, even when accounting for the shorter time period covered. We suspect this might also be a real trend with perhaps a sentiment that there are fewer 'big questions' remaining to be addressed in the Holocene of Great Britain or, more prosaically, the increasing difficulty of securing funding.

As well as changes in the quantity of research conducted, there have also been changes in the nature of palaeoecological studies. A clear trend over recent decades has been a shift towards multi-proxy studies. Records from the 1970s and 1980s are predominantly based on a single proxy (mostly pollen) but there has been increasing diversity since the 1990s. A particular example of this trend is the increasing inclusion of non-pollen palynomorphs (NPPs) in palynological studies (Fig. 3c). Although the majority of pollen studies still do not include NPPs there appears to have been a large jump this decade.

At the outset we expected that we would see a trend towards improved chronologies. However, while the errors in individual radiocarbon dates have more than halved, the number of dates (per year or per core) has remained broadly constant (Fig. 3). This is surprising as the real-terms cost of radiocarbon analysis has reduced considerably over this period. Researchers have perhaps prioritised the analysis of greater number of cores rather than increasing the number of dates per core.

In compiling the dataset we noted that a significant proportion of data only appears in student theses. We made no comprehensive attempt to follow theses through to publication but estimate that 15-20%

of site records are only ever presented in this format. This is a considerable quantity of data and the real figure may be higher as relevant theses were often hard to identify. The recent trend in UK academia towards producing PhD theses in the form of a collection of papers may help reduce this proportion in the future.

Publication standards and conventions.

The preparation of the database required us to inspect many hundreds of papers. During the course of this exercise we have made various observations about publication standards and conventions, which are worth disseminating. In making these observations we do not mean to preach, but simply to highlight areas where small changes would be helpful to facilitate future studies. Although our data is from British peatlands we believe that many of these observations would hold across Quaternary palaeoecology more generally.

In producing the compilation we noted a clear trend for a reduction in the proportion of studies publishing stratigraphic data (Fig. 4). Whereas stratigraphic diagrams or descriptions are almost ubiquitous in publications from the 1970s and 1980s (>90%) they are now presented in less than two thirds of publications. Partly this decline may be due to the increasing prevalence of macrofossil analysis with a perception that macrofossil data renders more general stratigraphic description unnecessary. However, even when only considering studies that did not present macrofossil data, the decline remains stark (Fig. 4). In compiling this dataset we found stratigraphic information extremely helpful to differentiate peat from non-peat, to identify the base of the peat profile and to understand variability in peat composition and properties. We believe there is a strong case for stratigraphic data to be routinely presented. Indeed, stratigraphy remains important even when macrofossil data is published as it provides additional information, such as the presence of mineral layers or changes in colour or decomposition of the peat, which may not be apparent from macrofossils alone.

We noted that the details of coring location provided in publications were often not sufficiently specific to allow the coring site to be located with a high degree of precision. We calculate that 23% of studies either did not present a grid reference for their coring location, this reference was obviously incorrect (e.g. in the sea), or was less precise than the eight figure (two letters plus six numbers) Ordnance Survey grid reference we consider minimally adequate (there was no clear temporal trend in this proportion (Fig. 4)). Many of these studies did present sketch maps. However, we found that matching author’s sketch maps with published maps for the same regions was often difficult and generally introduced a substantial degree of imprecision. Even a standard eight figure grid reference is insufficiently precise to allow a coring spot to be accurately re-located on the ground in the future. Most researchers will now have access to GPS technology when in the field and we recommend that coordinates are recorded and published to the maximum degree of precision possible.

Conventions for the publication of radiocarbon data are well established, of which the most important are the publication of laboratory codes and uncalibrated, as well as calibrated, dates (Stuiver and Polach, 1977). While a majority of published studies abided by these conventions we located a non-trivial number of studies (>5%) that failed to either present uncalibrated dates and/or did not include laboratory codes. These conventions are important to allow dates to be traced and re-calibrated with new calibration curves. Dates only published in calibrated form, only presented in terms of an age mid-point, or only as a point on a graph are unlikely to be useful for future analysis. We stress the importance of abiding by these conventions.

Finally we note that it is often difficult to judge the nature of a peatland site on the basis of published information. To a large extent this is because there is no universally-accepted system for classifying peatlands. One author's 'poor fen' may be another's 'valley bog', 'soligeneous mire' or 'peat-filled basin'! As a universal system of classification is unlikely in the near future we advocate the publication of as much supporting information as possible to allow readers to judge the site for themselves. Particularly important in this respect is information on vegetation. The ideal would be for researchers to survey vegetation using an accepted system, such as the UK National Vegetation Classification (Rodwell, 1991). Most researchers will have taken photographs of their sites in the field and these can be a useful aid to the reader in understanding the nature of the site. Sketch maps and site profiles provide useful further information and data on loss on ignition can be very useful to distinguish peat from other sediments.

A proposal for future publications.

Since the 1970s palaeoecological papers have reduced in average length by almost 40% (Supplementary Figure 2). This trend towards shorter papers probably reflects both a desire among authors to present results concisely and increasingly stringent journal limits (Statzner and Resh, 2010), and may partly explain why some information has been increasingly omitted. However, the advent of online supplementary material in most journals means that there is now little barrier to the presentation of supporting information: it is entirely possible to have *both* a concise, focussed, paper and comprehensive presentation of the results. We propose that it would be useful for future authors to make much more use of online supplementary material to present study meta-data. Doing so would ensure that all essential information is presented in all studies, and would facilitate future compilations of literature particularly if information is presented in a consistent format. We suggest that essential information that should be presented in this way includes: the full location details, site description, vegetation, core stratigraphy, dating points and a list of palaeoecological methods applied. In Supplementary Material 2 we propose a pro-forma that could be used for this purpose and that we intend to use in our future work. We advocate the inclusion of this form, or an equivalent, in the supplementary material of future publications.

Value for secondary analysis.

We believe the compilation we assemble here will be of considerable value for secondary analysis. The most obvious use of the data is focussed on the original questions of each study. For instance, a large number of peatland studies have addressed vegetation history and could contribute to improving models of changing Holocene vegetation. While the European Pollen Database includes some of these sites, we identify many more that could potentially make a contribution. Many more recent studies have focussed on climate change and the integration of such records could contribute to better syntheses *cf*. (Charman et al., 2006). The charcoal records could contribute to understanding Holocene fire frequency. Clearly considerable work might be required to digitise old data but we believe this would be a worthwhile investment.

These datasets could also contribute in less obvious ways. Peatlands are valued for their role as a carbon sink and peatland conservation and management is increasingly driven by the necessity to conserve carbon stocks (Bain et al., 2011). The carbon stock of UK peatlands is quite poorly constrained; estimates reviewed by Lindsay et al. (2010) vary more than fivefold and there are very few records of long-term carbon accumulation (Anderson, 2002; Mauquoy et al., 2002; Turner et al., 2014). Previous palaeoecological studies may provide data to help improve this picture; many give information on peat composition and inorganic content, important terms in the carbon stock calculation. Radiocarbon profiles may help constrain estimates of Holocene carbon flux. Finally, simply the peat depth measurements may be of value to improving estimates of current carbon stock. Some of these applications will be re-visited in subsequent publications.

The peatlands of Great Britain are undoubtedly some of the most researched anywhere. The vast body of palaeoecological data brought together by this study is an enormous resource for future research.

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We welcome data contributions from readers. To make it easier to incorporate future additions and keep the database up-to-date we would appreciate if wherever possible data contributors could format their contributions to match those already listed.

Author contributions: RJP conceived the study, wrote the first draft of the manuscript and conducted data compilation. JR conducted data compilation. RA contributed to planning the study and helped supervise the work of JR. CEF contributed an earlier compilation of studies from Scotland. All authors contributed to the manuscript.

<u>Figures</u>

Figure 1. a) Methods applied in the identified studies. The 'other methods' group includes a very broad range of less popular methods such as magnetic susceptibility, x-radiography and coleopteran remains. Studies were only counted as including NPPs where a broad suite of microfossils were identified (not just *Sphagnum* spores for instance). b) Records by time period covered. Duration is calculated on a simplistic basis as the time difference between the oldest date and year of publication (where sampling

was conducted through the entire peat column) or the oldest and youngest date (where sampling did not continue to the surface). Radiocarbon ages are not calibrated.

Figure 2. Spatial distribution of peatland palaeoecological studies. Area shaded in brown is peatland distribution based on British Geological Survey surficial geology mapping.

Figure 3. Temporal trends in published palaeoecological site records from Great Britain. a) Number of studies over time; b) numbers of proxies employed by those studies; c) the proportion of pollen studies including non-pollen palynomorphs; d) dates per core; e) years per date; f) the mean error of dates. Bars for the decade from 2010 are shaded in white and comparisons to earlier decades should be made with caution. The number of proxies in b is based on the same groups used in Fig. 1.

Figure 4. a) Percentage of studies presenting stratigraphic information or diagrams. The hatched bars represent percentages re-calculated after excluding studies presenting macrofossil data. b) Percentage of studies not presenting site coordinates, or coordinates to low resolution (<8 digit ordnance survey reference).

Supplementary Figure 1. Changing motivations for palaeoecological studies of British peats. All core records were assigned to one of five exclusive categories. This is a subjective decision and does not fully account for the multiple motivations of individual authors.

Supplementary Figure 2. Changing length of publication for the studies we consider. Results include journal papers and book chapters, but not PhD theses or books.

Supplementary Material 1. The British Peatland Palaeoecology Meta-database.

Supplementary Material 2. Suggested pro-forma for future palaeoecological publications.

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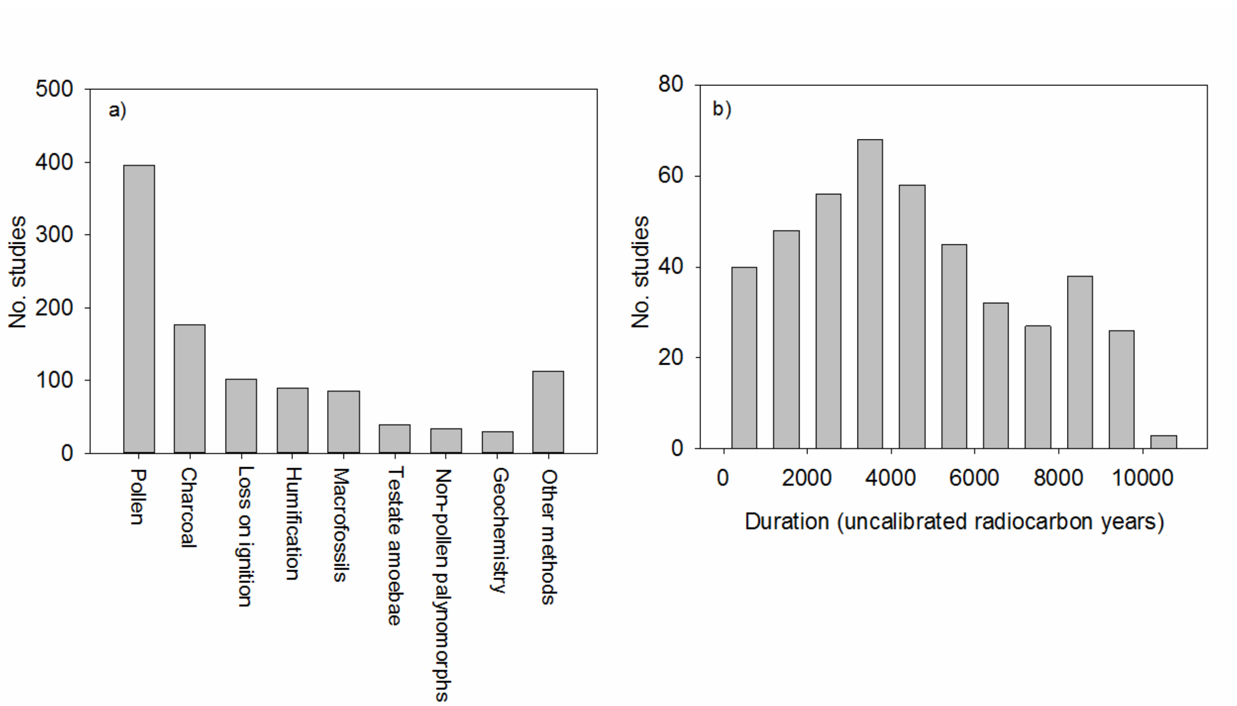


Figure 1. a) Methods applied in the identified studies. The 'other methods' group includes a very broad range of less popular methods such as magnetic susceptibility, x-radiography and coleopteran remains. Studies were only counted as including NPPs where a broad suite of microfossils were identified (not just *Sphagnum* spores for instance). b) Records by time period covered. Duration is calculated on a simplistic basis as the time difference between the oldest date and year of publication (where sampling was conducted through the entire peat column) or the oldest and youngest date (where sampling did not continue to the surface). Radiocarbon ages are not calibrated.

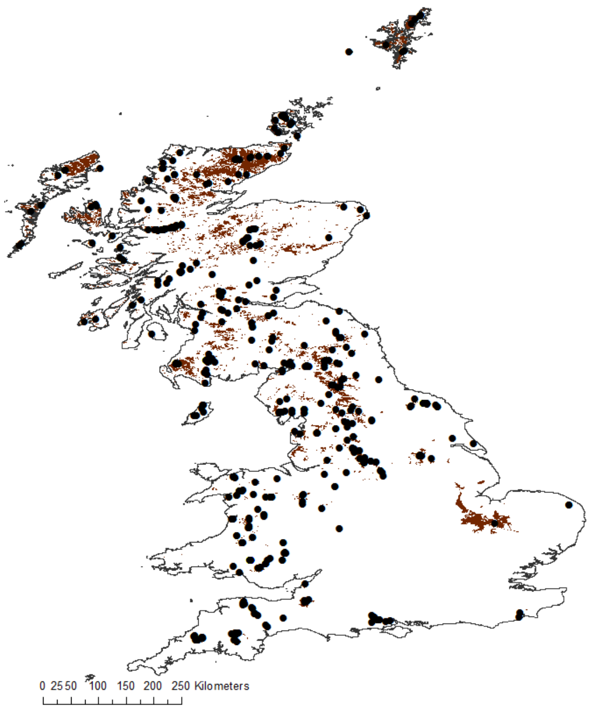


Figure 2. Spatial distribution of peatland palaeoecological studies. Area shaded in brown is peatland distribution based on British Geological Survey surficial geology mapping.

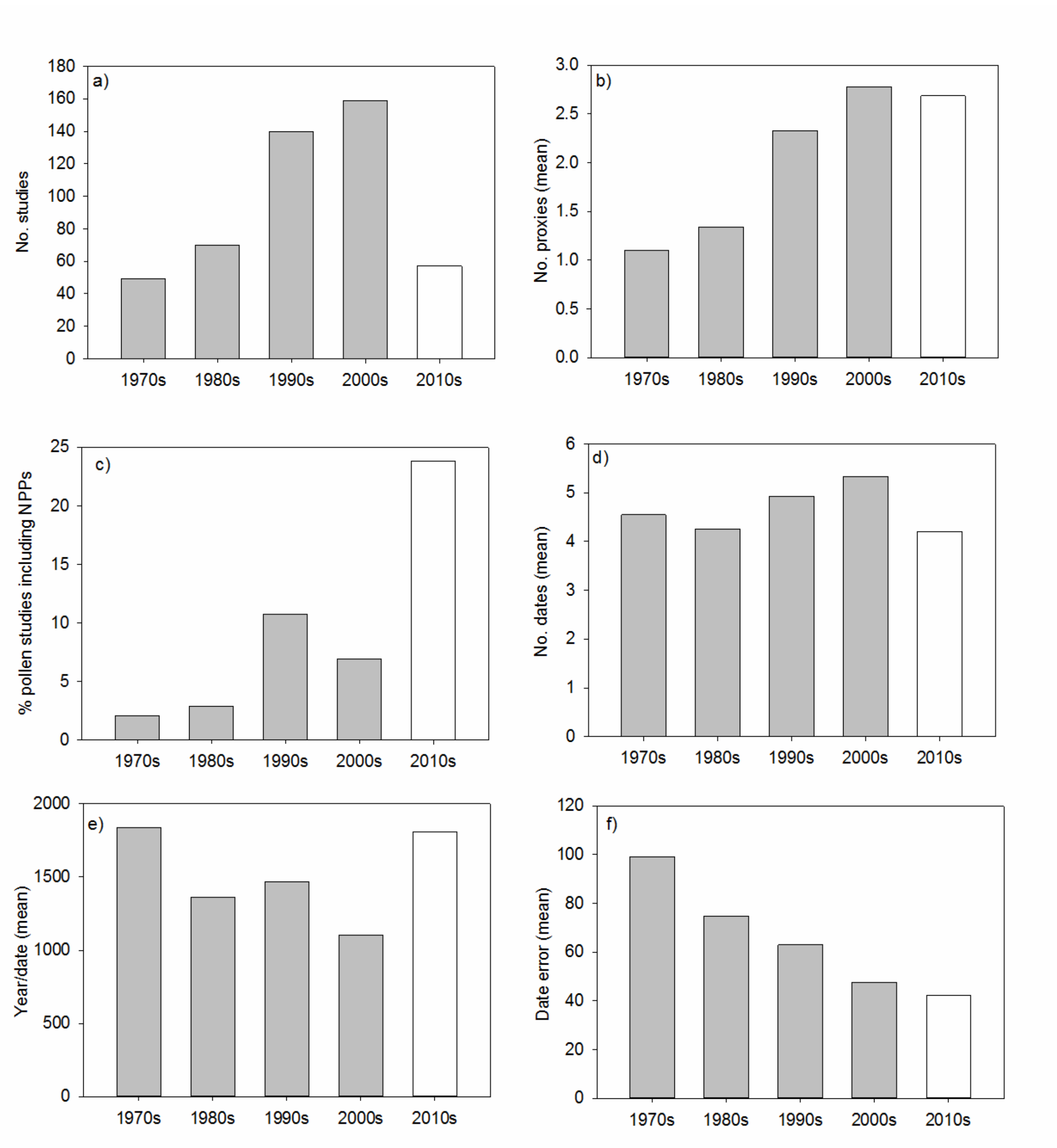


Figure 3. Temporal trends in published palaeoecological site records from Great Britain. a) Number of studies over time; b) numbers of proxies employed by those studies; c) the proportion of pollen studies including non-pollen palynomorphs; d) dates per core; e) years per date; f) the mean error of dates. Bars for the decade from 2010 are shaded in white and comparisons to earlier decades should be made with caution. The number of proxies in b is based on the same groups used in Fig. 1.

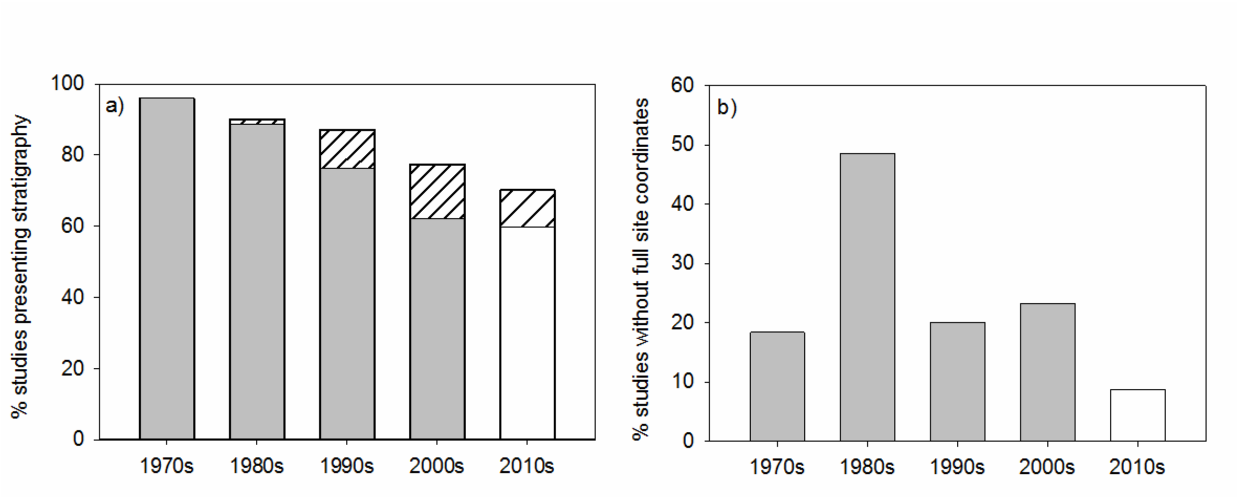
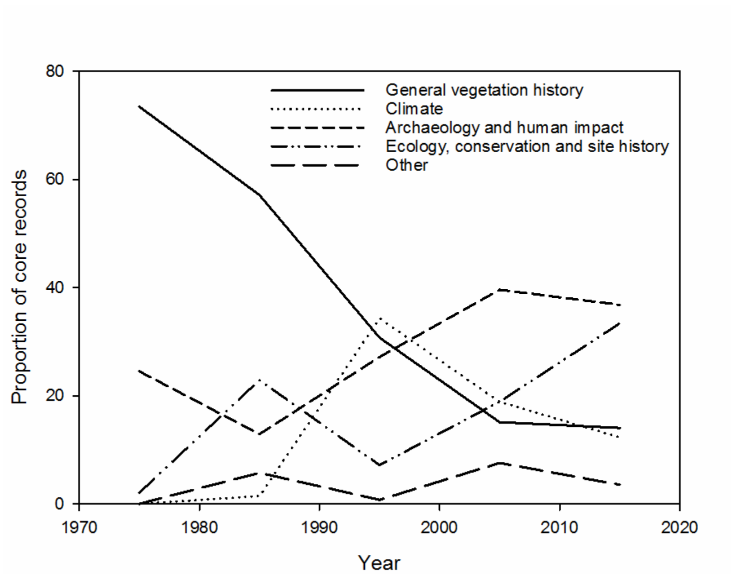


Figure 4. a) Percentage of studies presenting stratigraphic information or diagrams. The hatched bars represent percentages re-calculated after excluding studies presenting macrofossil data. b) Percentage of studies not presenting site coordinates, or coordinates to low resolution (<8 digit ordnance survey reference).



Supplementary Figure 1. Changing motivations for palaeoecological studies of British peats. All core records were assigned to one of five exclusive categories. This is a subjective decision and does not fully account for the multiple motivations of individual authors.

Supplementary Figure 2. Changing length of publication for the studies we consider. Results include journal papers and book chapters, but not PhD theses or books.

Palaeoecological record meta-data.

Site Name:							
Core code: *As assigned by author.*							
Country:							
Region:							
Coordinates: *Please give to the highest resolution possible and specify coordinate system used (e.g. WGS84).*							
Site type (general): *Specify general nature of site (e.g. 'peatland').*							
Site type (specific): *Note specific nature of site (e.g. 'raised bog').*							
Site description: *Provide a description of the field site.*							
Coring method: *Specify the corer used and any further details.*							
Vegetation: *Please provide as much details as possible, ideally survey-data using an established system (specify).*							
Radiocarbon dates: *Please provide full details for all ^{14}C dates.*	Depth lower (cm)	Depth upper (cm)	Date (BP)	Error	Laboratory code	Material dated	Method
Other dates: *Provide details of dates by other methods (e.g. tephra, ^{210}Pb).*							
Comments on dating: *Please provide any comments on dating and chronologies. For instance, details of any dates considered aberrant.*							
Palaeoecological methods applied: *Specify the methods applied.*							
Sampling resolution: *Specify the resolution of sampling for each method*							

applied.				
Stratigraphy: *Please provide as much detail as possible on core stratigraphy.*	Depth lower (cm)	Depth upper (cm)	Description (include Troels-Smith code if possible)	Contact
Comments on stratigraphy: *Please provide any comments on stratigraphy, for instance any evidence for an accumulation hiatus.*				
Have other data from the same core been described elsewhere? *If so, provide publication details.*				
Site photographs:	*Please append below.*			