The ecosystem of peatland research: a bibliometric analysis

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SUMMARY

(1) Peatlands provide a range of services to societies, such as sequestration of organic carbon, biodiversity protection, attenuation of water flow, and the provision of fuel, wood and fruit, among others. Despite their global importance, no study has yet characterised peatland research on a global scale. This study aims at providing a better understanding of the geographical distribution of peatland research, of its variations through time, and of the specific topics studied.

(2) Results show that peatland research has, between 1991 and 2017, become increasingly international and diversified, with more countries and study sites active, and an increase in foreign sites studied. We do observe, however, that the general vast peatland regions of the world showed relatively distinct profiles in terms of topics which, in most cases, are related to their geographical features.

(3) Peatland research has a spatial imbalance in favour of central Europe, with studies in Africa and Brazil highly under-represented in relation to their area, and those in western and eastern Siberia moderately under-represented. We also observe some topics have become increasingly studied during recent decades, e.g. climate change, fire, restoration and carbon, while others have been decreasingly studied, such as botany, nitrogen and coal.

KEY WORDS: bibliometrics, ecosystem, internationalisation, peatland, topic

INTRODUCTION

Peatlands are unique ecosystems, distinguished from non-accumulating wetlands by the presence of organic deposits of at least 30 cm thickness (Joosten & Clarke 2002). Peatlands are generally located in low-lying areas of tropical, temperate, boreal and sub-arctic regions (Wieder *et al.* 2006). The types of ecological processes and the rates at which they evolve are highly variable along the climate gradient. In general, tropical peatlands have higher net primary productivity and decay rates, while in northern peatlands both net primary productivity and decay rate are generally low (Hodgkins *et al.* 2018). Likewise, peatland vegetation is markedly different in tropical and in boreal and sub-arctic regions. Whereas forested peatlands are the main type in the tropics, in northern peatlands *Sphagnum* moss is the dominant plant, and trees are generally sparse, if present at all. What all peatlands have in common though, is their accumulating 'nature', as productivity of organic matter exceeds decay in the long-term. The thick coal seams located now hundreds of metres below the surface, the thick domes of woody peat in the tropics, and the acidic, spongy deposits that accumulated during the Holocene in the northern regions are testimony to the relative resilience of peatlands over decades, millennia, and geological epochs. Being efficient archives of climate and environmental change, peatlands have been studied by geologists, geochemists, palaeoecologists, biologists and archaeologists (Barber *et al.* 1994, Shotyk *et al.* 1996, Large 2007, Dommain *et al.* 2011, Viehweider *et al.* 2015). This broad research community, representing the 'ecosystem' of peatland research, has, to our knowledge, never been an object of study, and temporal variations in research topics and geographical coverage have not been measured. This article presents the results of a bibliometric study on peatland research, across the period 1991–2017.

Bibliometrics may be defined as the quantitative (statistical) evaluation of literature, under the premise that new knowledge is diffused through the scientific literature (Gingras 2016). By measuring scholarly articles, and their various characteristics, bibliometrics allow for the measurement of new knowledge, and of the context in which this knowledge is created (Sugimoto & Larivière 2018).

Peatland research

Peatlands provide a range of ecosystem services to societies (de Groot *et al.* 2002), including the sequestration of organic carbon, biodiversity protection, attenuation of water flow (thus minimising flood and drought risks) and the provision of fuel, wood, fruit and horticulture products. The current peatland organic carbon stock is estimated at ~ 500 Gt (gigatons), or about 30 % of the global soil organic carbon stock (Yu *et al.* 2010, Yu 2012). This reservoir has accumulated in many regions for multiple millennia, and the net transfer of carbon from the atmosphere to biomass and soil is calculated to have resulted in a cooling effect on Earth's climate over the course of the Holocene (Frolking & Roulet 2007). Stratified peat layers represent natural archives of various chemical, physical and biological indicators, which allow for reconstructions of local water table dynamics (Charman & Warner 1997), dust, N, P and K solutes and heavy metal deposition (Bragazza *et al.* 2006, De Vleeschouwer *et al.* 2014), permafrost dynamics (Jones *et al.* 2013), fire activity (Marcisz *et al.* 2015) and carbon accumulation rates (Yu 2011). Despite their relative resilience in the long term, peatlands are subjected to anthropogenic pressure and climate change. Ongoing climate change may negatively affect the global peatland carbon stock (Swindles *et al.* 2015, Gallego-Sala *et al.* 2018) through net emissions of carbon dioxide and methane resulting from drying and burning or from permafrost thawing (Voigt *et al.* 2019). Thus, peatlands may act as important feedback mechanisms to climate change (Ise *et al.* 2008).

In the more densely populated regions of the world, peatlands have been converted into arable land for centuries. In Europe, peatland ecosystems have been drained for forestry and agriculture and peat has been cut for fuel since the Medieval period. As a result, Europe has lost about half of its former peatland area over the last millennium (Joosten & Clarke 2002). Tropical peatlands have been less affected historically, but peatland area loss rates are increasing. For example, between the 1980s and 2010, Peninsular Malaysia, Sumatra and Borneo lost 20 % of their peatland area to industrial plantations (Miettinen *et al.* 2012). During the second half of the 20th century, recognition of the multiple ecosystem services provided by peatlands led to the adoption of conservation policies, for example through the Ramsar Convention on Wetlands, which entered into force in 1975, yet the effectiveness of these policies is mixed. Following the need for conservation, restoration techniques for affected sites were developed and applied, many in Europe (Vasander *et al.* 2003, Prach *et al.* 2014) but also in North America (Rochefort *et al.* 2003, Andersen *et al.* 2006) and the tropical regions (Page *et al.* 2009).

Peatlands show highly complex dynamics involving physical, chemical, biological and hydrological processes. Due to this complexity, they respond nonlinearly to external forcing or disturbance, i.e. they may show resilience to gradual forcing but shift to a new state as soon as a 'threshold' is crossed (Belyea 2009). In this light, peatland scientists need to acknowledge all possible key variables in order to accurately evaluate peatland response to external forcing, such as climate change (Morris *et al.* 2015, van Bellen *et al.* 2018). Numerical models, for example the Holocene Peat Model (Frolking *et al.* 2010) and DigiBog (Baird *et al.* 2012), are capable of simulating temporal and spatial variations in peat accumulation and they are essential in apprehending the relative importance of the variables influencing peat accumulation. Meanwhile, peatland processes and their rates are strongly determined by local geography and climatic settings. Thus, in an ideal world, peatland research would not be limited to specific geographical settings. A geographically balanced understanding of each aspect of peatland research would favour an accurate representation of global peatland dynamics. In other words, imbalances in the global distribution of peatland research may create a bias in the understanding of specific topics in peatland science.

The aim of this study is to characterise peatland research at global scale between 1991 and 2017. Specifically, we aim to map the geographical distribution of research activity in terms of countries undertaking the research and the location of study sites, and to reconstruct variations in these through time, for both peatland research globally and for a range of major topics.

METHODS

Data

Data were obtained from the Science Citation Index (Expanded) which is integrated in Clarivate's Web of Science (WoS), on 27 November 2018. This database has a documented bias towards English-language periodicals (Mongeon & Paul-Hus 2016), which may be hazardous when studying global issues. However, the timeframe of analysis of 1991–2017 is largely dominated by communications in English; limiting the corpus to English communications may be an accurate representation of the availability of knowledge to the major part of the current research community. Peatlands are identified in English by a diverse terminology. For example, the terms ‘peatland’ and ‘mire’ refer to all types of peat-accumulating ecosystems, whereas ‘bog’ and ‘fen’ are subsets of these. ‘Bog’ is often used to represent a peatland with a water table disconnected from its surrounding, regional hydrology. ‘Fen’, in contrast, is defined by the presence of a linkage between ecosystem water table and catchment drainage and more nutrient-rich, or minerotrophic, conditions (Wheeler & Proctor 2000). ‘Moor’ is rather poorly defined, representing both bogs and fens, but often referring to shrubby peatlands which may even be barren of peat deposits.

In order to obtain a representative corpus of scientific articles on peatlands, the query ‘peatland* OR (bog AND peat*) OR (fen AND peat*) OR (mire AND peat*)’ was applied to both titles and abstracts indexed for the period between 1991 and 2017. The query purposely included the terms designating the ecosystem as the focus was on peatland research at any spatial scale, rather than research on peat as a physical substance. As a result, the corpus included articles on pre-Quaternary ‘fossilised’ peatlands in the discipline of geology and petrology. The applied query generated a high precision since the addition of ‘peat’ to ‘bog’, ‘fen’ and ‘mire’ helped to reduce noise created by non-related research articles on subjects that incorporate these words. One journal indexed by WoS, *Mires and Peat*, was considered a ‘specialist’ journal on peatland research and all articles published in this journal were included in the corpus. For each article, title, year of publication, country of the institution of the first author, journal name, abstract and keywords were extracted.

General characterisation of peatland research

To evaluate the general development of peatland research, the number of articles in this area was compared to a baseline, which was defined by all articles indexed by WoS in the disciplines of Biology, Physics, Chemistry, Mathematics and Earth & Space (combined) between 1991 and 2017. As peatland research is generally incorporated in at least one these disciplines, we hypothesise the research and publishing practices of these disciplines are similar to those of peatland research, and therefore any relative change in the number of articles published in peatland research would be proportional to changes in scientific interest.

Geographical analyses

The global distribution of peatland research activity was measured by identifying the country of the affiliation of the first author of each article as well as the country or region of the field site. The country of the affiliation of the first author was used as indicator of the origin of the research. This variable was indexed in WoS and retrieved without further manipulations. The identification of the location of the research sites was performed by analysing title and abstract for each article, identifying and evaluating mentions of geographical entities. For articles lacking a clear mention of research site locations in the title or the abstract the full text was screened for the geographical location(s) of the study. Research site locations were grouped at the level of the country and the resulting dataset was used to evaluate linkages between national research production and research locations. In addition, a dataset was created re-grouping sites at the regional level for Canada, the USA and Russia, following the spatial distribution of regions with major peatland area and carbon stocks (Yu 2012). A few smaller islands, such as Svalbard and Easter Island, were grouped as well. Canadian sites were classified as either western Canada, eastern Canada, or the Hudson Bay lowlands. Sites within the USA were assigned to either conterminous USA, hereafter referred to as ‘USA’, Alaska or Hawaii, while Russian sites were grouped either within European Russia, western, or eastern Siberia. Articles with research sites in multiple countries were assigned multiple countries or regions. Research without a clear reference to field sites, such as global-scale studies or laboratory experiments, were not included in geographical analyses.

Topic analyses

WoS assigns a variable number of keywords to each article, which are based on their cited references. Keywords were assumed to represent the topics covered by each article and thus the frequency of keyword occurrence may be used as an indicator of the publication of knowledge in a specific topic. As it may be hazardous to identify the number of keywords needed to accurately quantify the importance of a specific topic, the aim of this analysis was not to compare the relative importance of different topics or disciplines among them, but rather to evaluate changes in the importance of specific topics through time. Keyword analyses started by ranking all single keywords according to the total number of occurrences. In this ranking, some of the most common keywords were too broad (for example, ‘peatlands’ and ‘peat’) and a selection of main topics was performed to ensure that only those keywords that could be reasonably assigned to specific topics were analysed. These keywords were quantified according to the queries detailed in Table 1. Extensions of basic keywords were retrieved using truncation. For example, to retrieve all articles on restoration, ‘restor’ was used, which allowed for the detection of ‘restoration’, but also ‘restoring’, etc. For geographical analyses, keyword occurrences were quantified per country or region of the study site.

The results of keyword analyses were compared with an evaluation of the development of disciplines, based on journal scope. Groups of journals were identified *a priori*, and the number of articles published per group of journals was assumed to reflect the development of the journal’s discipline. Journals were classified according to keywords in the journal title, and, in cases where the title did not provide sufficient detail, on the scope of the journal as found on its website. Similar to keyword analysis, the aim was to evaluate the relative change in discipline importance through time, rather than to compare multiple disciplines. Thus, journal groups were not assumed to be exhaustive but, rather, to be a representative sample of the discipline. All journals in the corpus were ranked according to the number of articles published, and the 100 highest ranked journals were selected for analysis. Six of these 100 journals could not be assigned to a specific discipline, including *Mires and Peat*, as well as multidisciplinary journals such as *PLOS One*. These journals were classified in a group of ‘generalists’. Finally, 37 journals could not be assigned to a clear discipline, such as *Biogeosciences*, or had a clear regional scope, for example *Acta Societatis Botanicorum Poloniae*, or had a too narrow scope, such as *Radiocarbon*. These journals were not included in the analyses.

Table 1. Keyword totals, identified as topics, and queries applied for each keyword.

Topic	**Query**	***n***
Carbon	carbon NOT radiocarbon	1814
Botany	vegetation	1131
Carbon dioxide	carbon-dioxide OR co2	895
Methane	methane OR ch4	839
Climate change	climate-change	678
Holocene	holocene	514
Nitrogen	nitrogen	484
Biodiversity	diversity	399
Hydrology	hydrolo OR groundwater	344
Isotopes	isotop	285
Fire	fire	259
Restoration	restor	257
Testate amoebae	testate OR rhizopod	246
Microbiology	microb	235
Phosphorus	phosphorus	214
Management	manag	190
Pollution	pollution	148
Permafrost	permafrost	145
Coal	coal NOT charcoal	133
Mercury	mercury	90

RESULTS

Trends in article publication

A total of 8117 articles, published in 1062 different journals, were retrieved and analysed. Over the 1991–2017 period, the number of articles published per year showed a strong increase, from 93 in 1991 to 622 in 2017 (Figure 1). When compared to the baseline curve (i.e. all natural sciences), peatland research increased from 0.04 % in 1991 to 0.12 % in 2017, thus nearly tripling its relative share over this period. The strongest increase, both in absolute and relative terms, occurred between 2006 and 2014. Of all journals, *Holocene* was the highest ranked, accounting for 219 articles (2.7 % of all articles published), followed by *Biogeosciences* with 161 articles (2.0 %) and *Science of the Total Environment* with 157 articles (1.9 %) (Table A1 in the Appendix). The number of different journals increased from 69 to 250 journals between 1991 and 2017 (Table A2). The data showed a strongly skewed distribution, with 20 % of the journals publishing 79 % of the articles. Such inequality is codified in several 'Laws' of which Bradford's Law of Scattering (Bradford 1934) is the most relevant here.

Journal discipline

The analysis of the number of articles published in disciplinary journals showed strongly diverging trends per discipline (Figure 2). The most striking trend was quantified for the generalist journals, which increased more than any of the disciplines between 1991 and 2017, but especially after 2009. Journals on palaeo-science and management and conservation in peatlands increased their coverage, with palaeo research increasing predominantly between 1991 and 2000, and management and conservation between 2010 and 2017. Strong declines were quantified for botany, geology and pollution between 1991 and 2017. Biogeochemistry had a particular trend, consisting of a strong increase after 1991, which culminated in 2004, followed by a strong decline. Climate and environmental change journals showed a slightly declining number of articles published after a peak in 2006.

Geography of author affiliation and study sites

Geographical distribution of author affiliations

Between 1991 and 2017, affiliations of first authors originated in 75 different countries. The distribution of research articles was highly skewed, as the 15 greatest producers (20 % of the total number of countries) generated 85 % of the articles. Top producers were Canada, the UK and the USA, at 14.3 %, 14.0 % and 12.8 % of the total number of articles (Figure 3). Peatland research was dominated by European institutions (including Russia), at 61.9 %, and Canadian and American institutions, at 27.1 %. Elsewhere, China (3.0 %) and Japan (1.7 %) were major contributors, while countries south of 30 °N accounted for 5.7 % of the total articles published.

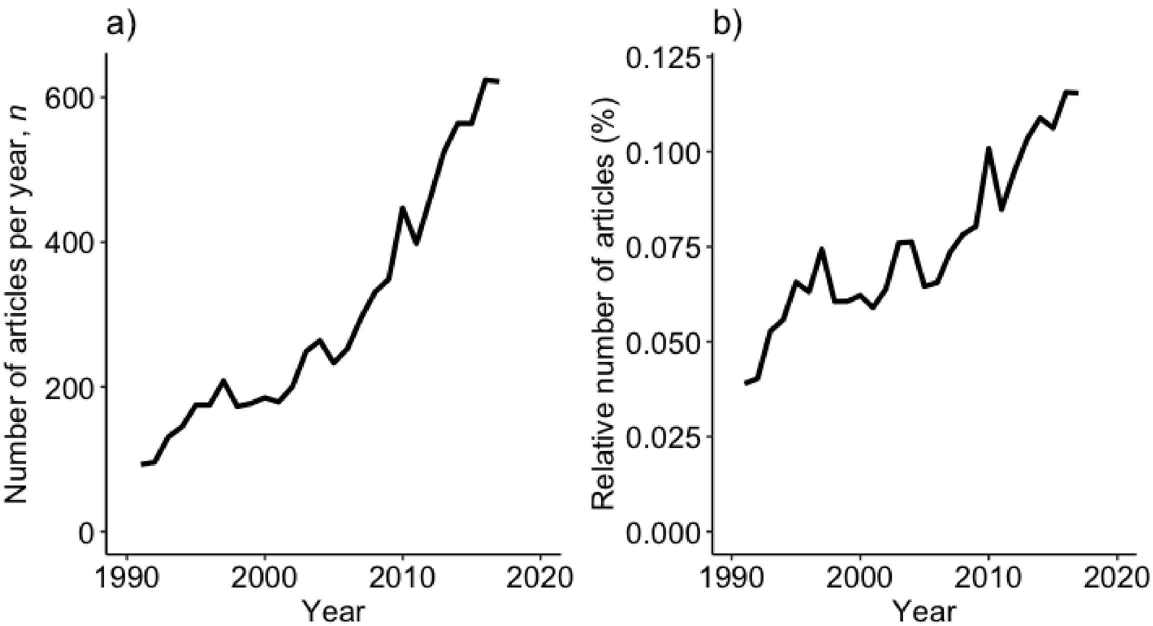

Figure 1. a) Absolute increase in the number of articles in peatland research and b) relative number of articles, obtained by normalising against a baseline curve which included all articles indexed by Web of Science in the disciplines of Biology, Physics, Chemistry, Mathematics and Earth & Space.

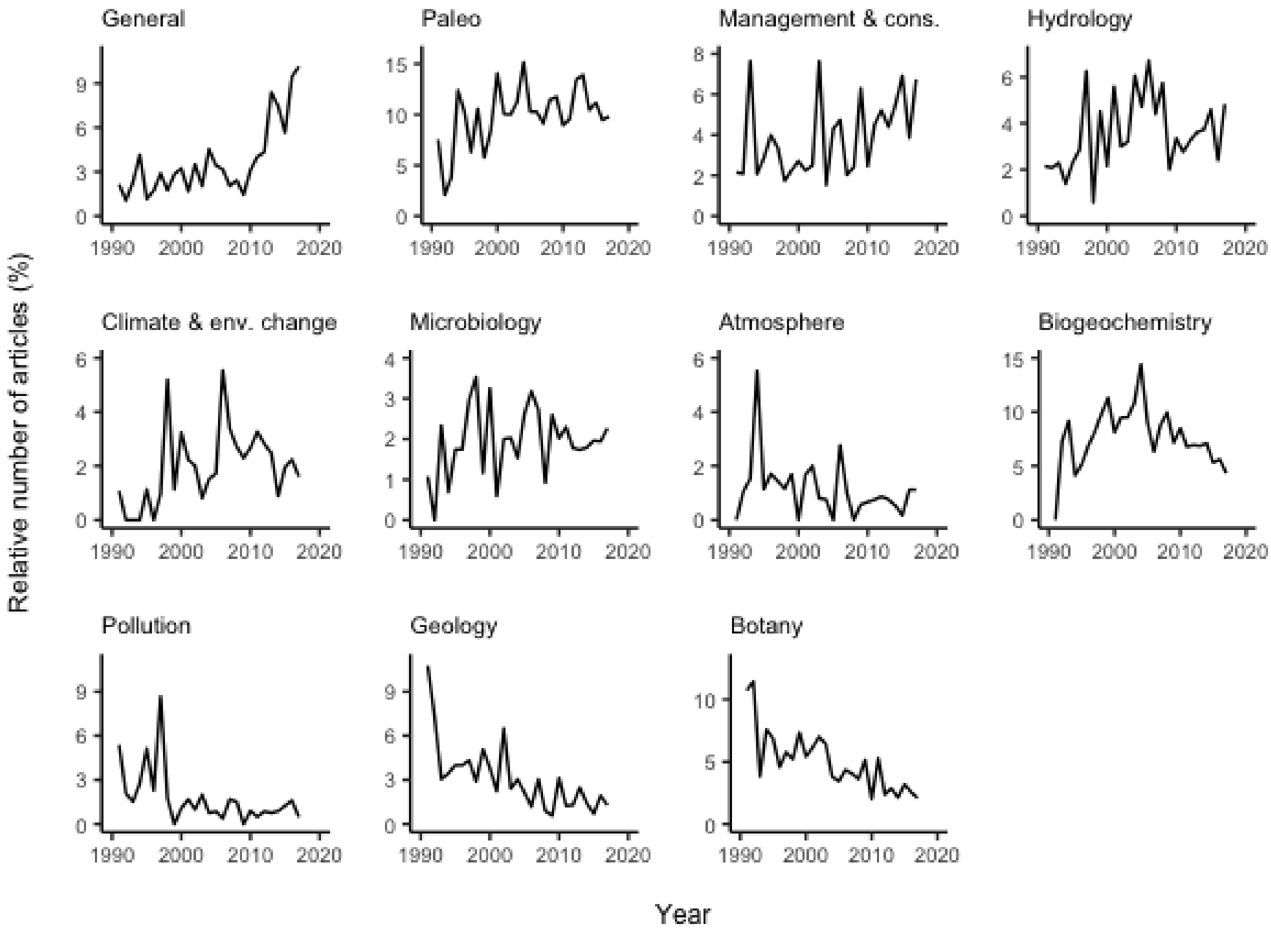

Figure 2. Trends in journal disciplines, relative to the total number of articles per year. Vertical axes differ among journals.

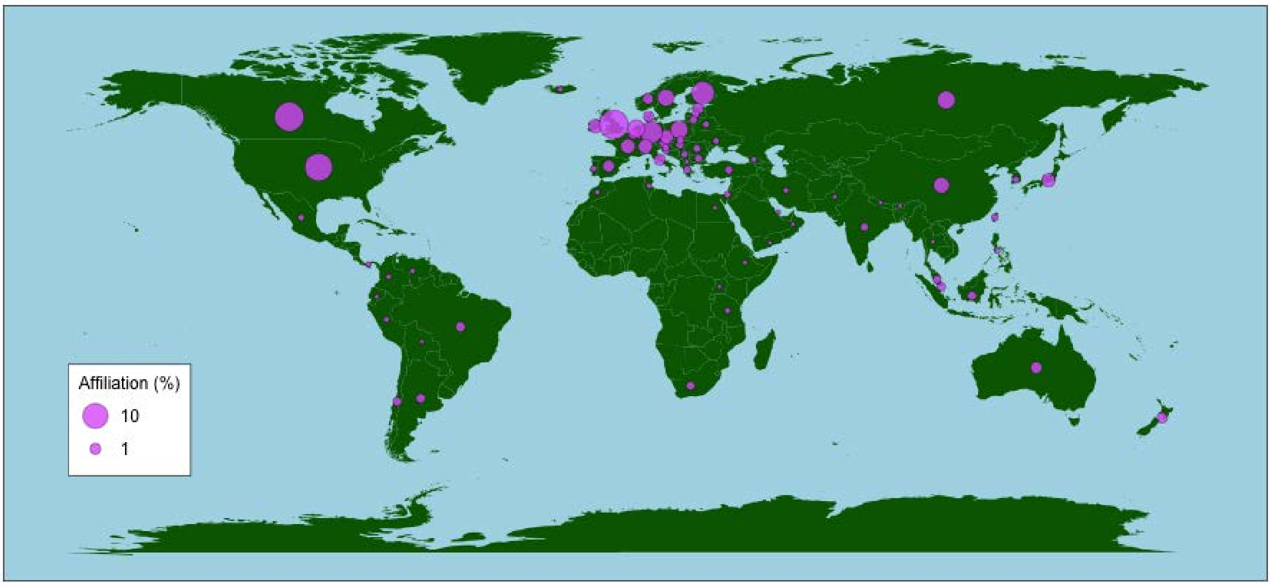

Figure 3. Proportion of affiliations per country, relative to the global total, for 1991–2017. Proportion shown by circle area. Examples 10 % and 1 % in legend.

Author affiliations through time

Canada and the USA accounted for ~ 50 % of the total number of articles published in the early 1990s but showed strong relative decreases in the rate of research article publication, especially between 1991 and 2008, after which their relative number of articles stabilised (Figure 4). Peatland research in China increased from no articles in the early 1990s to 6 % of the total articles in 2017, with the sharpest rise after 2009. China's increase contributed to the relative decline in research by European institutions, especially those based in the UK, The Netherlands, Sweden, Finland and Switzerland. In Europe, strong increases were found for Germany, Poland and Spain. The most recent decade was further characterised by an increase in research articles from institutions in Brazil, Argentina, Indonesia, Singapore and Malaysia, yet these remained small contributors at a global level, each generally limited to 1–2 % of total research articles.

Geographical distribution of study sites

Study site locations were found for 7533 articles; the remaining 584 articles could not be linked to specific sites and were excluded from further analyses. The 7533 articles were linked to 8455 sites at the country/region level, i.e. including the regions of Canada, the USA and Russia; after regrouping at the country level 8279 study sites remained. Sites were spread over 120 different countries and regions. At the country/region level, the global study site distribution was similar to the distribution of affiliations, with 20 % of the countries with the largest number of study sites encompassing 84 % of all study sites. The UK, eastern Canada and Finland held the largest proportion, at 10.3 %, 8.6 % and 8.1 % of the global total (Figure 5). Research was highly concentrated in Europe, at 54.9 %, and Canada and the USA, at 25.9 % of the global total. China and Indonesia also presented large numbers of sites, at 2.9 % and 2.7 % of the global total, respectively. Although the countries south of 30 °N had larger numbers of study sites than affiliations, they accounted for only 11.2 % of the global total, with larger numbers in South America and southern Asia and smaller coverage in Africa.

Study sites through time

In the early 1990s, 70 % of the study sites were in Canada, the USA, the UK and Scandinavia. While there was also some research in South America and in Australia and New Zealand, research was nearly absent on the other continents (Figure 4). As the research focus became more international, the

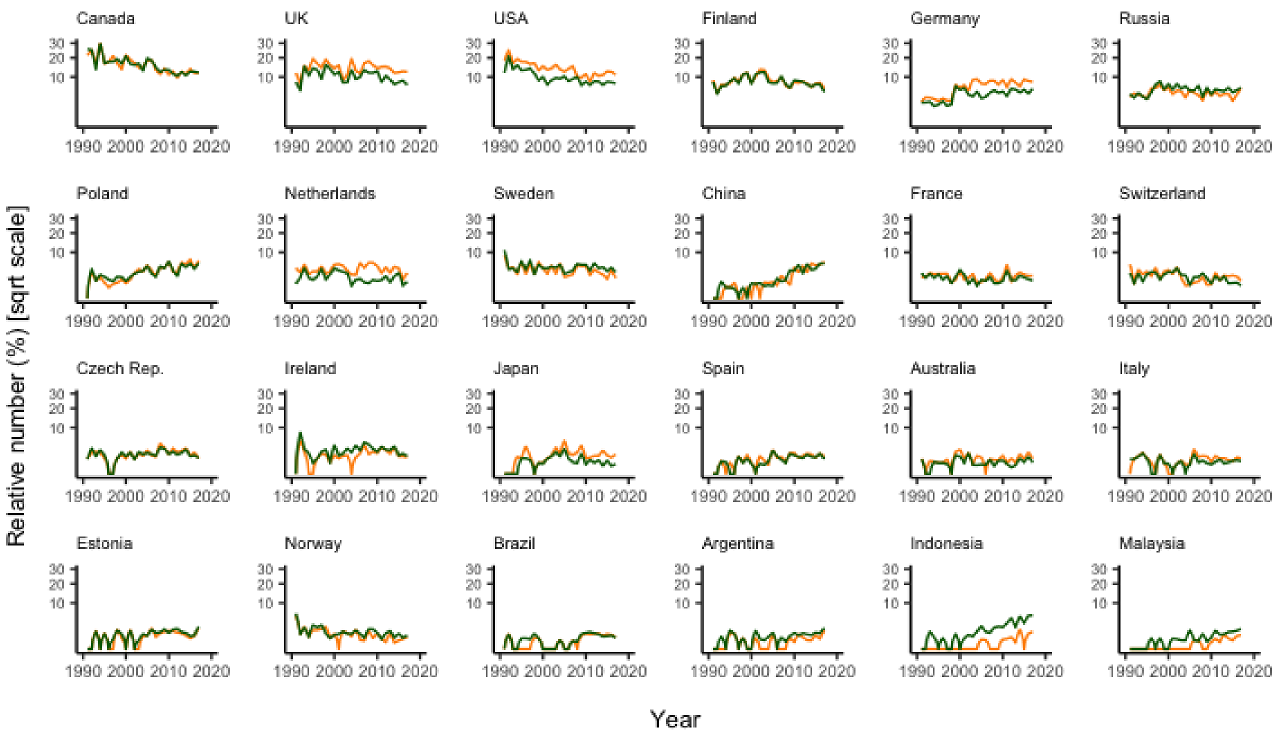

Figure 4. Relative number of articles, to the global total number of articles per year, according to the relative number of articles produced (orange) and the study site (green), for the most productive countries and major southern countries. Relative numbers are shown on a square-root transformed scale. Countries are ordered, from left to right, according to total number of articles.

number of study sites increased in South America at the end of the 1990s, first in Argentina, and after 2007 also in Brazil. At the onset of the 21st century, research intensified on sites in Indonesia, China, Poland and Germany, and peatlands were increasingly the focus of research elsewhere in eastern Europe, South America and eastern and southeastern Asia. As a result, in 2017, the total number of study sites in Canada, the USA and northern Europe had decreased from 70 % to 35 % of the total. Research in Africa remained marginal, and recent trends towards increasing activity were not detected in our database.

In general, study sites mirror trends in countries' research activity. Major deviations between trends in research production and study site location were observed in Poland and the Czech Republic since the 1990s, where the number of articles published increased at a greater rate than their number of national study sites (Figure 4). Study sites became rarer after 2003 in The Netherlands, Japan and, to a lesser extent, Germany and Italy, even though national research article numbers remained high. During the same period, major changes were found in Indonesia and Malaysia, from which the number of articles did not, however, follow the rapid increase in the number of study sites.

National and international focus of research

The global focus of research has become more international: an increasing proportion of articles have a study site outside the country of the first authors (Figure 6). Before 2003, 18 % of the articles had at least one study site abroad, increasing to 26 % for the period 2003–2017. Nevertheless, trends in research focus differed among countries, and the higher share of international studies after the start of the 21st century could be assigned to an increasing international focus, especially by authors from the UK, Germany, The Netherlands, Sweden and, to a lesser extent, Japan (Figure 6). We also observe that the number of countries with study sites increased more rapidly than the number of countries performing research. This could be explained by a stronger tendency for countries to perform research abroad, especially since 2003.

Overall, research focus differed a lot among countries, with some countries performing a majority of their research abroad and others investigating study sites mostly within their borders (Figure 7). Argentina (98 %), Ireland (91 %), Brazil (90 %), China, Finland, Estonia, Poland (all at 89 %), Russia (88 %) and Canada (86 %) all had high proportions of their articles based on domestic sites, which implies their research focus was strongly national. A strong international focus appeared limited to the wealthiest countries: only 46 % of the research performed by Japan was based on domestic sites, with 47 % for The Netherlands, 55 % for Australia, 57 % for Germany and 60 % for Italy (Figure 7). Japan focused strongly on Indonesia (32 %) and Malaysia (8 %), while Dutch institutions mainly investigated sites in Sweden (15 %), the UK (5 %) and Ireland (4 %). Important changes over the study period were found, however. While many northern countries increased their international scope between

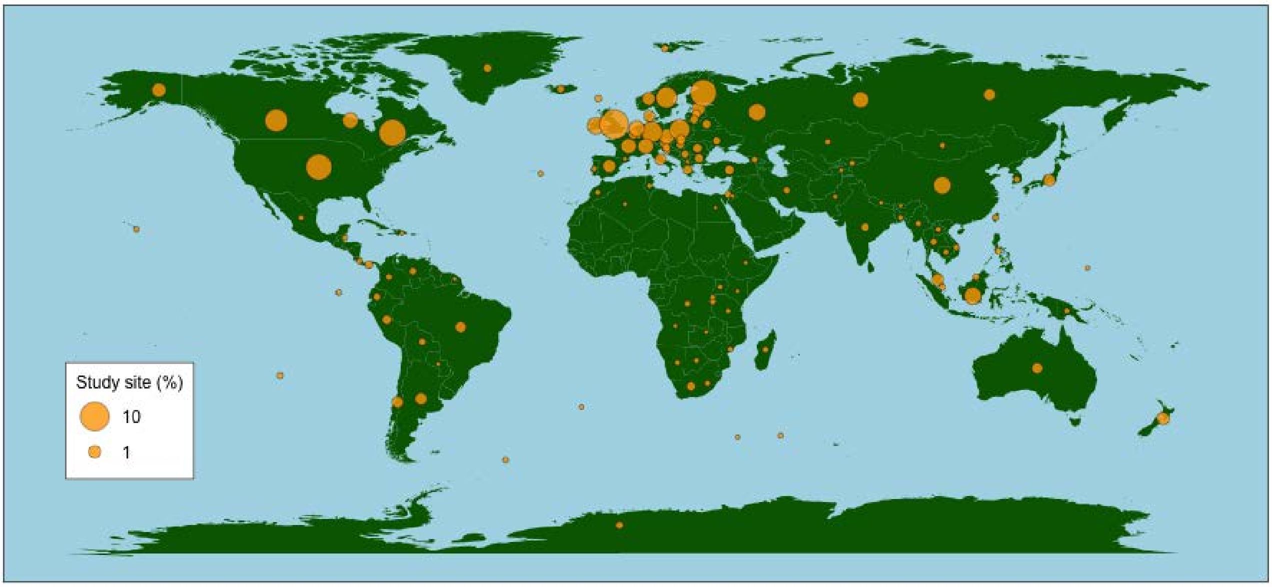

Figure 5. Proportion of study sites, relative to the global total, for 1991–2017. Proportion shown by circle area. Examples 10 % and 1 % in legend.

the early 1990s and 2017, such as the UK, The Netherlands, Sweden and Japan, others, such as Russia, China and Estonia, appeared not to have shifted their focus. Brazil, Indonesia and Malaysia mostly started investigating foreign sites after 2010.

Foreign and domestic research

Study sites were generally located within the country of the first author's affiliation (Figure 8). The UK, USA, Germany, Poland, The Netherlands, China and the Czech Republic had high proportions (85 % or more) of the study sites on their territories investigated by local researchers. Lower values were found for Canada (72 %), Ireland (60 %), Norway (60 %), Russia (59 %) and Sweden (56 %), and a clear trend towards a relative increase in research by foreigners in Swedish, Norwegian and, to a lesser extent, Russian peatlands was apparent over the study period (Figure 6). Argentina (48 %), Malaysia (26 %) and Indonesia (12 %) all had a major part of the research on their territories performed at foreign institutions. Japan accounted for 19 % of the research in Indonesian peatlands while Germany (12 %), the UK and the USA (both 10 %) were also highly active there. In Malaysia, domestic researchers were responsible for 26 % of the research, with Japanese and British institutions each accounting for 15 %. The major part of research in Argentina was performed by the USA (14 %), The Netherlands (9 %) and the UK (7 %). After 2010, Indonesia, Malaysia and Argentina increased their share of research on domestic study sites, attaining 19 %, 31 % and 71 % in 2017, respectively (Figure 6). Whereas Indonesia and Malaysia also started performing research abroad, Argentina mainly kept a national focus. At the same time, China and Japan showed the highest proportions of study sites investigated by domestic institutions.

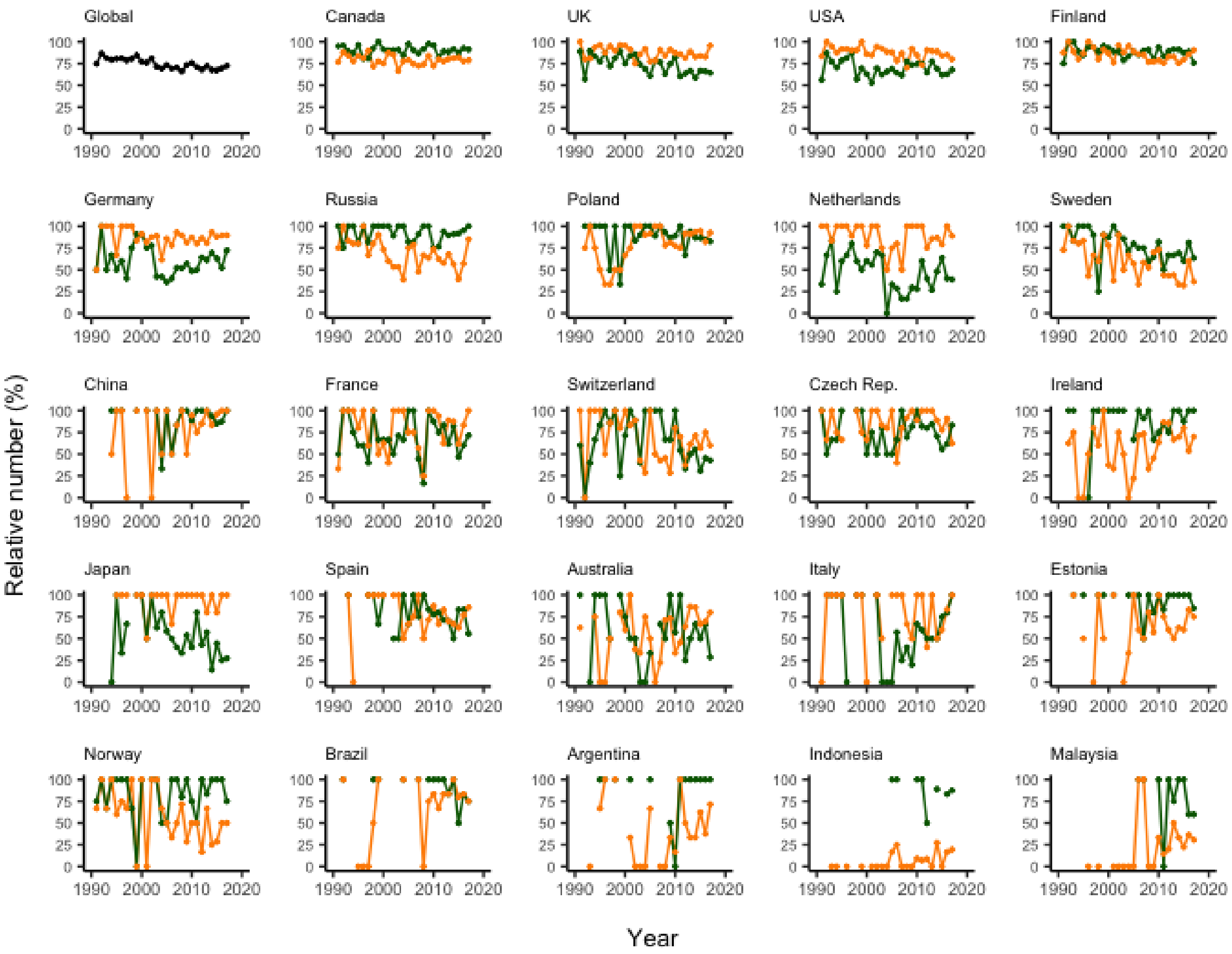

Figure 6. Relative number of articles whose first author is from country X that study peatlands in country X (green), and of peatlands in country X studied in articles from country X (orange). The global panel shows the total proportion of domestic studies. Countries are ordered according to the total number of articles.

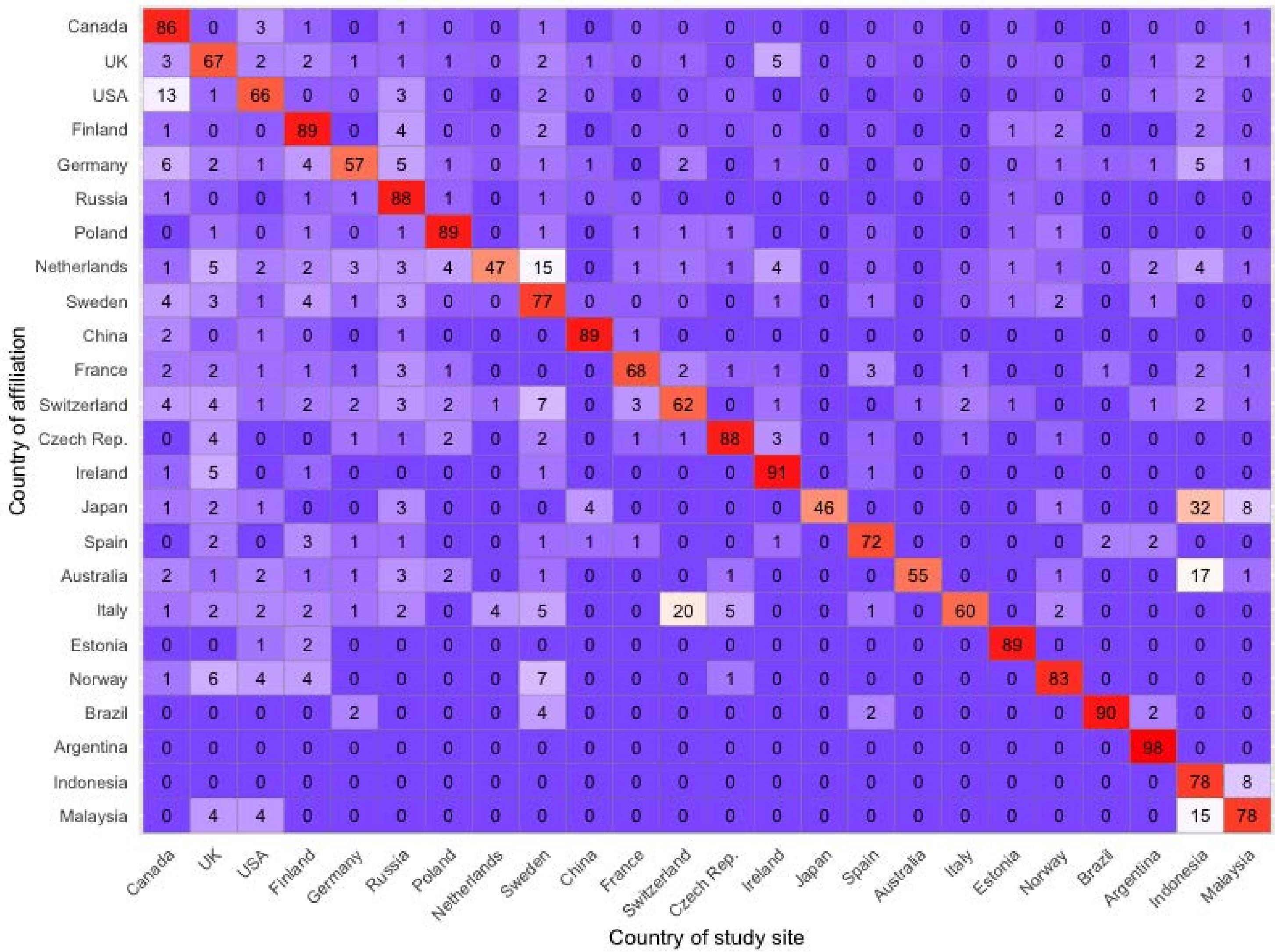

Figure 7. Proportion (%) of research performed according to the location of the study sites, relative to the total number of articles produced per country, with countries performing research listed vertically and study sites horizontally. Example of interpretation: 32 % of research performed by Japan was on study sites in Indonesia.

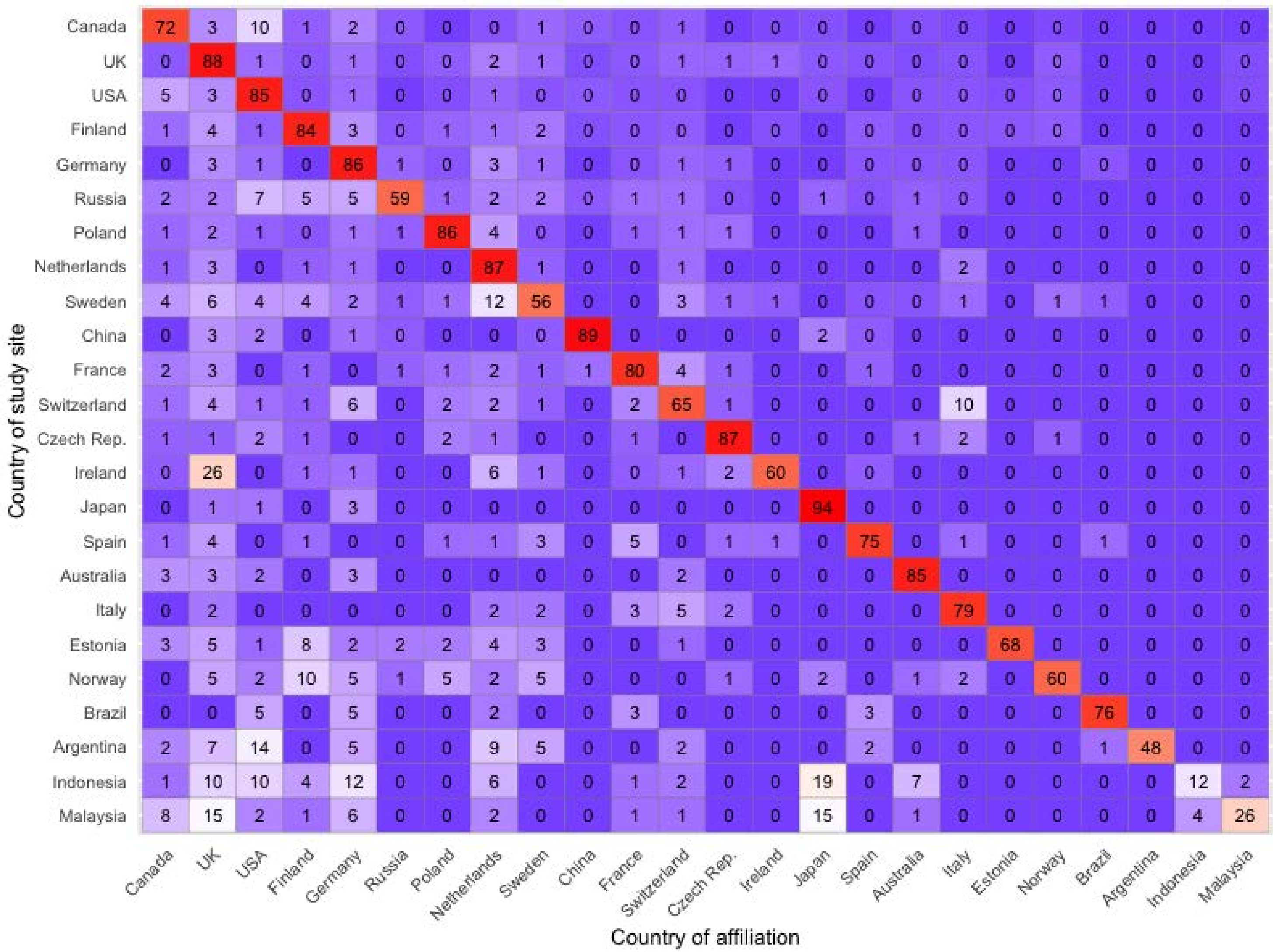

Figure 8. Proportion (%) of fieldwork performed according to the location of the study sites, relative to the total number of study sites per country. Study sites are listed vertically and countries performing research horizontally. Example of interpretation: 19 % of the articles with study sites located in Indonesia were authored by Japanese institutions.

Topic analysis

A total of 11852 single keywords were attributed to 7291 articles. The 20 % most common keywords accounted for 79 % of the occurrences; 73 % of the keywords were not used more than twice. This feature allowed for a focus on a highly reduced number of keywords while maintaining a representative image of the whole corpus.

Geographical trends in topics

In the early 1990s, about half of the articles were based on boreal-arctic sites, decreasing to about a third in 2017 (Figure 9). This relative decrease can be attributed to increasing research in tropical regions, going from 3 % in 1991 to 12 % in 2017; the major part of this increase occurred between 2004 and 2017. The number of articles published based on sites in temperate and subtropical regions remained relatively stable.

Greenhouse gas, biology, hydrology and palaeo(ecology) topics

Carbon. The most common topic, *carbon*, was mainly studied in the UK (14 %), Finland (10 %) and boreal regions in general: eastern Canada (9 %), western Canada and Sweden (both at 7 %) (Figure 10). Few articles were found for central and eastern Europe, e.g. Poland (2 %), European Russia (2 %), France (1 %), Switzerland (1 %) and the Czech Republic (< 1 %). A popular topic in the boreal-arctic in the 1990s, *carbon* has been increasingly studied in both temperate and tropical regions after 2000, although studies mainly focused on Indonesia (3 %) (Figure 9).

Carbon dioxide. The topic *carbon dioxide* was mainly studied in Finland and eastern Canada (both at 14 %) and the UK (13 %). Southern regions, including Brazil, Australia and Argentina (each < 1 %) had a very small number of studies. Nevertheless, carbon dioxide was more frequently studied in tropical regions than methane, and its share increased from close to zero around 2000 to ~ 15 % in recent years. During the same period, and as observed for methane, research focus generally shifted from boreal-arctic to temperate regions.

Methane. Methane dynamics was predominantly studied in the USA, the UK (both at 14 %) and Finland (13 %). It appeared not to be studied in Brazil, relatively rarely in southern and central Europe and Argentina (< 1 %) and was uncommon in Indonesia (2 %) and Malaysia (< 1 %). A strong temporal trend in research on methane was found

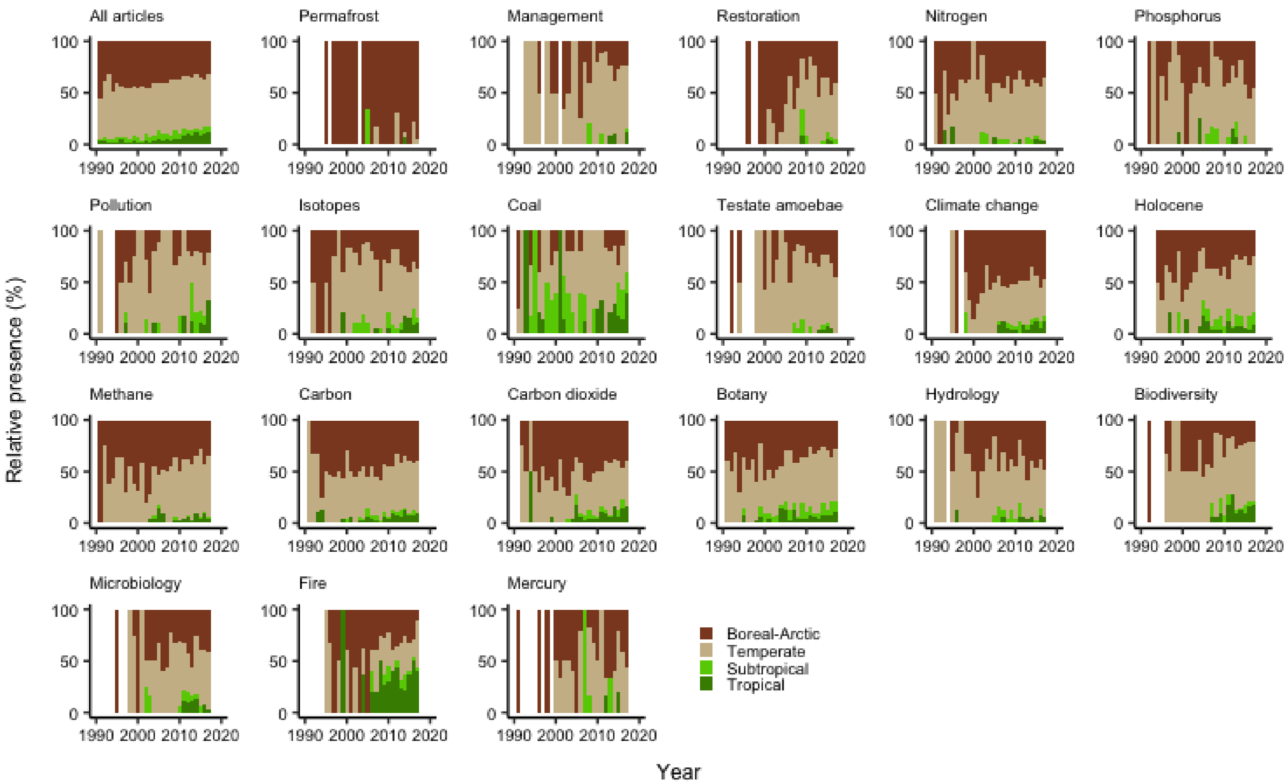

Figure 9. Temporal dynamics of research topics, quantified by the number of articles in which keywords appeared, according to four geographical zones. Topic order follows the order in the dendrogram of Figure 10.

(Figure 9). Whereas studies were strongly oriented towards boreal-arctic regions at the start of the 21st century, containing 80 % of the study sites, focus shifted to temperate regions, attaining 60 % in recent years, while a small increase in tropical regions was observed as well, attaining up to 10 %.

Botany. The topic *botany* was relatively evenly studied globally, with highest values in eastern Canada (11 %), the USA (10 %) and the UK (9 %). Small numbers were found for western (< 1 %) and eastern Siberia (1 %) and European Russia (2 %), as well as Malaysia (< 1 %) and Brazil (1 %). Since the 1990s, research has increased in temperate regions to the detriment of boreal-arctic regions, while the share of tropical regions has remained relatively stable.

Hydrology. Hydrology research was highly concentrated geographically, with 46 % of sites located in Canada and the USA (including Alaska), with USA at 16 % and eastern Canada at 15 %, while the UK accounted for 14 % of the sites. Tropical regions had small numbers of studies on hydrology, with Indonesia at < 1 %, and no documented studies in Malaysia and Brazil. Except for a slight increase in research in tropical regions, no temporal trend in geographical distribution was detected.

Holocene. Research on peatlands as Holocene archives was studied primarily in the UK (11 %) with a relatively high number of studies in China (7 %). In the late 1990s and early 2000s, the topic *Holocene* was mainly studied in the boreal-arctic, attaining

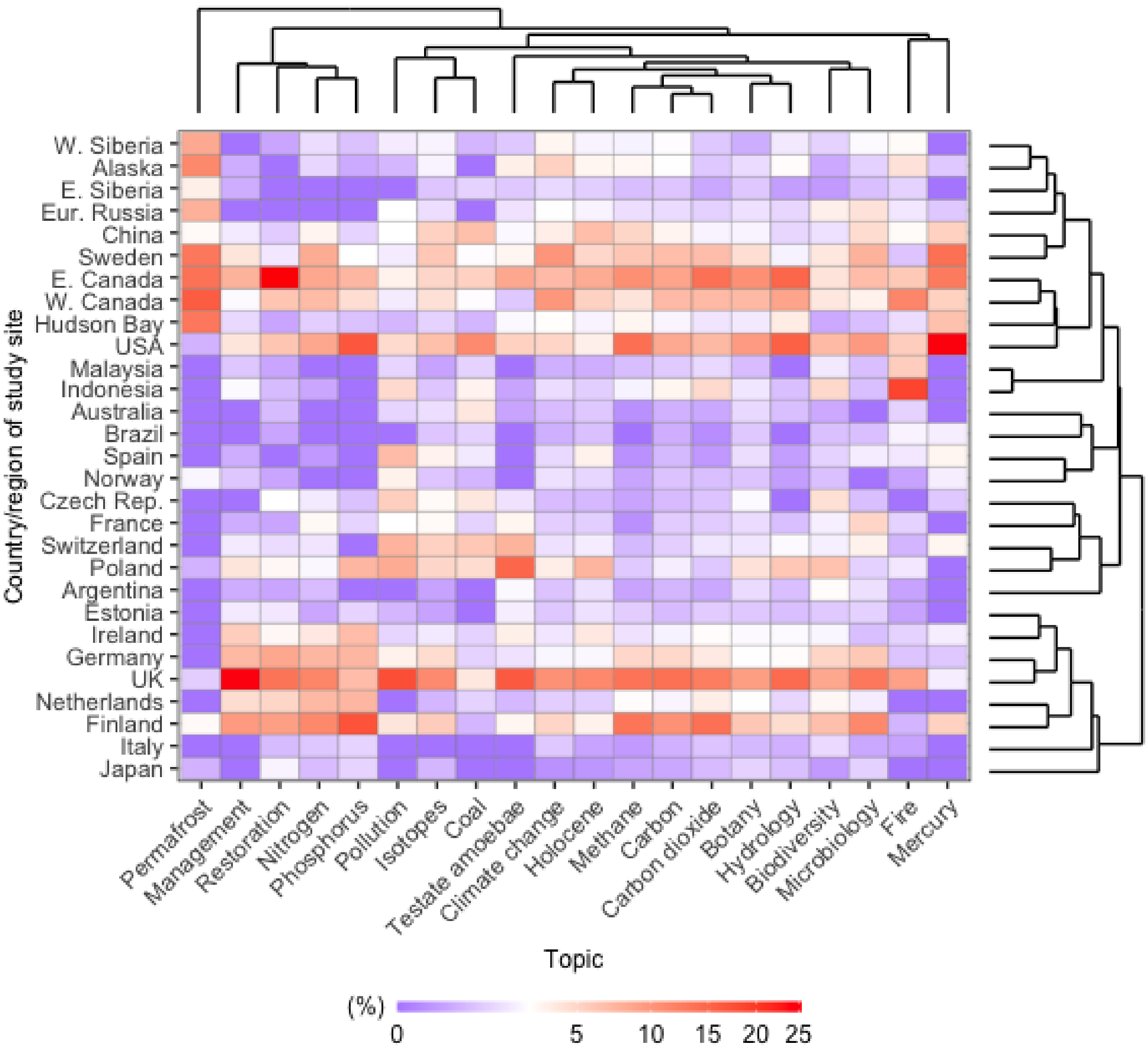

Figure 10. Relative number of study sites, indicated by colour (legend at the bottom) at the country/region level, for each topic. Countries/regions and topics are sorted according to hierarchical clustering, following dendrograms at the right and top of the heatmap.

values well over 50 %, but temperate regions became dominant afterwards, attaining 54 % in 2017. Tropical regions were evaluated on Holocene timescales relatively frequently between 2000 and 2010, but the proportion of studies has stagnated since.

Climate change. The topic *climate change*, well-correlated with the topic *Holocene*, was found to be evaluated primarily in the UK, Sweden and western Canada (each at 10 %), with relatively high values for eastern Canada (7 %) and Alaska (5 %) and boreal regions in general. As reconstructed for other topics, the relative importance of temperate regions has increased since the 1990s, but *climate change* remained primarily studied in the boreal-arctic regions, at ~ 50 % of the total in 2016 and 2017. It was relatively rarely covered in tropical regions with Brazil and Malaysia (< 1 %) and Indonesia (2 %) all accounting for small numbers of studies.

Microbiology. The UK (13 %) was the main area for the topic *microbiology*, followed by Finland (11 %) and the USA (10 %). Many studies were found for the conterminous USA, but boreal North America had a relatively small number of studies. Relatively large values were found for European countries including Sweden (8 %), Germany (6 %) and France (5 %). Tropical countries had small numbers of studies, with Indonesia, Malaysia and Brazil all at < 1 %, and relative numbers of studies in tropical regions have declined since 2014.

Biodiversity. Research on biodiversity had a relatively strong focus on southern countries, yet in absolute numbers the UK referred to the most sites, at 8 %, followed by the USA and Finland (both at 7 %). Indonesia accounted for 5 % of the study sites. Boreal-arctic regions had considerably smaller coverage and the reconstructed relative decline in biodiversity research after 2007 can be attributed to the intensification of research on this topic in tropical regions.

Testate amoebae. Testate amoeba research showed an inverted temporal trend compared to most topics, as it developed strongly in temperate regions in the 1990s, and then declined, shifting towards boreal-arctic regions. Overall, research was strongly concentrated in only two countries, the UK (16 %) and Poland (15 %). Other main areas included eastern Canada (9 %), Switzerland (7 %) and the USA (5 %), while Alaska (4 %) was also relatively well represented. Tropical peatlands appeared to have very small numbers of studies, with no reported studies in Malaysia and Brazil, and Indonesia having a value of < 1 %.

Anthropogenic topics

Phosphorus. Finland and the USA, both at 17 %, had the most study sites on phosphorus, followed by relatively densely populated European countries: Germany, The Netherlands, Poland, the UK and Ireland, all at 7 %. Tropical and less densely populated boreal regions had very small relative numbers, yet in boreal regions research has become relatively more important in recent years.

Nitrogen. Associated with trends in the topic *phosphorus*, yet less concentrated geographically, studies on nitrogen were most frequent in the UK (12 %) and Finland (11 %). They were common in the USA, eastern Canada and Sweden (each at 8 %), Germany and The Netherlands (each at 7 %). They were absent from Brazil and Malaysia, as well as less densely populated countries and regions, such as Australia, Norway, European Russia and eastern Siberia. No recent increase in activity in this topic in the tropical regions emerged.

Restoration. Restoration was most studied in eastern Canada, with 25 % of sites, followed by the UK (13 %) and Finland (9 %). Research on restoration showed a strong geographical shift around 2005. Before 2005, research was generally performed in boreal regions, while more recently this topic was predominantly studied in temperate regions. As found for phosphorus and nitrogen, very few studies focused on restoration in tropical regions.

Management. Peatland management was relatively well studied in the UK (24 %) and research was generally concentrated in temperate regions, and northern Europe in particular, with many projects in Germany (7 %), Ireland (6 %) and The Netherlands (5 %). In recent years, peatland management studies have increased in Indonesia (3 %).

Geochemistry topics

Coal. The topic *coal*, clustered with isotopes and pollution, was little related to geographical regions: many articles were found on all continents, except Antarctica. A large number of studies were made in subtropical and tropical regions, with small numbers for boreal-arctic regions. The largest number of study sites were found in the USA (11 %), followed by China (7 %) and Switzerland (6 %).

Isotopes. No particular types of isotope research were excluded. Isotope research was mainly performed in the UK (11 %), followed by the USA (7 %), Sweden and Finland (both at 6 %). Compared with other topics, Switzerland (5 %), Spain (3 %) and Australia (2 %) had a high coverage. During the 1990s, isotopes were mainly studied in boreal regions, but the focus shifted towards temperate regions, culminating around 2000, at 83 %. Although temperate regions maintained the greatest share of research at 40 to 50 %, in 2017, boreal-arctic regions accounted for 30 to 40 % of study sites.

Pollution. Research on pollution was strongly concentrated in the UK, at 18 %, followed by (central) European countries Poland (8 %), Switzerland, Spain (both at 7 %) and the Czech Republic (5 %), while Indonesia had 5 % of study sites. After 2008, research expanded towards boreal-arctic, subtropical and tropical regions; as a result, temperate regions accounted for less than 50 % in 2017.

Other topics

Mercury. The topic *mercury* was highly concentrated in the USA (24 %) and to a lesser extent in Sweden (14 %) and eastern Canada (13 %). Besides the Scandinavian countries, it was rare in Europe and generally absent in European Russia, western and eastern Siberia as well as Indonesia and Malaysia.

Fire. Research on fire was frequent in both tropical and boreal-arctic regions, with the largest number of studies in Indonesia (19 %), followed by western Canada (12 %) and the UK (9 %), and a relatively frequent occurrence in Alaska (4 %). Central and northern Europe generally had very small numbers of studies. Before 2006, research was strongly oriented towards boreal-arctic regions, yet the proportion of study sites in tropical regions has increased since, while those in temperate regions remained stable. As a result, in 2017 only 11 % of research on fires was performed in the boreal-arctic.

Permafrost. Unsurprisingly, permafrost research was highly concentrated in the boreal-arctic, and especially in Canada, with western Canada at 16 %, eastern Canada at 14 % and the Hudson Bay region at 13 %. Permafrost research was typical, yet with lower percentages, in western Siberia and European Russia (both at 8 %) as well as in eastern Siberia (4 %).

The clustering of countries/regions according to topics shows strong associations between topics studied and geographical proximity of sites (Figure 10). Malaysia and Indonesia have very similar profiles. Northern European countries group together, including Estonia, Ireland, Germany, the UK, The Netherlands and Finland and another cluster is formed by the Czech Republic, France, Switzerland and Poland. A distinct group of boreal regions is formed by the Russian regions, China, Sweden and Alaska, while the other North American regions appeared to form a distinct group as well. The separation of Sweden and Finland is interesting, with research in Finland having a stronger focus on topics often associated with disturbed peatlands, such as restoration, management and phosphorus studies, and less attention for permafrost, compared to Sweden.

Temporal trends in topics

Topic importance

Topics evolved in different and highly variable ways, with some topics absent in the early 1990s but developing rapidly during the following years and others declining throughout the observation period (Figure 11). Over the entire study period, greatest increases were in the topics *climate change*, *fire* and *restoration*. Some of the currently most important topics started to appear only in the course of the observation period: *climate change, fire* and *microbiology* in 1995, *Holocene* in 1994 and *restoration* in 1996. Shorter-term trends were found for the topics *isotopes* and *testate amoebae*, increasing strongly between 1991 and 2003 but stabilising in the following years. A declining relative importance was found for studies on the topics *coal* and *pollution*. The topics associated with anthropogenic activity showed a shifting interest, as *restoration* and *management* increased, *nitrogen* and, to a lesser extent, *phosphorus* declined.

DISCUSSION

Geographical trends in research focus

International research

Globally, research focus has become more international between 1991 and 2017, with more countries performing research, an increasing number of countries with study sites, and a relative increase in the number of articles based on study sites ‘abroad’, and particularly in tropical regions. As a result, relative to the global peatland area, research has become less biased towards central and western Europe. In particular, the development of research in both China and Indonesia has been remarkable. However, whereas the former has become a major producer of articles on peatlands, the latter, one of the main tropical countries with extensive peatland cover, has a very limited share. Research in Norway, Sweden, Russia and Canada was relatively frequently performed by foreign institutions. This may partly be explained by the vast extent of peatlands in the four countries combined with a low population density; the net ‘import’ of researchers may compensate for a relative lack of human resources internally.

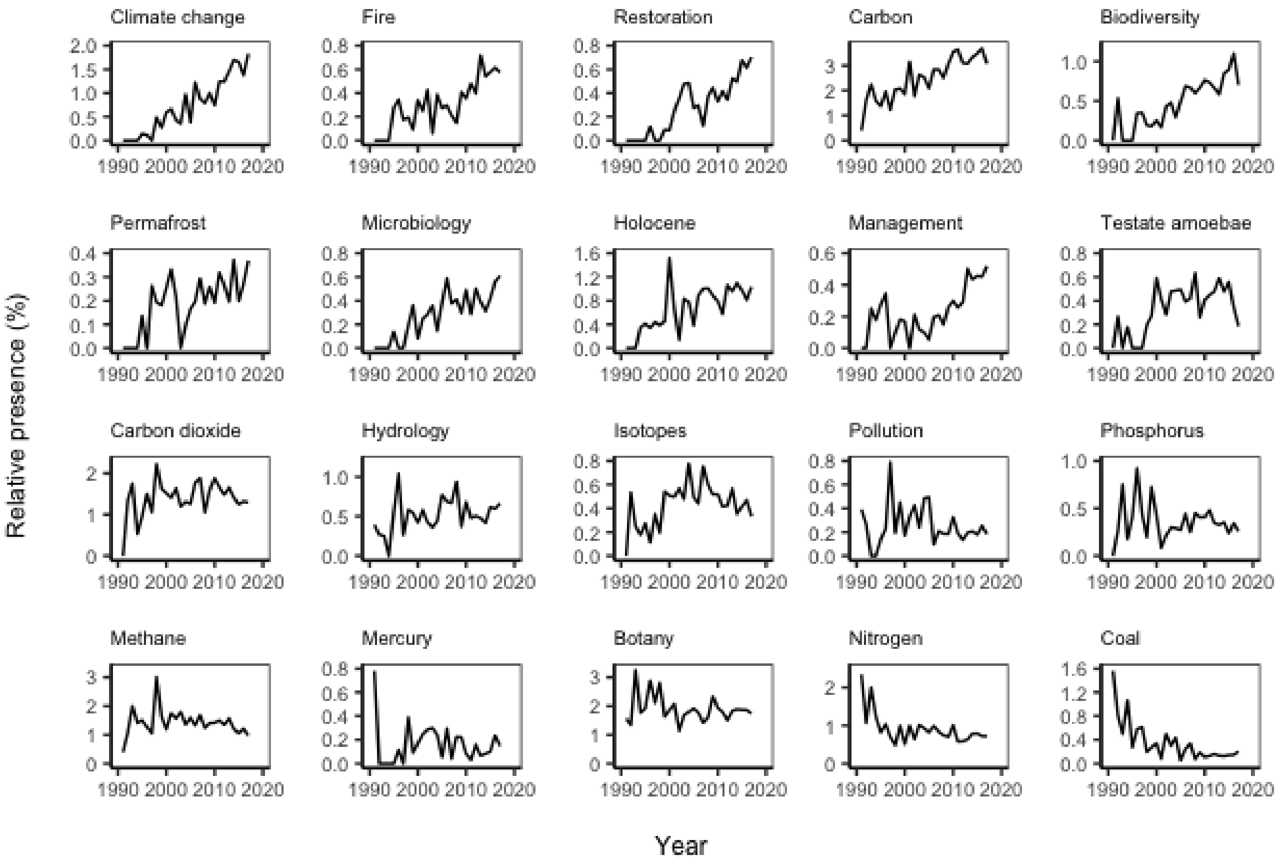

Figure 11. Research activity indicators per topic, defined by the quotient of the number of occurrences of each keyword in a given year and the total number of keywords for the same year. Topics are ordered from left to right according to the intensity of change over the entire interval, quantified by the difference of the average z-scores of the 1991–1995 and the 2011–2017 periods. Z-scores were defined by subtracting the mean from each value and subsequent division by the standard deviation of the mean.

The relative shares of internal and international research per country showed diverging trends over the course of the study period. Some tended to increase their share of research abroad with time. For example, during the 1990s, the UK performed about 20 % of its research on sites abroad, increasing to 35 % in recent years; and Sweden increased its international focus from close to zero to up to 40 % during the same period. Interestingly, research focus seemed to be related more to geographical proximity than to past colonial relationships. In contrast, a relative increase in domestic research focus was observed for countries which were starting to increase their research potential: an increase in general rate of article publication appeared positively linked with the proportion of fieldwork done by domestic institutions, as observed in Poland, China, Indonesia, Malaysia, Argentina and Brazil. The tendency of researchers to work abroad is associated with a range of factors, related to individual researchers, disciplines, institutions and the external environment (Woldegiyorgis *et al.* 2018). For example, the relative number of international staff in departments and the mobility of individual researchers positively influence the potential for internationalisation of research. The feasibility of international research is also dependent on access to funding (Woldegiyorgis *et al.* 2018). These factors are typically more often present among the wealthiest countries, which are also the countries that increased their international focus over the study period. Finally, an increase in internationalisation may also be the result of researchers unconsciously searching for 'globally significant' topics, as such topics enhance the chance of publishing in more prestigious, high tier journals, which leads, in some countries, to financial rewards. As a consequence, research on rather local phenomena not likely to be of global interest may become more infrequent (Gingras 2016). An evaluation of the number of citations received by the articles included in our study showed that articles presenting a study site abroad (defined relative to the country of the affiliation) received a higher number of citations than those based on domestic study sites only (Figure A1 in the Appendix).

As scientific research is developing in many countries south of 30 °N, it may be possible authors from these countries feature relatively frequently as co-authors on articles published by northern institutions; however, this study did not allow for the evaluation of co-author origins or collaborations. The notion of countries as contributors to knowledge development should be used carefully. In some topics, especially smaller disciplines, a country's expertise may rely upon a limited number of institutions or authors. In such a case, it may be hazardous to assign research expertise to specific geographical or cultural factors.

Study site distribution relative to the global peatland area

The number of articles published per country/region, as an indicator of research activity, was compared with the global peatland distribution, based on PEATMAP data (Xu *et al.* 2018) and other syntheses and inventories (Joosten 2009, Iturraspe *et al.* 2012, Izquierdo *et al.* 2015, Dargie *et al.* 2017, Tanneberger *et al.* 2017) (Table A3). Spatial imbalances in research were quantified by the quotient of the number of articles to the area of peatlands within the same country/region. Countries which lacked a research site were not evaluated.

Resulting ratios showed that a spatial research focus imbalance exists towards western, central and southern European countries, which have been the focus of study much more frequently than may be expected based on their peatland area (Figure 12 and Table A3). For example, the UK contains only 0.5 % of the global peatland area but as much as 10.2 % of the study sites, thus presenting a quotient of 20. Among the major European countries, the Czech Republic and Switzerland showed the greatest quotients, at 294 and 277, respectively. A positive bias was also typically observed for small islands in isolated regions, including Easter Island, Galapagos, Svalbard and the Azores. The countries with the greatest peatland area, Russia and Canada, accounted for 36.2 % and 26.8 % of total peatland area, but only 6.0 % and 16.4 % of study sites, resulting in quotients of 0.17 and 0.61, respectively (Table A3). The smallest quotients were typically found in tropical countries, such as the Democratic Republic of the Congo (ratio of 0.01), Zambia (0.03), Angola (0.05), Uganda (0.07), Brazil (0.09) and Kenya (0.10) and countries with low population densities: few sampling sites was found for eastern Siberia (0.06), Mongolia (0.08) and western Siberia (0.15), as well as the Hudson Bay lowlands (0.13). Thus, at the global level, study site distribution was poorly related to peatland extent.

Spatial imbalance in research topics

Discrepancies between quantifications of research activity and peatland area may raise a red flag: could our understanding of peatland dynamics be biased towards those regions we study most frequently? To what extent can we evaluate a spatial imbalance in research? It may be hazardous to claim that spatial imbalances in research activity and peatland area have resulted in a bias in the understanding we have of the various topics. For example, in order to understand the effect of fire in peatlands, it appears meaningful to study peatland fire activity where burning is frequent or severe, and a perfect balance between study sites and peatland area at global scale would not be useful, as fires affect peatlands disproportionately in specific regions, for example in western Canada and Indonesia (Turetsky *et al.* 2015). On the other hand, carbon dynamics is a major topic in peatland research at the global scale, as it is precisely the accumulation (potential) of organic matter, and thus carbon, that defines peatlands and distinguishes these from other wetlands that lack such accumulation. Accurate quantifications of global carbon emissions and stocks are unattainable if regions exist which lack inventories, and quantifications of carbon dioxide and methane fluxes, as well as total carbon sequestration. Accurate quantification of this kind would require a research effort that is at least roughly proportional to the peatland area. We therefore evaluated the presence of a spatial imbalance for these topics.

Carbon

In absolute terms, *carbon* was typically studied in northern European and North American boreal regions (Figure 9). When weighted against the peatland area, research appeared positively biased primarily towards countries with modest or low peatland area: central Europe, Chile, Argentina, Greenland and a range of countries in southern and southeastern Asia (Figure 12). Research on carbon was slightly over-represented in Finland (quotient of 6.1), Ireland (5.7), Poland (5.5), Sweden (4.7) and eastern Canada (4.1). With a quotient of ~ 1, carbon research was in balance with peatland area in Alaska, China, Indonesia and western Canada. Among the major peatland regions and highly undersampled were western Siberia (0.2), the Hudson Bay lowlands, Brazil and eastern Siberia (all at 0.1), Papua New Guinea and the Democratic Republic of the Congo (< 0.1). Based on these numbers, we hope that our work may persuade researchers and funders

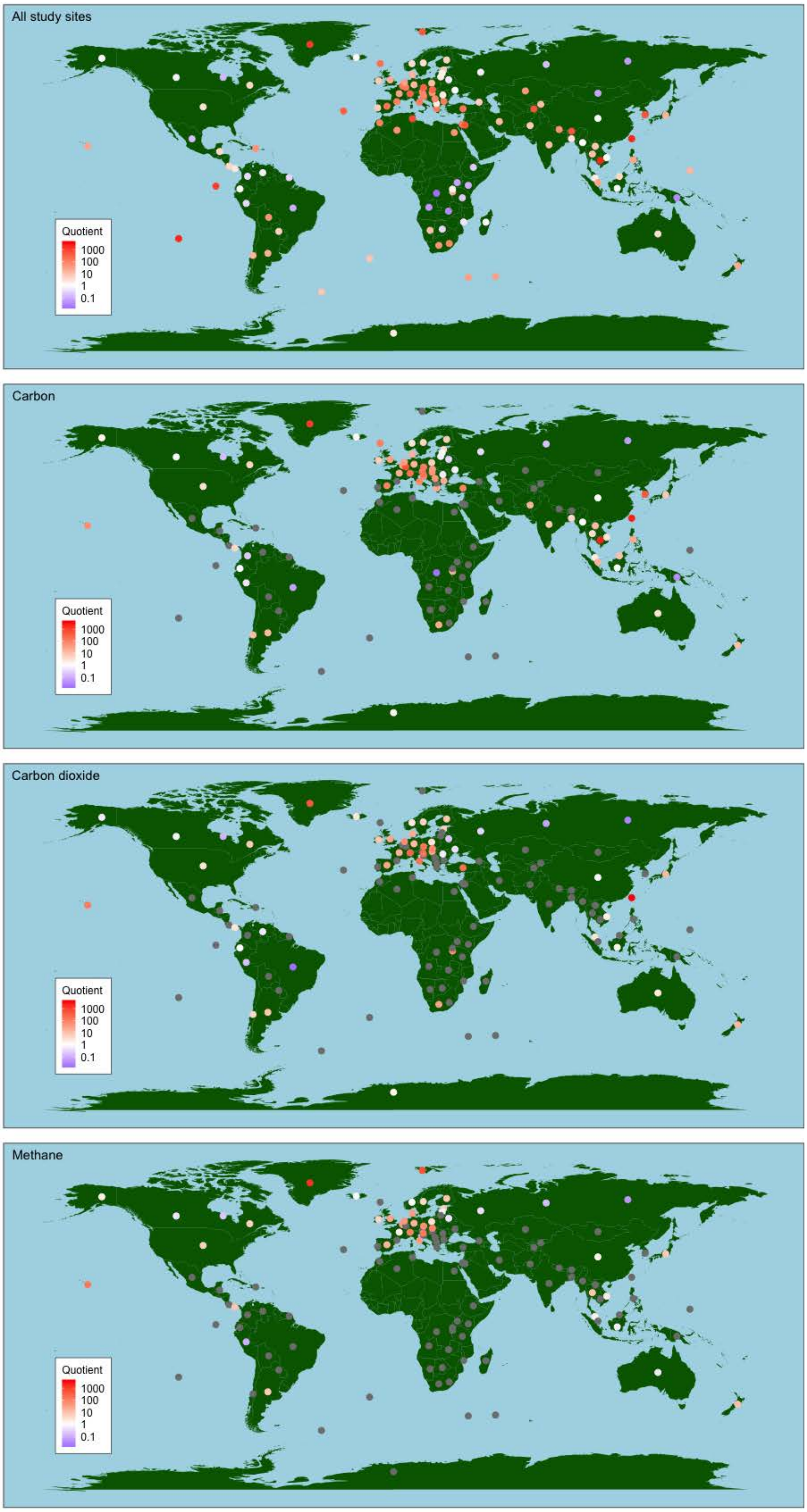

Figure 12. Global peatland study imbalances, as quantified by the quotient of the relative number of articles and the peatland area, per country/region, for all studies and the topics carbon, carbon dioxide and methane.

to intensify research in remote regions with vast peatland expanses. Interestingly, such intensification would be desirable in both the boreal-arctic, especially in Siberia and the Hudson Bay lowlands, and the tropical regions of Africa and South America.

Carbon dioxide
The research effort on *carbon dioxide* appeared less balanced than that on *carbon* (Figure 12). The main undersampled regions were the Hudson Bay lowlands (0.1), western and eastern Siberia and Brazil (all at < 0.1) while the Democratic Republic of the Congo did not have any study site in our sample, probably in part because the vast extent of these peatlands has been confirmed only recently (Dargie *et al.* 2017). Alaska showed a slight undersampling, at 0.6, substantially lower than the quotient of 1.4 found for *carbon*. The main reason for these smaller quotients, compared to studies on carbon, may be of logistic nature, because carbon dioxide (flux) studies generally require more equipment and specific transportation, and they are logistically challenging as sites may need to be visited at a certain frequency throughout the year. The positive bias towards central European sites was found for *carbon dioxide* as well, and research in Malaysia (2.8) and Indonesia (1.4) was on the positive side of the balance.

Methane
The distribution of research sites on *methane*, relative to peatland area, was similar to that on *carbon dioxide*. A main difference was found in the boreal-arctic regions, mainly Alaska, western and eastern Siberia and the Hudson Bay lowlands, which were all more frequently studied on *methane* than on *carbon dioxide*. This tendency may be explained by permafrost thaw and associated methane emissions, particular for these regions (Christensen *et al.* 2004). Nevertheless, except for Alaska, which had a quotient of 1.6, each of these regions remained undersampled on *methane*, with ratios varying between < 0.1 and 0.2. Ratios showed relatively little research in tropical regions, for example in Indonesia (0.6), Brazil, the Democratic Republic of the Congo and Papua New Guinea, each having substantial areas of peatlands but lacking study sites. Again, research was generally biased towards central European countries.

Temporal evolution of topics
The analyses of keywords showed that *climate change* and the associated carbon cycle have become the main topics in peatland science between 1991 and 2017. The popularity of peatlands as objects of study within the natural sciences may lie primarily in their ability to sequester carbon, thus affecting atmospheric greenhouse gas concentrations, and the global climate. Peatlands act as important feedback mechanisms on climate change, as their accumulation potential, in terms of biomass and carbon, is generally related to the water balance, which is strongly influenced by temperature and precipitation regimes (Yu *et al.* 2009, Page & Baird 2016).

Increasing importance was found as well for the topics *biodiversity*, *management* and *restoration*, suggesting a relative increase in topics associated with the environmental sciences and a growing attention for human-environment interactions. This corresponds with a tendency towards ‘problem-solving’ topics in ecology research, defined as related to ‘actual, specific environmental problems’ (Carmel *et al.* 2013). The relative increase in the topic *fire* can be explained by its association with both climate change and anthropogenic activity. Whereas in boreal regions fire activity may be enhanced by regional warmer and drier conditions, the occurrence of fire at low latitudes is mainly related to anthropogenic activity, by deliberate ignition and enhanced by active drainage of peatlands (Turetsky *et al.* 2015). Increases in the importance of the topics *climate change* and *biodiversity* over recent decades were also found in a global bibliometric study on aquatic ecosystems (Liao & Huang 2014) and in ecology research (Carmel *et al.* 2013).

Relative declines were observed in botany and geochemistry, including *coal*, *pollution* and *nitrogen*. The declining presence of the topics *pollution* and *nitrogen* may appear to contradict an increasing attention for human-environment interactions in research. One explanation may be that the knowledge on the effect of pollution on peatland ecosystems may be considered relatively established, and as a result the focus may have shifted towards the remediation of affected peatlands, as partly reflected by the topics *management* and *restoration*. A decline in the keyword *pollution* for recent decades was also found in an evaluation of research on aquatic ecosystems in general (Liao & Huang 2014). Changes in government policies and industrial interests may also have affected the funding of research projects in some disciplines and countries.

Thus, we have seen that peatland research has changed in terms of geography and topics. In the 1990s, most articles were produced by a few countries, mainly Canada, the UK and the USA. Countries generally strongly focused on domestic sites and therefore a vast majority of study sites were situated in these countries as well. The commonest topics were *botany*, *coal* and *nitrogen*; the topics *methane*, *carbon dioxide* and *carbon* were also relatively frequent.

By the 2000s contributions increased from Germany, Poland, China and Spain, and as a result, an increase in study sites in these countries. Northern countries, especially the UK, Germany, The Netherlands and Japan, increased their international scope. These two trends resulted in an increase in the number of countries with study sites, especially in Indonesia and Malaysia. Meanwhile, the topics *climate change*, *biodiversity* and *microbiology* increased, and new topics such as *restoration* and *testate amoebae* emerged.

In the 2010s internationalisation spread with an increase in the numbers of countries with study sites as well as those performing research. Nevertheless, the relative number of published articles based on 'foreign' study sites has remained stable since 2003, at around 25 %, which may be explained by the fact that emerging countries tend to perform research internally before, eventually, developing a more international scope.

The vast peatland regions of the world showed distinct profiles, with some related to geographical features such as permafrost or fire activity. Overall, considering the global peatland distribution, peatland research showed a spatial imbalance in favour of central Europe, with studies in Africa and Brazil highly under-represented, and those in western and eastern Siberia moderately under-represented.

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Appendix

Table A1. Classification of the top 100 journals and number of articles published in peatland research. Within each discipline, journals are ranked according to the number of articles published between 1991 and 2017.

Discipline	Journal	Articles, *n*		
		1991–2017	**1991–2004**	**2005–2017**
Atmosphere	Atmospheric Environment	47	14	33
	Agricultural and Forest Meteorology	36	5	31
	Journal of Geophysical Research-Atmospheres	34	30	4
Biogeochemistry	Soil Biology & Biochemistry	124	28	96
	Biogeochemistry	122	52	70
	Global Biogeochemical Cycles	111	68	43
	Organic Geochemistry	80	23	57
	Geochimica et Cosmochimica Acta	73	17	56
	Environmental Science and Technology	64	17	47
	Applied Geochemistry	28	11	17
Botany	Plant and Soil	71	24	47
	Journal of Ecology	61	40	21
	Journal of Vegetation Science	39	16	23
	New Phytologist	32	17	15
	Plant Ecology	32	10	22
	Applied Vegetation Science	30	11	19
	Bryologist	23	17	6
	Annales Botanici Fennici	21	10	11
	Nova Hedwigia	19	7	12
Climate and environmental change	Global Change Biology	127	20	107
	Global and Planetary Change	25	6	19
	Climatic Change	20	10	10
General	Mires and Peat	141	0	141
	Wetlands	137	55	82
	PLOS One	39	0	39
	Scientific Reports	36	0	36
	PNAS	19	1	18
	Nature	17	8	9
Geology	International Journal of Coal Geology	143	76	67
	Chemical Geology	27	10	17
	Canadian Journal of Earth Sciences	23	15	8

Discipline	Journal	Articles, *n*		
		1991–2017	**1991–2004**	**2005–2017**
Hydrology	Hydrological Processes	131	40	91
	Journal of Hydrology	94	30	64
	Water Resources Research	53	8	45
	Hydrology and Earth System Sciences	25	6	19
Management and conservation	Forest Ecology and Management	90	28	62
	Ecological Engineering	84	8	76
	Wetlands Ecology and Management	47	11	36
	Biological Conservation	32	14	18
	Biodiversity and Conservation	27	12	15
	Restoration Ecology	26	4	22
	Journal of Environmental Management	25	3	22
	Ecological Indicators	19	0	19
Microbiology	Applied and Environmental Microbiology	35	13	22
	Microbiology	34	15	19
	Fems Microbiology Ecology	32	10	22
	International Journal of Systematic and Evolutionary Microbiology	26	4	22
	Microbial Ecology	25	7	18
	Geomicrobiology Journal	24	10	14
	European Journal of Protistology	19	1	18
Palaeo	Holocene	219	82	137
	Quaternary Science Reviews	115	18	97
	Palaeogeography Palaeoclimatology Palaeoecology	94	29	65
	Quaternary International	93	10	83
	Journal of Quaternary Science	82	25	57
	Review of Palaeobotany and Palynology	53	17	36
	Quaternary Research	50	20	30
	Boreas	49	13	36
	Vegetation History and Archaeobotany	39	14	25
	Journal of Paleolimnology	34	8	26
	Journal of Archaeological Science	23	4	19
Pollution	Water Air and Soil Pollution	74	49	25
	Environmental Pollution	39	12	27

Table A2. Number of articles published, number of journals, and average number of articles per journal, from 1991 to 2017.

Year	Articles published, *n*	Journals, *n*	Articles/ journal, *n*
1991	93	69	1.3
1992	96	76	1.3
1993	131	83	1.6
1994	145	84	1.7
1995	175	100	1.8
1996	175	106	1.7
1997	208	104	2.0
1998	173	102	1.7
1999	177	98	1.8
2000	185	108	1.7
2001	179	109	1.6
2002	200	113	1.8
2003	249	136	1.8
2004	264	130	2.0

Year	Articles published, *n*	Journals, *n*	Articles/ journal, *n*
2005	233	137	1.7
2006	253	122	2.1
2007	296	158	1.9
2008	331	176	1.9
2009	349	190	1.8
2010	447	209	2.1
2011	398	207	1.9
2012	461	215	2.1
2013	525	220	2.4
2014	564	235	2.4
2015	564	238	2.4
2016	624	241	2.6
2017	622	250	2.5

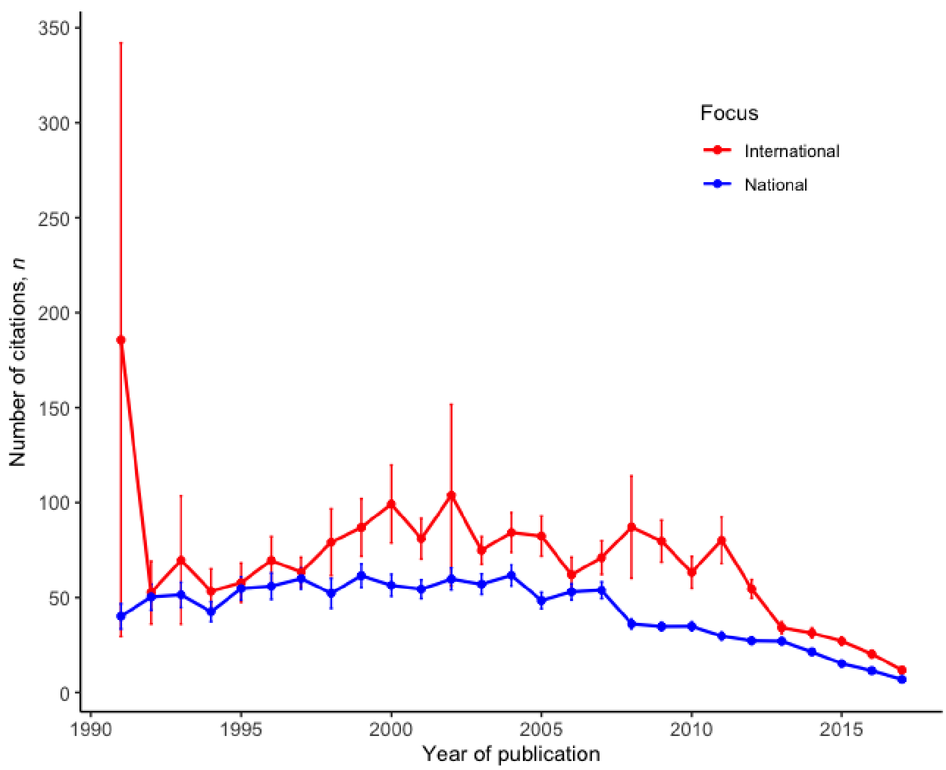

Figure A1. Mean numbers of citations received, according to Web of Science, for articles with at least one study site abroad (relative to the country of the affiliation) and articles based only on domestic study sites, according to the year of publication. Vertical bars represent ± 1 standard error of the mean. The 1991 extreme value for articles with at least one study site abroad is caused by 2996 indexed citations of Gorham (1991).

Table A3. Absolute and relative peatland area, numbers of author affiliations and study sites, at the level of countries and regions. Countries and regions are ranked by the number of study sites.

Major entity	**Secondary entity**	**Peatland area (km^2)**	**Peatland area (%)**	**Author affiliations**		**Study sites**		**Imbalance quotient**	**Reference for peatland area**
				n	**(%)**	***n***	**(%)**		
Canada		1132593	26.76	1157	14.25	1384	16.37	0.61	Xu *et al*. (2018)
	Eastern Canada	90660	2.14	-	-	724	8.56	4.00	Xu *et al*. (2018)
	Western Canada	368105	8.70	-	-	482	5.70	0.66	Xu *et al*. (2018)
	Hudson Bay	673828	15.92	-	-	178	2.11	0.13	Xu *et al*. (2018)
UK		22052	0.52	1139	14.03	874	10.34	19.84	Xu *et al*. (2018)
USA		197878	4.68	1039	12.80	804	9.51	2.03	Xu *et al*. (2018); Joosten (2009)
	USA conterm.	118497	2.80	-	-	670	7.92	2.83	Xu *et al*. (2018)
	Alaska	79344	1.87	-	-	132	1.56	0.83	Xu *et al*. (2018)
	Hawaii	37	0.00	-	-	2	0.02	27.06	Joosten (2009)
Finland		71911	1.70	644	7.93	682	8.07	4.75	Xu *et al*. (2018)
Russia		1532673	36.21	339	4.18	509	6.02	0.17	Xu *et al*. (2018)
	European Russia	185809	4.39	-	-	237	2.80	0.64	Xu *et al*. (2018)
	Western Siberia	627525	14.83	-	-	190	2.25	0.15	Xu *et al*. (2018)
	Eastern Siberia	719339	17.00	-	-	82	0.97	0.06	Xu *et al*. (2018)
Sweden		60819	1.44	290	3.57	399	4.72	3.28	Xu *et al*. (2018)
Germany		13480	0.32	567	6.99	377	4.46	14.00	Xu *et al*. (2018)
Poland		16392	0.39	334	4.11	347	4.10	10.60	Xu *et al*. (2018)
China		136963	3.24	241	2.97	241	2.85	0.88	Xu *et al*. (2018)
Indonesia		148331	3.50	36	0.44	232	2.74	0.78	Xu *et al*. (2018)
Ireland		16575	0.39	150	1.85	226	2.67	6.83	Xu *et al*. (2018)
The Netherlands		2733	0.06	323	3.98	173	2.05	31.69	Tanneberger *et al*. (2017)
Switzerland		304	0.01	176	2.17	168	1.99	276.81	Xu *et al*. (2018)
France		2772	0.07	194	2.39	165	1.95	29.79	Xu *et al*. (2018)
Czech Republic		277	0.01	161	1.98	163	1.93	294.34	Xu *et al*. (2018)
Estonia		9270	0.22	82	1.01	107	1.27	5.78	Xu *et al*. (2018)
Spain		343	0.01	107	1.32	102	1.21	148.92	Xu *et al*. (2018)
Norway		15737	0.37	72	0.89	100	1.18	3.18	Xu *et al*. (2018)
New Zealand		1961	0.05	69	0.85	90	1.06	22.97	Joosten (2009)
Argentina		2410	0.06	40	0.49	81	0.96	16.82	Iturraspe *et al*. (2012), Izquierdo *et al*. (2015)

Major entity	Secondary entity	Peatland area (km^2)	Peatland area (%)	Author affiliations		Study sites		Imbalance quotient	Reference for peatland area
				n	(%)	*n*	(%)		
Malaysia		22398	0.53	27	0.33	80	0.95	1.79	Xu *et al*. (2018)
Japan		2314	0.05	142	1.75	70	0.83	15.14	Joosten (2009)
Chile		2276	0.05	29	0.36	68	0.80	14.96	Xu *et al*. (2018)
Denmark		2029	0.05	61	0.75	66	0.78	16.28	Tanneberger *et al*. (2017)
Italy		266	0.01	83	1.02	63	0.75	118.63	Xu *et al*. (2018)
Australia		8978	0.21	92	1.13	60	0.71	3.35	Xu *et al*. (2018)
Brazil		311967	7.37	49	0.60	58	0.69	0.09	Xu *et al*. (2018)
Belgium		146	0.00	54	0.67	42	0.50	144.00	Joosten (2009)
Austria		189	0.00	57	0.70	40	0.47	105.94	Joosten (2009)
Peru		49991	1.18	4	0.05	36	0.43	0.36	Joosten (2009)
Turkey		120	0.00	24	0.30	35	0.41	146.00	Joosten (2009)
Slovakia		60	0.00	12	0.15	33	0.39	275.32	Joosten (2009)
Romania		7690	0.18	19	0.23	32	0.38	2.08	Tanneberger *et al*. (2017)
Greece		103	0.00	16	0.20	29	0.34	140.94	Tanneberger *et al*. (2017)
South Africa		295	0.01	30	0.37	29	0.34	49.21	Joosten (2009)
Bulgaria		112	0.00	20	0.25	27	0.32	120.67	Joosten (2009)
Belarus		22352	0.53	12	0.15	25	0.30	0.56	Joosten (2009)
Hungary		300	0.01	25	0.31	24	0.28	40.05	Tanneberger *et al*. (2017)
Greenland		10	0.00	0	0	23	0.27	1151.33	Joosten (2009)
Lithuania		6460	0.15	18	0.22	23	0.27	1.78	Tanneberger *et al*. (2017)
Latvia		7514	0.18	17	0.21	22	0.26	1.47	Tanneberger *et al*. (2017)
India		955	0.02	19	0.23	20	0.24	10.48	Joosten (2009)
Ukraine		10000	0.24	8	0.10	17	0.20	0.85	Tanneberger *et al*. (2017)
Panama		3291	0.08	2	0.02	15	0.18	2.28	Joosten (2009)
Iceland		5777	0.14	3	0.04	14	0.17	1.21	Tanneberger *et al*. (2017)
Serbia		100	0.00	13	0.16	14	0.17	70.08	Tanneberger *et al*. (2017)
Slovenia		84	0.00	9	0.11	14	0.17	83.43	Joosten (2009)
Antarctica		3000	0.07	0	0	13	0.15	2.17	Joosten (2009)
Ecuador		4991	0.12	1	0.01	12	0.14	1.20	Joosten (2009)
Thailand		631	0.01	1	0.01	12	0.14	9.52	Joosten (2009)
Bolivia		99	0.00	1	0.01	10	0.12	50.56	Joosten (2009)
Israel		46	0.00	9	0.11	10	0.12	108.82	Joosten (2009)

Major entity	Secondary entity	Peatland area (km^2)	Peatland area (%)	Author affiliations *n*	Author affiliations (%)	Study sites *n*	Study sites (%)	Imbalance quotient	Reference for peatland area
Venezuela		7928	0.19	2	0.02	10	0.12	0.63	Joosten (2009)
Svalbard		10	0.00	0	0	9	0.11	450.52	Joosten (2009)
Brunei		991	0.02	0	0	8	0.09	4.04	Joosten (2009)
Croatia		33	0.00	7	0.09	8	0.09	121.35	Tanneberger *et al*. (2017)
Colombia		9999	0.24	3	0.04	7	0.08	0.35	Joosten (2009)
Faroe Islands		29	0.00	0	0	7	0.08	120.83	Joosten (2009)
Iran		295	0.01	3	0.04	7	0.08	11.88	Joosten (2009)
Singapore		137	0.00	29	0.36	7	0.08	25.58	Joosten (2009)
Burundi		148	0.00	0	0	6	0.07	20.29	Joosten (2009)
Georgia		443	0.01	3	0.04	5	0.06	5.65	Joosten (2009)
Philippines		103	0.00	2	0.02	5	0.06	24.30	Joosten (2009)
South Korea		5	0.00	10	0.12	5	0.06	500.58	Joosten (2009)
Vietnam		2382	0.06	0	0	5	0.06	1.05	Joosten (2009)
Cambodia		1	0.00	0	0	4	0.05	2002.31	Joosten (2009)
DR Congo		145500	3.44	0	0	4	0.05	0.01	Dargie *et al*. (2017)
Easter Island		1	0.00	0	0	4	0.05	2002.31	Joosten (2009)
Kazakhstan		49	0.00	0	0	4	0.05	40.86	Joosten (2009)
Madagascar		1854	0.04	0	0	4	0.05	1.08	Joosten (2009)
Mongolia		26291	0.62	0	0	4	0.05	0.08	Joosten (2009)
Myanmar		1910	0.05	0	0	4	0.05	1.05	Joosten (2009)
Papua New Guinea		59992	1.42	0	0	4	0.05	0.03	Joosten (2009)
Taiwan		1	0.00	8	0.10	4	0.05	2002.31	Joosten (2009)
Bangladesh		566	0.01	0	0	3	0.04	2.65	Joosten (2009)
Costa Rica		349	0.01	0	0	3	0.04	4.30	Joosten (2009)
Kyrgyzstan		140	0.00	0	0	3	0.04	10.73	Joosten (2009)
Laos		191	0.00	0	0	3	0.04	7.86	Joosten (2009)
Lesotho		19	0.00	0	0	3	0.04	79.04	Joosten (2009)
Mexico		9910	0.23	7	0.09	3	0.04	0.15	Joosten (2009)
Portugal		271	0.01	5	0.06	3	0.04	5.54	Joosten (2009)
South Georgia		200	0.00	0	0	3	0.04	7.51	Joosten (2009)
Tunisia		2	0.00	2	0.02	3	0.04	750.86	Joosten (2009)
Azores		3	0.00	0	0	2	0.02	333.72	Joosten (2009)

Major entity	Secondary entity	Peatland area (km^2)	Peatland area (%)	Author affiliations *n*	Author affiliations (%)	Study sites *n*	Study sites (%)	Imbalance quotient	Reference for peatland area
Belize		249	0.01	0	0	2	0.02	4.02	Joosten (2009)
Botswana		2991	0.07	0	0	2	0.02	0.33	Joosten (2009)
Crozet Islands		30	0.00	0	0	2	0.02	33.37	Joosten (2009)
Galapagos		1	0.00	0	0	2	0.02	1001.15	Joosten (2009)
Morocco		10	0.00	2	0.02	2	0.02	100.12	Joosten (2009)
Mozambique		1933	0.05	0	0	2	0.02	0.52	Joosten (2009)
Namibia		99	0.00	0	0	2	0.02	10.11	Joosten (2009)
Pakistan		149	0.00	1	0.01	2	0.02	6.72	Joosten (2009)
Rwanda		791	0.02	0	0	2	0.02	1.27	Joosten (2009)
Tanzania		4493	0.11	6	0.07	2	0.02	0.22	Joosten (2009)
Uganda		13640	0.32	1	0.01	2	0.02	0.07	Joosten (2009)
Algeria		10	0.00	0	0	1	0.01	50.06	Joosten (2009)
Andorra		5	0.00	0	0	1	0.01	100.12	Joosten (2009)
Angola		9910	0.23	0	0	1	0.01	0.05	Joosten (2009)
Bhutan		1	0.00	1	0.01	1	0.01	500.58	Joosten (2009)
Dominican Republic		10	0.00	0	0	1	0.01	50.06	Joosten (2009)
Egypt		10	0.00	1	0.01	1	0.01	50.06	Joosten (2009)
Ethiopia		2191	0.05	1	0.01	1	0.01	0.23	Joosten (2009)
French Guiana		1599	0.04	0	0	1	0.01	0.31	Joosten (2009)
Jordan		1	0.00	0	0	1	0.01	500.58	Joosten (2009)
Kenya		4900	0.12	0	0	1	0.01	0.10	Joosten (2009)
Luxembourg		4	0.00	1	0.01	1	0.01	125.14	Tanneberger *et al*. (2017)
Macedonia		281	0.01	1	0.01	1	0.01	1.78	Tanneberger *et al*. (2017)
Micronesia		35	0.00	0	0	1	0.01	14.30	Joosten (2009)
Nepal		10	0.00	1	0.01	1	0.01	50.06	Joosten (2009)
Paraguay		98	0.00	0	0	1	0.01	5.11	Joosten (2009)
Prince Edward Islands		15	0.00	0	0	1	0.01	33.37	Joosten (2009)
Tajikistan		1	0.00	0	0	1	0.01	500.58	Joosten (2009)
Tristan da Cunha		65	0.00	0	0	1	0.01	7.70	Joosten (2009)
Zambia		15410	0.36	0	0	1	0.01	0.03	Joosten (2009)
World (major entity level)		4232369	100.00	8117	100.00	8455	100.00	1.00	Xu *et al*. (2018)