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Investigating patterns of wildfire in Ireland and their correlation with regional and global trends in fire history

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A B S T R A C T

In recent years a number of studies have suggested that trends in wildfire can be seen at a regional, national and global scale, and can be explained by interactions with factors such as anthropogenic activity and climate. As future susceptibility to fire is expected to be high it is important to understand such interactions and drivers of fire to help manage and mitigate against its destructive impacts for the future. This paper examines trends in wildfire within Ireland, between a range of study sites in both upland and lowland ecosystems. A synthesis of the Irish charcoal record is also provided, utilising the new Paleofire package in R, which is used to compare charcoal trends from the UK, Europe, North America and the World. This will help to determine potential drivers of wildfire at a variety of geographical scales. This study highlights how the Irish study sites display independent fire regimes at the local scale, dictated by specific local conditions; while the composite record for Ireland is in agreement with large scale trends in fire activity from across the globe, which are dictated by factors such as climate, temperature, precipitation, atmospheric CO_2 concentration and anthropogenic activity.

1. Introduction

Globally wildfire is dictated by factors such as climate, vegetation, human activity and land use, which have been in fluctuation with the increase in atmospheric CO_2 concentration and the onset of climate change (Prentice et al., 2011). In recent years with the increase in global warming there has been a wide concern for the implications this will have on wildfire (Westerling et al., 2006) with many hypothesising that wildfire will increase in the future (Girardin and Mudelsee, 2008), creating more frequent and intense impacts on the environment and people (Gonzalez et al., 2010; McKenzie et al., 2004). It is therefore important to study the interactions between fire and its controlling factors, as well as seek to identify any patterns in wildfire that may exist regionally, nationally or even globally (Marlon et al., 2013).

A number of studies have examined global trends in wildfire and identified that globally fire was generally low in the Late Glacial and Early Holocene, and subsequently increased throughout the Holocene (Daniau et al., 2012; Marlon et al., 2013; Power et al., 2008). These trends are consistent with the global increase in temperature seen through the glacial-interglacial transition. However examining various regions reveals that not all areas follow a similar pattern, presumably due to specific local conditions that were either conducive or unfavourable to fire. It can also be seen that changes in land use or human activity are not sufficient alone to explain the record of biomass burning at a regional or continental scale during the Holocene (Marlon et al., 2013), although they do play a significant role at the local scale.

Over the past 150 years the global expansion of intensive grazing, agriculture and fire management have contributed to a decline in biomass burning (Marlon et al., 2008). This decline has occurred despite an increasing population and increasing air temperature. It has also been suggested that changes in CO_2 can reflect changes in biomass burning. Calvo et al. (2014) has stated that changes in CO_2 concentration are a major factor in changing global fire patterns, especially between glacial and interglacial periods. Human activity is another important factor thought to be affecting global fire regimes. The term 'Anthropocene' is being increasingly used to chronologically constrain the period of large scale environmental change being driven by human activity (Chin et al., 2013; Oldfield et al., 2014). Attempts to interlink fire activity and the Anthropocene have prompted the conclusion that biomass burning was increasing throughout the Holocene until very recently (Marlon et al., 2013). Despite this an increase in burning occurred

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from 12 to 10,000 cal BP as a consequence of deglaciation and an increase in global temperatures. Increasingly during the past two centuries, anthropogenic activities have played an important role in global biomass burning (Marlon et al., 2012), and factors such as population growth, fire suppression, land use change, agriculture, overgrazing, urbanisation and invasive plants, have caused changes in regional fire regimes (Bowman et al., 2011). Sedimentary charcoal records from the Global Charcoal Database (GCD) analysed by the Global Paleofire Working Group (GPWG) have concluded that biomass burning reflects regional climate changes and human activity is not sufficient to explain large-scale long-term variations. Therefore the charcoal records do not appear to support the Early Anthropocene Hypothesis (Bartlein et al., 2011).

This paper presents a comparative analysis of wildfire between seven study sites spread across Ireland, to identify regional trends, and examine how these tie in with wildfire at a global scale. Ireland's location in North West Europe adjacent to the North Atlantic Ocean produces a mild oceanic climate. The high level of precipitation experienced is anecdotally presumed to suppress wildfire, however recent data suggest that fire has been increasing in the Irish landscape in recent years (Nugent, 2015). This prompts a long term macro-charcoal study of paleo-fire in Ireland, where previous work was confined to micro-charcoal on pollen slides where temporal resolution is often low and spatial resolution too high. This is the first analysis of its kind in Ireland where the pattern of past fire regimes is largely unknown. This analysis will yield further information about the drivers of wildfire, how wildfire changes over time, and its response to current climatic changes, on a local and global scale. Ireland's unique location with little climatic variation provides the perfect backdrop to study oscillations in past environments, climate and extreme events. Future climate predictions for Ireland indicate that temperatures are to continue to increase, and summers are to become drier with up to a 20% reduction in precipitation (Gleeson et al., 2013). This will increase the vulnerability of the Irish landscape to wildfire, therefore studies such as this are essential to identify and quantify the drivers and patterns of wildfire in Ireland in the past, which will help to predict and manage the future impacts.

2. Study sites

Seven study sites from Ireland are utilised in this analysis, providing macro-charcoal records from lacustrine sediment. The sites represent a regional spread across the country, and comprise a range of upland (Borheen, Diheen and Kelly's Lough), lowland western (Cuckoo and Sheheree Lough) and lowland midland (Ballinderry and Cornaher Lough) environments. A contrasting geology is displayed with Carboniferous Limestone (Ballinderry, Cornaher and Sheheree Lough), Devonian Old Red Sandstone (Borheen, Diheen and Cuckoo Lough) and Devonian Granite (Kelly's Lough). Characteristics of the sites and more details, including vegetative composition are reported in Hawthorne (2015), also see Fig. 1. Common tree and herbaceous taxa are however observed regionally e.g. *Corylus* (hazel), *Pinus* (pine), *Quercus* (oak), and Poaceae (grass). Vegetation composition, local climatic conditions and anthropogenic activity may influence local fire occurrence, and exhibit variations on a site by site basis. Additional charcoal data are utilised from the Global Charcoal Database (v. 2) (Power et al., 2010) to assist in the composite analysis. Fig. 2 presents a world map of study sites used for the composite analysis here, with lacustrine sediment sites in red. The charcoal data from Ireland were generated from lacustrine sediment hence; only lake sites from the GCD were chosen for comparison in this study, and grouped into different regions depending on location i.e. Britain Europe, North America and Worldwide. The charcoal and dating methods vary between sites within the GCD, and detailed metadata are available for each site including dating technique, chronology, site type and charcoal method (Power et al., 2008). Some variation is accounted for in the data analysis via transformation and scaling to a constant temporal interval.

3. Methods

3.1. Macroscopic charcoal analysis

To generate the Irish charcoal data presented, charcoal analysis was carried out on contiguous samples at 1 cm spacing down the full sediment cores from all sites. The method for preparation was adapted from those described by Mooney and Black (2003) and Mooney and Radford (2001). Digital image analysis using Image J was applied once the samples were prepared, to generate count and area data, and follows methods similar to Schlachter and Horn (2012). Each of the sediment cores was also radiocarbon dated, and chronologies were produced using BChron and Intcal13 calibration curve (Haslett and Parnell, 2008). CharAnalysis (Higuera, 2009) a programme within Matlab was used to identify specific fire events, their magnitude, fire frequency and fire return interval. Specific parameters for this analysis were chosen in conjunction with an Ensemble Member strategy (Blarquez et al., 2013). This methodological approach was reviewed in detail by Hawthorne and Mitchell (2016).

3.2. Charcoal synthesis

The paleofire package within R (Blarquez et al., 2014), was used to analyse and synthesise the charcoal data from the seven study sites in Ireland, and the sites selected for analysis from the geographical regions (Britain, Europe, North America and Worldwide) from within the Global Charcoal Database (GCD). Discussions related to charcoal activity can be described as 'local' (within a few kilometres), 'regional' (a defined area within a country e.g. Galty Mountains) and 'national' (an entire country or nation).

Charcoal values can vary widely within and between sites due to multiple factors such as charcoal accumulation, varying analytical methods or type of record. To try and account for this, the charcoal records were standardised before generating any composite record (Power et al., 2008). A three step data transformation was employed which includes a minimax data rescaling, a variance homogenization using a Box and Cox (1964) data transformation, and a final rescaling to Z-scores. In this analysis another minimax rescaling was added after the Box-Cox transformation because Box-Cox transformed series are only comparable if they share identical λ values (Marlon et al., 2008). A synthesizing or compositing is carried out whereby the charcoal data from each of the selected sites are pooled to calculate a mean charcoal value across all sites at each time step. The composite curve is calculated using a data-binning procedure, where the mean charcoal value is calculated within each binning interval (500-years) and then the mean calculated for the whole series (Blarquez et al., 2014). The composite approach used here is similar to that of Power et al. (2008) but also combines methods proposed by Marlon et al. (2008) and Daniau et al. (2012). Confidence intervals associated with the composite curve were calculated using a bootstrap resampling of the binned charcoal series and the mean calculated for each bin 1000 times i.e. nboot = 1000. The method and parameters used here have been chosen to produce a composite record, as accurate as possible for the study sites in question.

Caution should however be taken when interpreting the curve where the number of study sites is low e.g. before 10,500 cal BP. Areas of the curve which contain a larger number of study sites

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