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MAPPING THE RESTORATION OF DEGRADED PEATLAND AS A FIELD OF RESEARCH AREA: A SCIENTOMETRIC REVIEW

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Abstract

Degraded peatland reduced many ecosystem services such as water quality and quantity, biodiversity, carbon storage, climate regulations and other cultural benefits. Therefore, several initiatives for the restoration of degraded peatland (RDP) have been attempted to restore the ecosystem processes, productivity and services of the degraded peatland to its original natural condition. Notwithstanding the popularity of RDP research among researchers and industry practitioners, a quantitative technique to map a comprehensive survey of the intellectual core and the general body landscape of knowledge on RDP research does not exist. In this study, a scientometric analysis was employed to analyze 522 documents using VOSviewer and CiteSpace. The Web of Science database was used to retrieve bibliographic records using the advanced search "TS (topic) =('*drained peatland restoration' OR 'drained bog restoration' OR 'drained mire restoration' OR degraded peatland restoration' OR 'degraded bog restoration' OR 'drained peatland reclamation' OR 'drained bog restoration' OR 'degraded peatland reclamation' OR 'degraded bog reclamation' OR 'drained mire restoration' OR 'degraded mire reclamation' OR 'degraded fen restoration' OR 'drained fen reclamation*'). The outcome sought to provide relevant information in RDP research such as (i) publication trends (ii) research outlets (iii) most influential keywords (iv) most influential institutions and authors (v) top influential countries active in RDP research. In addition, four clusters were identified for ascertaining the central theme of RDP research in which cluster one is linked to the central research theme-"impact of drainage on peatland ecosystem services; cluster two focused on the impact of peatland restoration on greenhouse gas emissions; cluster three is associated with peatland restoration and biogeochemical properties and cluster four is related to peatland restoration and species richness. A new research hotspot such as soil respiration was identified via the keywords with the strongest citation bursts. This study will provide the various stakeholders such as industry, journal editors, policymakers and the researchers instinctive understanding of the research status and the development frontier of RDP research.

Keywords: Peatland restoration, Degraded peatland, Scientometric, Publication trend analysis; Greenhouse gas; Drainage

1.0 Introduction

Peatlands are found in estimated 180 countries (Parish et al., 2008), covering 4.23 million km^2, or 2.84 % of the global land area; still, they play a significant role in mediating the ecosystem functions such as carbon storage, rich biodiversity, water retention and water quality and livelihood (Xu et al., 2017; Joosten 2009).

Nevertheless, most countries have degraded more than half of their original peatland coverage for agriculture and energy. One of the major causes of degradation of peatlands is the drainage for timber production, affecting approximately 15 million hectares in the northern boreal subarctic regions (Strack 2008). It has been estimated that 50 million ha (13 %) of peatlands have been directly altered by human land use in most European countries (Lappalainen 1996; Strack 2008; Tanneberger and Wichtmann 2011). For example, Germany has degraded more than 85% of its original peatlands, an estimated 930 000 ha of drained peatlands (Joosten et al., 2017). In Ireland, peat soils cover 21% of the total land area, with a total peatland area of 1,564,650 hectares, but it is estimated that only 10% of raised bogs and 28% of blanket bogs are in a natural state (Pike, 2021). Peatlands make up 12% of Southeast Asia, estimated to be around 27 million peatlands (Joosten et al., 2017). However, out of 27 million hectares of peatland, 12 million hectares (45%) are currently degraded. For example, in Indonesia, in the past 15 years, it has been estimated that 3 million hectares of Indonesia's peatlands have been burned to make way for farming and logging. In Scotland, 70 % of blanket bogs and 90 % of raised bogs have been damaged.

Degraded peatland reduced many ecosystem functions such as water quality and quantity, biodiversity and climate regulations (Bonn et al., 2016). Many studies have indicated huge amounts of carbon emissions into the atmosphere due to peatland deforestation and degradation, draining, and repeated fires (Jaenicke et al., 2010; Hooijer et al., 2014; Ballhorn et al., 2009). The removal of above- and below-ground biomass, peat decomposition and oxidation caused by drainage, and peat combustion are all major sources of carbon loss and CO_2 emissions into the atmosphere while the application of N fertilisers on degraded peatland acts as a source of N_2O emission especially when nitrogen fertilisers have been added to promote agricultural productivity (Mishra et al., 2021; Dohong et al., 2017). Tree harvesting by clear-cutting on drained peatland has also been reported to enhance the leaching of dissolved organic C (DOC), dissolved organic N (DON), and mineral N to surface waters and the nearest catchment in a boreal peatland (Könönen et al., 2018). The clear-cutting of trees exposes the peat surfaces to direct sunlight which and stimulates the decomposition of the drier peat through increased aerobic mineralisation causing high concentrations of DOC and associated watercolour to upland and seminatural catchments (Hooijer et al., 2014). Therefore, several restorations of degraded peatland (RDP) initiative has been attempted to restore the ecosystem processes, productivity and services of the degraded peatland to its original natural condition (ChiBonn et al., 2014; Haapalehto et al., 2011).

RDP research has tremendously received great notoriety from researchers but not limited to industry practitioners with several researchers publishing traditional review papers from different aspects to summarize its development and effectiveness. Several review studies (Prince et al., 2013; Leifeld and Menichetti, 2018; Chimner et al., 2017; Dohong et al., 2018; Andersen et al., 2017; Harrison et al., 2020) have made significant contributions to the RDP research discourse. Regardless, using the traditional reviews have some limitation since it has been qualitative and is subjected to manual evaluation according to the researcher's experience, which has been disparaged for irreproducibility and predilection to subjective biases (Yu et al., 2016; Hammersley, 2001).

According to Markoulli et al. (2017), traditional reviews seek to investigate the “trees”, but do not provide a wide overview of the “forest”. In addition, most existing review work has narrowed perspectives focusing on specificity, limiting aspects of RDP research. For example, Yuwati et al. (2021) review work focused on the restoration of degraded tropical peatland in Indonesia while Dohong et al. (2017) study focused on a review of the drivers of tropical peatland degradation in South-East Asia. However, to the best of our knowledge, the existing literature on RDP is restricted to specific locations and review studies that provide a complete insight into RDP using the quantitative technique are inadequately examined. To fill this gap, the present study employs analytical algorithms to map a comprehensive survey of the intellectual core and the landscape of the general body of knowledge on RDP research. Specifically, a scientometric analysis was examined to evaluate the intellectual discourse and landscape of the general body of knowledge of (i) Publication trend of restoration of degraded peatland (RDP); (ii) country’s co-authorship analysis, keywords co-occurrence analysis, research outlet analysis and document citation analysis and (iii) a comprehensive discussion on key themes using the keywords co-occurrence analysis.

1.1 *World Peatland Coverage*

Peatlands are a distinctive wetland type characterized by the accumulation of partially decayed organic matter, resulting in the formation of peat layers (Likens, 2009). To date, there is no accepted standard definition of 'peat' and 'peatland', with different interest groups often using their definitions for peatland. For example, Burton & Hodgson (1987) define peat or peatland as > 50% OM, measured as a loss on ignition, while Joosten and Clarke (2002) determined peatland or peat as sedentarily accumulated material which consists of about 30 % (dry mass) of dead organic material. In Ireland, 45-cm thick peat moss is considered a peatland, while Germany's minimum thickness is approximately 30 cm (Steffens, 1996).

Peatlands cover 2.84% of the global land area, mainly in the mid-high latitudes of the Northern Hemisphere, with Canada containing 27% of the world's peatlands and is the second country with the most peatlands after Russia (Xu et al., 2018). Bogs and fens are the dominant peatland types in Canada. Bogs cover 67 % (762×10^3 km^2) of the total peatland area and fens cover 32 % (367×10^3 km^2), while marshes and swamps cover the remaining 1% (Tarnocai, 2006b). Boreal (and polar), temperate, and tropical zone contribute about 83.3%, 4.0, and 12.7%, respectively, to the total peatland coverage (Leifeld, and Menichetti, 2018). Active peat formation is found in the moist temperate climates predominate in the northern areas of the circumboreal taiga zone of coniferous forests, Finland, Alaska and Canada (Tarnocai and Stolbovoy, 2006). The percentages of the global breakdown of peatland area coverage (4.23 million km^2) are shown in Figure 1, with the highest and the lowest percentage of peatland coverage from Asia and the Ocean, respectively

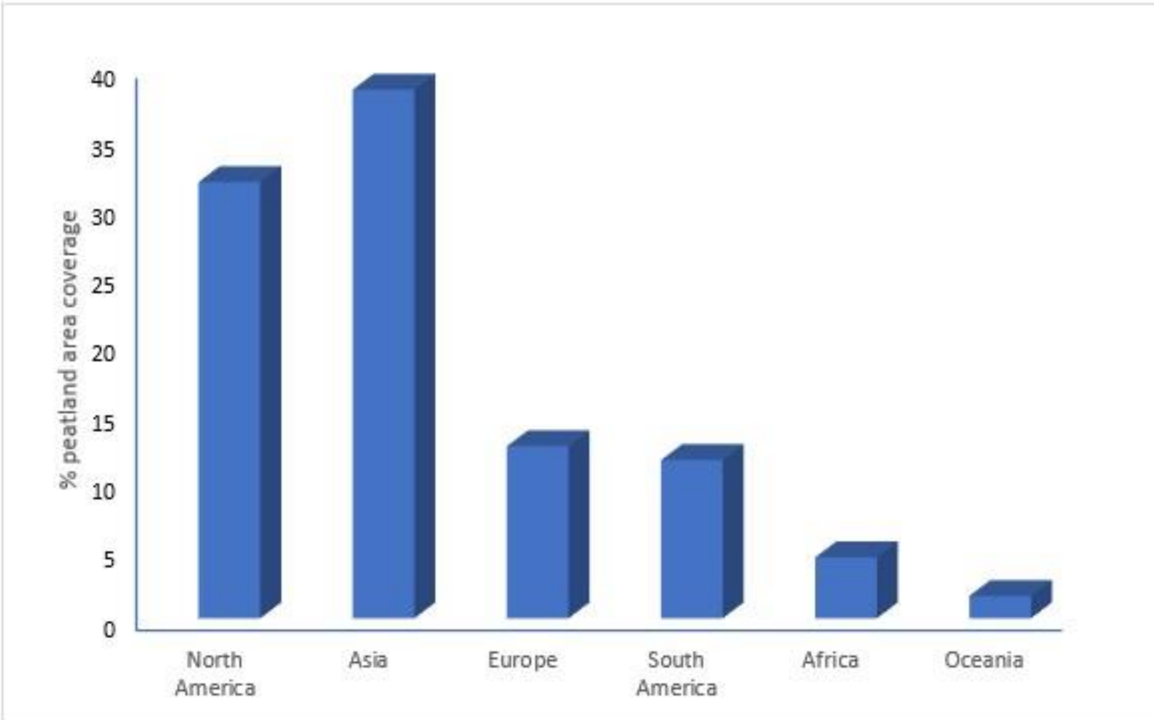

Figure 1: Percentage of the world peatland coverage. Data used was retrieved from PEATMAP (Xu et al., 2018). As a result, 4.23 million km^2 was used as the total global peatland area coverage

Also, peatlands are predominant outside the boreal zone proper in Ireland, Scotland, Germany, southwest Sweden, and northern Poland, northern Minnesota and the Everglades of Florida (Sjörs, 1980). Canada contains an estimated of 27 % of the world's peatlands and is the second country with the most peatlands after Russia. Generally, peatlands are widespread in Asia, North America, Europe and South America (FAO, 2012).

1.2 Types of peatlands

Peatland formation results from flooding or waterlogged conditions, which results in the inhibition of organic materials decompositions, specifically plant material, due to the oxygen diffusion being impeded by the flooding conditions (Dise, 2009). There are many different ways of classifying peatland based on the purposes of the classifications. Recently, peat-forming systems have been classified into two broad peat-forming types based on the hydrogenetic type: the ombrogenous (nutrient-poor bogs) and geogenous bogs (fen), which differ in vegetation cover, water availability, and nutrient supply, geography and climate and many more(Flores et al., 2016). Water availability on peatland surfaces is significant for the distribution of vegetation, biomass productivity, nutrient transfer, decomposition and preservation of organic matter in the peatland types. Nutrients (chemical elements, compounds and metals) supplied to the peatland, stimulate the growth metabolism of plants either positively or negatively affecting the biodiversity, thereby influencing the type of peatland form (Lamers et al., 2012).

Topography and climate conditions are factors that cannot be ignored during peatland formation since they affect the productivity of the ecosystem by influencing the phytosociology, biomass production, energy flux, plant dynamics, and soil and nutrient cycling (Graniero and Price, 1999). For example, herbaceous plant remains in the temperate climatic region to produce fibric to hemic peats during decomposition, while in the humid climatic region, highly decayed woody plant remains to produce hemic to sapric peats influencing the nutrient flux and types of peat form (Flores, 2014).

Ombrogenous peatlands (bog) receive water and nutrients from the atmosphere as they are isolated from groundwater and they are found mainly in the temperate and the tropics region, with differing peatland types, vegetation cover, peat depth, and topography (Lavoie et al., 2015; Joosten & Clarke, 2002). Unlike fen, ombrogenous bog depends only on rainfall for water and nutrient supplies influencing the vegetation and the plant biomass cover resulting in the formation of above-ground biomass known as the raised and the blanket bog (Nykänen et al., 1998: Flores, 2014).

The raised bog is characterized by complex structures of organic debris reaching an estimated thickness of 12 meters, comprising three sediments stratigraphy, namely a basal tier of the bog formed under minerotrophic groundwater, sub-surface and upper tiers, respectively (Hammond, 1981). Also, the layers formed in the raised bog consist of loose living moss at the surface, dead moss and the partially decomposed peat that retards evapotranspiration during the intense temperature rise, hence protecting the bog from water loss (Minayeva and Sirin, 2011). Raised bogs consist of low concentrations of dissolved nutrients and low pH (<5.0) with *Sphagnum mosses* but can also contain patches of sedge (Carex sp.), small shrubs, and trees (Bubier et al., 1995).

A blanket bog consists of peat, a moderately deep accumulation of 2.6 m thick deposited on gentle to steep slopes (Hammond, 1981), having a low pH (<5.0), and a predominate vegetation cover of Vaccinium *myrtillus, t'mpetrum nigrum,and Diplophyllum_albican.* The onset of the blanket bog formation is closely correlated with climatic deterioration within the post-glacial period, and its formation is controlled by climatic factors such as rainfall (> 1,250 mm), high atmospheric humidity, and topography (Hammond, 1981). The topography influences the flow of nutrients leached by rain and the vegetation distribution, as reported by Hammond, (1981). The high acidity of ombrotrophic bogs originated from their organic acids, predominately fulvic and humic acid and the sequestration of cations in peat. Generally, the pH of the blanket and the raised bogs is dependent on the carboxylic acid (R−COOH) content of dissolved organic matter (DOM) originating in the peat, ion exchange with living plants, e.g., bryophytes and the nutrient content received from their atmosphere (Sjörs and Gunnarsson, 2002).

Fens are wetlands with accumulated peat of 40 cm thick, receiving water and nutrients from rainfall, inflowing streams and groundwater, making them fertile for plant growth compared to the Ombrogenous peatlands. The enriched water from the inflowing streams and the surrounding watershed provides an array of minerals for a diverse plant community and stimulates the degree of oxygenation to the organic substrate, thereby accelerating peat decomposition (Miettinen & Liew, 2010). The formation of geogenous bogs occurs at raised bogs bases (Ombrogenous bogs) and the central plain, in river valleys, and poorly drained hollows adjacent to raised bogs. The fens are characterized by acidic to alkaline water ranging from 4.5 to 7.5, with brown mosses and herbaceous plants as the common vegetation (Crum, & Planisek, 1992). The high pH of the fen is due to the input of water and minerals from the ground, overland runoff and the nearby watershed serving as a source of more mineral-derived alkalinity and higher pHs (Bridgham et al., 1999). With increasing pH, Sjörs, (1950) subdivided fen into acidic fens, intermediate fens, and rich fens. Sjörs and Gunnarsson, (2002) conclude that the high pH of an intact or undisturbed fen peatland is due to the release of bicarbonate and carbonate from the groundwater to buffer the pH of the fen.

1.3 Effect of degraded peatland on ecological functions

The impact of peatlands that have been degraded or disturbed has changed in physical characteristics, biology, and chemistry, resulting in a loss of the ecological function of the peat, putting environmental and social-economic development at risk (Maftu'ah et al., 2019). Some of the repercussions of disturbing peatland include hydrophobicity, increased soil acidity, and decreased total organic carbon (TOC) and total organic nitrogen (TON) (Anshari 2010). Irreversible drying conditions indicate degraded peat features (Salmah et al., 1982). According to Valat et al. (1991), the hydrophobic character of peat soil is caused by; the presence of humic acid, which is naturally hydrophobic because its particles are covered by wax, and; the presence of non-polar groups such as ethyl, methyl, and temporary aromatic compounds, which cause the hydrophilic group to decrease; absorption of hydrophobic substances such as oil, fat, and N-organic fractions on the surface of the humic fraction. Soil hydrophobicity can aid in evaluating soil quality and fertility factors (Matejková et al., 2012). According to (Maftu'ah et al., 2019), soil water content at the study site showed a substantial variation. Compared to natural peatlands and agricultural land, there was a considerable decrease in water content in degraded peatlands, reaching more than 3 times lower.

Soil pH in degraded peatlands is 3.62, whereas in agricultural soils it is 4.70 (Maftu'ah et al., 2019). According to (Maftu'ah et al., 2019), the overall pH of soil differed significantly. Ion H^+ and Al^{3+} were the main sources of the low pH in the peat in the examined area (Maftu'ah et al., 2019). The dissociation of organic acids, specifically plant-derived acids, which are usually dominated by fulvic and humic acid in peat was the source of the H^+ ion. Organic acids play a significant role in peat soil's low pH. Carboxylates (R-COOH) and phenols (C_6H_4OH) are the most abundant reactive groups in decomposed organic matter, and they dominate the exchange complex. Strong organic acids can dissociate and produce enormous amounts of ions. The presence of Al ions is also a source of higher acidity (Maftu'ah et al., 2019).

In an experiment, disturbed or degraded peatlands had the highest total N values, while natural peatlands had the lowest (Maftu'ah et al., 2019). This is because plant materials contribute to organic matter in the soil, and natural peatlands have low decomposition rates, which may help maintain high organic matter (Maftu'ah et al., 2019). Because bog drainage has been demonstrated to boost production rates, dissolved organic carbon (DOC) concentrations are a particular concern in degraded peatlands (Bussell et al., 2010). This could be due to increased microbial activity and phenolic component breakdown caused by oxygenation (Fenner and Freeman, 2011) and changes in peat structure (Holden, 2006; Minkkinen and Laine, 1998). Other nutrients, such as nitrogen (N) and phosphorus (P), which are held in substantial amounts in peat soils' upper layers, are also prone to losses as a result of oxygenation and subsequent mineralization (Miller et al., 1996; Tiemeyer et al., 2007).

Peatland is one of the World Wildlife Fund's internationally important ecological regions (Brooks et al., 2006). The majority of wild animals and flora have been known to thrive in this location due to ideal habitats such as fertile soil, rainforest, and a favourable environment (Adesiji, et al., 2015). According to Parish and Looi (1999), agricultural development causes peatland removal, which results in a loss of biodiversity and habitat for some indigenous flora and wildlife. Prior to the invasion of peatlands for logging and expansion of oil palm plantations, there was a high level of vegetation and fauna (Adesiji, et al., 2015).

Emissions from degraded peatlands are estimated at 2 gigatonnes of CO 2e annually due to peatland deforestation and degradation, draining, and repeated fires (Zheng et al., 2021). The removal of above- and below-ground biomass, peat decomposition and oxidation caused by drainage, and peat combustion are all major sources of carbon loss and CO_2 emissions; Hooijer et al., 2012; Hooijer et al., 2006). Draining peatland for large-scale agriculture and industrial plantations has been a global concern in recent decades due to significant CO_2 emissions from peat oxidation and decomposition, contributing to global climate change (Biancalani and Avagyan, 2014; Hooijer et al., 2012).

2.0 Methodology

This current study employs analytical algorithms known as scientometrics to detect the intellectual structure of restoration of degraded peatland (RDP) by analysing the major topic studied and connections among researchers and major studies (Nikolenko et al., 2017). Scientometric is a subset of informetric analysis process and visualisation of bibliometric data of a particular research theme. This method is useful for visualising significant patterns and trends in RDP research discourse. Scientometric studies produce an authentic and less skewed result that is not influenced by any individual's or author's perspective (Martinez et al., 2019; Şenel, 2019; Baker et al., 2021). Furthermore, it provides solutions to the difficulties experienced by scholars doing traditional reviews and connects journals, keywords, writers, publications, and nations within a specific study topic (Darko et al., 2020; Zhang et al., 2021). Therefore, the study uses maps and bibliometric data to quantify research trends and highlight research hotspots in the RDP research discourse.

2.1 Data collection and search strategy

Web of Science (WOS) database was selected to retrieve bibliography information of documents in RDP research. The WOS was chosen for the data collection because its research entails over 3,300 carefully selected publishers and over 12,000 high-impact journals, indexed in the database since 1900 (Li et al., 2021). The data used for this study was extracted on January 15, 2022, from the online library of Technological University Dublin) using the advanced search "TS (topic) = (‘*drained peatland restoration’ OR ‘drained bog restoration’ OR ‘drained mire restoration’ OR degraded peatland restoration’ OR ‘degraded bog restoration’ OR ‘drained peatland reclamation’ OR ‘drained bog restoration’ OR ‘degraded peatland reclamation’ OR ‘degraded bog reclamation’ OR ‘drained mire restoration’ OR ‘degraded mire reclamation’ OR ‘degraded fen restoration’ OR ‘drained fen reclamation*’). If the defined terms appeared in the title, keywords, or abstracts, the documents would be identified. In addition, data refinement techniques were employed such that the "document type" was limited to "review" and "article" only while the language type was limited to english only and the "timespan" was set to 1945 to 2021". As a result, 522 documents were retrieved by keyword based-bibliometric for the scientometric analysis. Retrieved documents from the WOS database were then saved in "plain text" with "full record and cited references".

2.2 Science Mapping

Scientometric techniques such as network construction through keywords co-occurrence analysis, document co-citation analysis, citation burst analysis, outlets direct citation analysis, and co-authorship analysis were carried out via Vosviewer and CiteSpace. Vosviewer and the CiteSpace were selected as science mapping tools to analyse the retrieved bibliographic data in the RDP research discourse. Vosviewer is a software tool offering the basic functionality for producing, visualising, and exploring bibliometric networks (Van Eck & Waltman, 2020).

The output of the VOSviewer is a distance-based map that consists of nodes and edges,whereas the node size reveals the frequency of occurrence of a topic in the abstract and titles of published documents in relation to specific research topics and the edges indicate the relations among the nodes, strength and weight of the relations (Perianes-Rodriguez et al., 2016; Oraee et al., 2017). In addition, the total length strength is attributed to the strength of the relationship between nodes as reported in Elisha et al. (2021) while a link refered to a connection or a relationship between two items.

Fractional counting was selected for the creation of the distance-based map. The idea of selecting fractional counting is to decrease the influence of documents having many authors such that the co-authorship link strength between two authors is evaluated not only by the number of documents co-authored by the authors but also by the total number of authors of each of the co-authored documents (Van Eck & Waltman, 2013).

Similarly, to the Vosviewer, the CiteSpace also performs visual analytic functions of science mapping, as reported in Chen (2006). In this study, burst detection in CiteSpace was used to provide evidence of which keywords have frequently been cited within RDP research. The burst detection in CiteSpace is based on Kleinberg's algorithm (Kleinberg, 2002)

2.2.1 Keywords co-occurrence analysis

Keywords represent a published document's content or the core theme of a research paper, (Shrivastava, & Mahajan, 2016; Van Eck & Waltman, 2014; Cabo et al., 2011). According to Su et al. (2010), keyword analysis offers an opportunity for ascertaining the central theme of particular research topics. (Chen et al., 2021; Van Eck & Waltman, 2014; Hosseini et al., 2018: van Eck et al., 2010). To compute the visualisation of the keywords, all keywords were used rather than the author's keywords. According to Hosseini et al. (2018), using all keywords for mapping-based studies produces a large number of terms that are not solely dependent on authors' experience and knowledge in choosing appropriate research keywords. All keywords have been widely used in several science mapping-based studies (Fridell et al., 2020; Ravikumar et al., 2016; Williams et al., 2016; Zhang et al., 2017). A total of 2578 keywords were obtained from the WOS database using the fractional counting methodology. Regarding the "minimum number of occurrences" for a keyword to be included in the network, a value of 9 was selected, an inclusion criterion met by 103 of the 2578 keywords.

2.2.2 Outlets direct citation analysis

Outlets' direct citation analysis could be significant to researchers in identifying the best journals for their research publication (Hosseini et al., 2018). Furthermore, according to Guidry et al. (2004) and Darko et al. (2019), performing outlets' direct citation analysis assists the journal editors in making adjustments to the goals and objectives of their journals and institutions/libraries in optimising the resources allocation for investing in journals. A total of 181 sources were obtained from the WOS database using the fractional counting methodology. The "minimum number of documents of a source" and the "minimum number of citations of a source" were set to 5 and 60, respectively. Of the 180 sources found, 20 items met the threshold and were added to the resultant network for the outlet's direct citation analysis in RDP research.

2.2.3 Document citation networks in RDP

Document citation analysis helps reveal the intuition of the structure of a scientific knowledge domain. The concept of citation was used as a research method to measure the degree of relationship between documents and the impact of the publication. Therefore, citation analysis of documents was computed to analyse the citations of documents in the RDP research domain. A total of 522 documents were reported using the fractional counting methodology. The minimum number of citations of the documents" was set to 70. Of the 522 documents found, 18 items met the threshold and were added to the resultant network.

2.2.4 Co-authorship analysis

Co-authorship networks can evaluate scientific collaboration networks". The minimum number of documents of an author and citations were set to 7 and 40, respectively. Of the 1366 authors, only 15 authors met the threshold and were added to the resultant network.

2.2.5. Active countries in the RDP research

The significance of determining the most active countries in the RDP research domain is to enhance future collaboration, specialities and expertise; promote the exchange of technologies and innovation among countries, as reported in Wuni et al. (2019). The resultant network was generated by setting the minimum number of documents and the citation of a country to 11 and 20, respectively. Of the 51 countries of RDP research discourse, 12 met the threshold.

3.0 Results and Discussion

3.1 Publication trend of RDP research

The RDP literature data retrieved from WOS revealed that RDP research began in 1991 based on our search keywords as seen in Fig 2. The first study was conducted by Van Diggelen et al. (1991) as they analysed the Hydro-ecology of the fen system Leiper Posse in eastern Germany. Poddubny and Galat conducted the second study published in *Regulated Rivers: Research & Management* journal. Poddubny and Galat (1995) research titled “Habitat associations of upper Volga River fishes: effects of reservoirs” recommended that the restoration of degraded bog areas or flood plains enhance the diversity and productivity of fishes in the upper Volga River. This indicates that RDP research has been around since 1991. Fig 2 shows the publication trend of RDP from 1991 to 2021. The number of documents published increased from 1 document in 1991 to 61 documents in 2021. Fig 2 showed an exponential increase of published documents over the reported period (1991-2021), which may probably be due to the world recognition of the significance of RDP research in the enhancement of ecosystem services. Examples of ecosystem services indicators that have been reported to enhance after the restoration of degraded peatland from 1991 to 2021 were atmospheric CO_2 sequestration (Waddington and Warner, 2001), vegetation (Tuittila et al., 2000), organic carbon (Wallage, 2006), porewater (Meissner et al., 2003) etc.

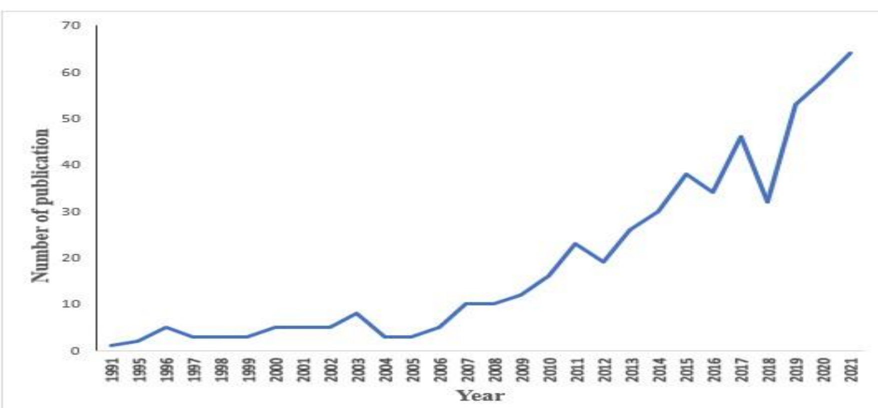

Fig 2: Trends in the RDP publication from 1991 to 2021.

A steady and tremendous increase in RDP research was observed from 2012 to 2015, with a sharp decrease in 2016. Unexpectedly, there was an increase in published documents from 2019 to 2021. The rising importance of RDP research agrees with Andersen et al. (2017) and Waddington et al. (2010) findings that most countries have degraded more than half of their original peatland coverage for agriculture and energy use, resulting in greenhouse gas emissions. Therefore, RDP research aims to decrease greenhouse gas emissions and enhance on-farm biodiversity conservation and other environmental-related issues. For example, Chapman et al. (2012) emphasized that integrating RDP as mitigation measures for reducing GHG in Scotland could provide up to 2.7 Mt CO_2-eq savings per year. A similar observation was made in Ireland that restoring degraded peatland through rewetting could reduce CO_2 emissions by enhancing C sequestration, as Wilson et al. (2012, 2013) reported.

An overview of the RPD is presented in Table 1. As observed in Table 1, the total number of citations increased from 1991 to 2021—however, a slight fluctuation of citations per published document is seen with the highest total times cited observed in 2021. Therefore based on search keywords in this study, it can be deduced that since RDP started in 1991, there have been 522 published documents, achieving total times cited of 10480 in the RDP research field.

Table 1. Characteristics by year of publications of the RDP from 1991 to 2021.

Published Year	Total Publications (TC)	Total times cited (TP)	TC/TP	% Total Publication
1991	1	0	0	0.2
1992	*	*	*	*
1993	*	*	*	*
1994	*	*	*	*
1995	2	2	1	0.4
1996	5	17	3	1.0
1997	3	12	4	0.6
1998	3	26	9	0.6
1999	3	38	13	0.6
2000	5	35	7	1.0
2001	5	61	12	1.0
2002	5	53	11	1.0
2003	8	78	10	1.5
2004	3	72	24	0.6
2005	3	90	30	0.6
2006	5	108	22	1.0
2007	10	110	11	1.9
2008	10	115	12	1.9
2009	12	162	14	2.3
2010	16	246	15	3.1
2011	23	255	11	4.4
2012	19	295	16	3.6
2013	26	377	15	5.0
2014	30	508	17	5.7
2015	38	561	15	7.3
2016	34	786	23	6.5
2017	46	801	17	8.8
2018	32	902	28	6.1
2019	53	1082	20	10.2
2020	58	1330	23	11.1
2021	64	1603	25	12.3

***No publication found**

3.2 Structure of the body of knowledge in RDP: Research Outlet, Keywords Co-occurrence Analysis, Document Citation analysis,

3.2.1 Keywords co-occurrence Analysis

The keywords co-occurrence network analysis helps to group the keywords into different clusters. Four clusters were obtained entailing 74 nodes, 2730 links and a total link strength of 1242.50 as seen in Fig 3, depicting the major keywords and their inter-relatedness of the current RDP research. The colours of each node indicate the different clusters to which the terms belong. A term was assigned to each cluster to provide in-depth interpretation and understanding of the central research theme within the RDP.

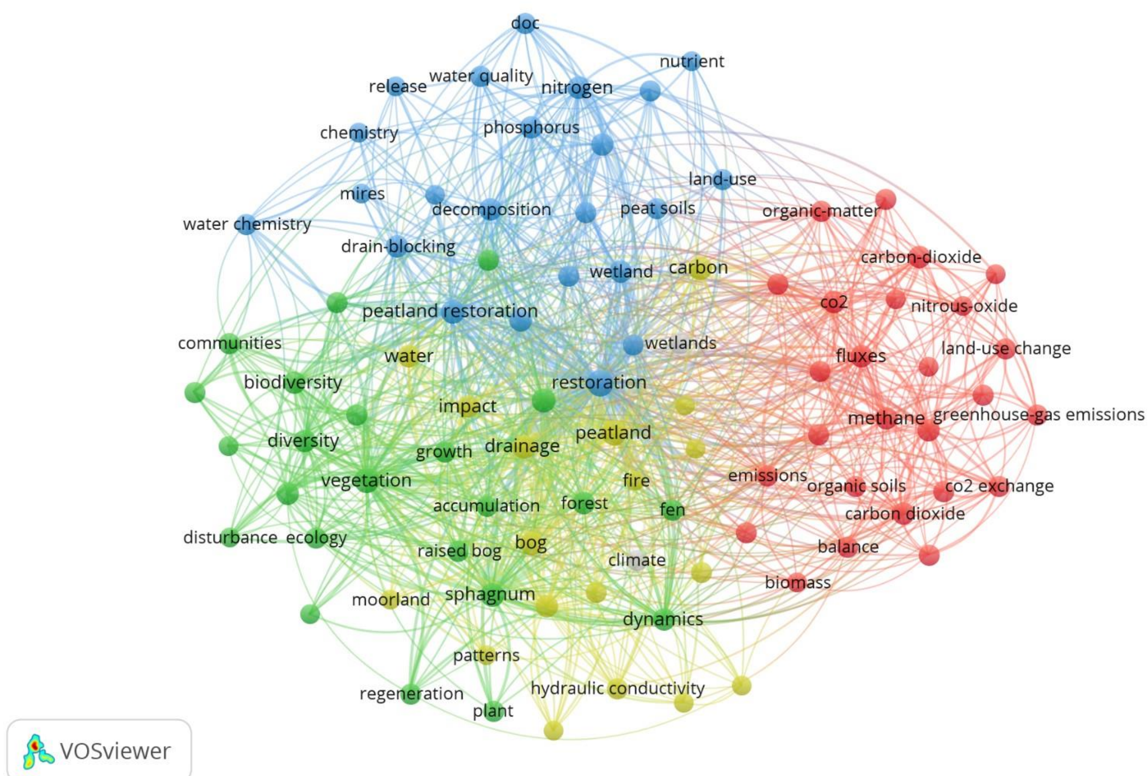

Fig 3: Main areas of RDP (co-occurrence network of keywords)

Cluster #1

Keywords explaining peatland drainage impact are classified into cluster one, represented in yellow, containing drainage, climate change, hydrology, water, hydraulic conductivity and fire (Fig 3). The analysis of all keywords revealed that the keywords in cluster one are linked to the central research theme- “impact of drainage on peatland ecosystem services”, suggesting that peatland drainage is a major threat to peatland degradation.

Peatland formation results from flooding or waterlogged conditions, which results in the inhibition of organic materials decompositions, specifically plant materials, due to the oxygen diffusion being impeded by the flooding conditions (Dise,2009). As a result, peatland drainage is being done by constructing drainage canals to lower the groundwater table, allowing peatland conversion to various land uses such as agriculture, plantation, forestry, and mining (Jaenicke et al., 2010; Rydin and Jeglum, 2013). However, the depletion of the groundwater leads to peat oxidation, consolidation, and shrinkage resulting in peat subsidence, carbon emissions, and increased fire hazards, all of which exacerbate climate change (Hooijer et al., 2012; Dohong et al., 2017).

The peatland drainage issues are closely tied to climate change consequences, a major environmental phenomenon (Waddington & Price, 200; Holden et al., 2004; Prévost et al., 1999; Joosten, 2009; Hooijer et al., 2012). Therefore, there is no doubt that RDP research has been focused on how drainage affects climate change, water chemistry, and hydrology, serving as the justification for the RDP according to the keywords seen in cluster 1. In cluster one, drainage has the highest keyword occurrence and strong links to climate change and other keywords, implying that drainage significantly impacts climate change.

Notwithstanding the less coverage of peatland worldwide, it plays a significant role in mediating fluxes of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) between soil and the atmosphere (Martikainen et al. 1993). Peatland drainage stimulates soil aeration and oxygen concentrations, facilitating the growth and activity of aerobic microbes resulting in soil organic carbon decomposition, thereby reversing the carbon flux into a net CO_2 emission into the atmosphere (Smith, & Conen, 2004; Ojanen et al., 2013; Nykänen et al., 1998; Blodau, 2002). The aeration created by the drainage stimulates the nitrification process, increasing the emission of N_2O, especially in the minerotrophic peatlands (Hribljan et al. 2014; Wang et al. 2017; Aerts & Ludwig 1997, Gao et al., 2014, Liimatainen et al., 2018). Mikaloff et al. (2019) predicted that the emission effects from drained peatlands in 2020–2100 entail 12–41% of the remaining GHG emission budget. Also, runoff from drained peat through the drainage channels has known to cause degradation of water catchments and their downstream quality (Kaila et al., 2016; Prévost et al., 1999; Piirainen et al., 2013; Nieminen et al., 2017; Skaggs et al., 1994; Nieminen et al., 2017b). Peatland drainage results in higher dissolved organic carbon (DOC) concentrations in surface and pore water and increases DOC export into nearby streams (Strack et al., 2008). Marttila et al. (2018). observed high concentrations of nutrients and suspended sediment, mainly dissolved nitrogen and phosphorus, were found in headwater streams in catchments containing drained peatland, which agrees with similar studies reported by Mattson et al. (2003) and Nieminen et al. (2017).

In addition, biogeochemical properties of peatland that have been affected by drainage are organic matter decomposition and fractions, soil respiration, soil enzymes, elemental concentration, microbial degradation, peat humification etc. (Brown et al., 2015; Harris et al., 2020; Krüger et al., 2015; Xu et al., 2021; Macrae et al., 2013; Moore et al., 2006; Hulatt et al., 2014; Olde et al., 2009). Also, studies on the impact of peatland drainage on the vegetation cover have been conducted by Ramchunder et al. (2009) and Haapalehto et al. (2011). For example, Stewart & Lance (1991) reported a complete disappearance of *Sphagnum capillifolium* on 20 years of drained raised bog. Wilson et al. (2010) studied the effect of drainage on the plant species abundance within a Welsh blanket peatland. They reported a less abundance of peat-forming plant species, specifically *Eriophorum angustifolium.*

Cluster #2

The second cluster (red portion of Fig. 3) focuses on the impact of peatland restoration on greenhouse gas emissions, specifically N_2O, CO_2 and CH_4 emissions. Despite peatlands covering about 3 % of the earth's surface, they store ~644 Gt of C and 8–15 Gt N of the terrestrial biosphere (Leifeld and Menichetti, 2018; Ahmad et al., 2020; Turetsky et al., 2015). Currently, drainage accounts for ~10% of global peatlands degradation, transforming them from a net sink to a net source of greenhouse gas (GHG) (Leifeld and Menichetti, 2018; Knox et al., 2015).

The consequences of drainage to stimulate greenhouse gas emissions into the atmosphere facilitated the need for peatland protection and Restoration as proximate mitigation measures (Wilson et al., 2015). Dohong et al. (2018) review the techniques for effective tropical peatland restoration. According to Dohong et al. (2018), hydrological restoration through peatland rewetting has effectively reduced greenhouse gas emissions from degraded peatland. According to Strack and Zuback (2013), rewetting of degraded peatland reduced CO_2 emission through the reduction of peat mineralization as well as negligible N_2O emissions as a result of lowering the availability of mineral nitrogen in saturated conditions.

The hydrological restoration of degraded peatland involves a process known as rewetting/reflooding (O'Brien et al 2007). Rewetting is the process whereby deliberately introduced ditches or gullies are blocked to reduce the surface runoff outflow or allow water levels within the peat to return to their natural state (Ahmad et al., 2020). The significance of peatland rewetting is to enhance the peat hydrological properties by raising the groundwater table so that the hydrological properties of the drained peatland are recovered and stabilized as close as possible to its pre-logging and pre-drainage hydrological conditions (Page et al. 2009a; Panda et al. 2012).

Several studies observed that rewetting of drained peatland stimulates CO_2-C sink functions immediately (Tuittila et al., 1999; Zeng & Gao, 2016; Cui et al., 2017). This is because rewetting reduces the diffusive oxygen supply in the peatland, thereby creating an anaerobic environment, which inturns, inhibits the organic matter and the litter decomposition resulting in soil organic matter accumulation and the formation of peat layer (partially decomposed organic matter) (Kim et al. 2011; Herbst et al., 2011). However, the rewetting of degraded peatland stimulates the CH_4 gases since the resulting anoxic conditions created by the rewetting are conducive to methanogenesis. Vanselow-Algan et al. (2015) and Hahn et al. (2015) reported a methane emission of 148 g CH4 m^{-2} yr^{-1} and 260 g CH4 m^{-2} yr^{-1}, respectively exceeding the default IPCC emission factor for rewetted drained peatland in the temperate region (29 g CH4 m^{-2} yr^{-1}). Kandal et al. (2019) observed an increase in CH_4 emission after 12 years of rewetting compared to the undrained site. They attributed their findings to the decomposition of aboveground biomass under inundated soil surface conditions.

Therefore, restoration management intended to reduce CO_2 and CH_4 emissions should prevent on-site aboveground biomass deposition combined with site inundation (Kandal et al., 2019). N_2O emission reduction from rewetted peatlands is due to the raising of the groundwater table, thereby inhibiting nitrification and the denitrification process (Oktarita et al., 2017; Pärn et al., 2018). However, the resulting GHG fluxes from rewetted peatland may differ due to temperature, vegetation cover, growing season length, microbial community composition, biogeochemistry, previous land-use history, prevailing biomass species, and site (Renou-Wilson et al., 2014; Wrage-Mönnig et al., 2018).

Cluster #3

Cluster 3 (blue) is associated with peatland restoration and biogeochemical properties, specifically dissolved organic carbon . Keywords found in cluster 3 are (phosphorus, nitrogen, carbon, water quality, water table, decomposition, dissolved organic carbon and drain blocking). Degraded peatland is known to have high nutrient contents since the lower water tables of the drained peatland expose deeper peat to oxic conditions resulting in the high decomposition of the organic matter/peat layers and nutrient mineralisation in the peat matrix. The drained peatlands contribute to the loss of carbon through the aquatic fluxes of carbon (e.g. DOC) into downstream water bodies as reported in Limpens et al (2008).

Restoration of the degraded peatland will result in the inhibitory effects of low nutrient concentration and DOC transport. Hence making RDP research target DOC due to its consequences (D'Andrilli et al., 2010; Tfaily et al., 2013). DOC transport from degraded peatland to nearby catchment causes organic and inorganic micropollutants and enhances bacterial regrowth within water distribution systems (Gough et al., 2016; Holden, 2005;). Haapalehto et al. (2014) reported long-term decreases in DOC and nutrient leaching but temporary increases in N and P for the first five years of degraded peatland restoration. Also, major nutrient such as phosphorus and nitrogen content has been extensively studied in a restored peatland (Nieminen et al., 2017; Moore et al., 2005; Munir et al., 2017; Salmon et al., 2021).

Cluster #4

Cluster 4, represented in green, is related to peatland restoration and species richness, having keywords such as biodiversity, conservations, sphagnum, vegetation, plant etc). Since co-occurrence keywords are essential in reflecting and defining research contents, cluster 4, as seen in Fig 3, revealed degraded peatland restoration on the vegetation development. Peatlands vegetation supports numerous invertebrates, birds and bryophytes (Warner and Asada, 2006).

Therefore, Vegetation development on drained peatland has been an indicator to measure the success of peatland restoration (Van Dijk et al., 2007; Richert et al., 2000; Tuittila et al., 2000) since the vegetation response plays a significant role in carbon and greenhouse gas budget of a peatland (Peacock et al., 2013). The vegetation development on restored sites depends on the water table, plant propagules, temperature and the nutrient status of the site (Strack et al. 2014; Campbell and Rochefort 2003).

Blocking drained ditches in drained peatland is frequently used to increase the water table (WT) to enhance the establishment of peat-forming plant species. Some peat-forming plant species that have been reported to have re-established after restoring degraded peatland *are Eriophorum vaginatum Sphagnum cuspidatum, and Sphagnum auriculatum Calluna vulgaris, Vaccinium myrtillus, Erica tetralix,* and *Empetrum nigrum* (Komulainen et al., 1998, Lavoie et al., 2005). Peacock et al. (2013) reported that ditch blocking increased plant species richness in restored peatland-whereas *Eriophorum vaginatum* and *Eriophorum cuspidatum were* the primary colonising species, with additional colonisation by *Eriophorum angustifolium*, algae, and other sphagnum species.

Table 2 shows the top 25 most active keywords in the RDP research domain based on the numerical statistics of the variations in the node sizes and total link strength (co-occurrence connection or links) of the keywords. Out of 2578 all keywords, the top five (5) most active keywords used in the RDP research domain are restoration, vegetation, peatland, drainage, and dynamics.

Table 2: Top 25 Most Active Keywords in Restoration of Degraded Peatland Research.

Keyword	Occurrences	Total link strength
Restoration	179	175
Vegetation	108	107
Peatlands	69	68
Drainage	64	63
Dynamics	49	49
Nitrogen	49	48
Water	49	49
Carbon	46	46
Bog	44	43
Sphagnum	44	44
Management	40	39
Diversity	39	39
Biodiversity	36	36
Fluxes	35	35
Rewetting	35	35
Wetlands	35	33
Hydrology	33	33
Phosphorus	33	32
Conservation	32	32
Impact	32	32
Wetland	32	32
Methane	31	31
Soil	31	31
Decomposition	29	29
Fen	29	29

Further, co-occurrence keywords analysis was performed using cite space to investigate the topics receiving significant attention in the RDP research domain (Fig. 4).

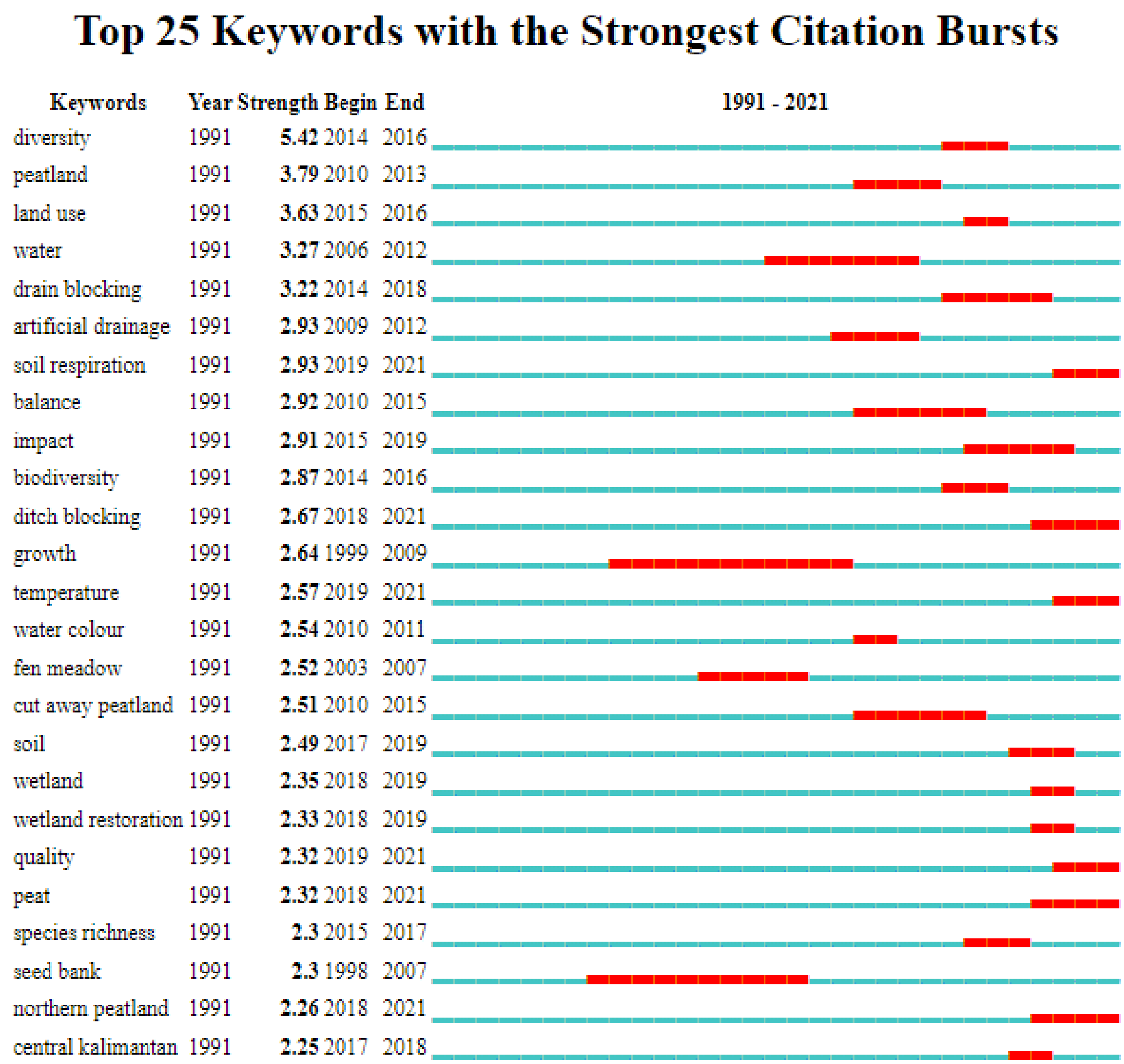

Fig. 4: Top 25 keywords with the strongest citation bursts in the RDP (1991–2021).

Figure 4 shows the burst time of most co-occurring keywords or research hotspots in the RDP research domain with the strongest citation bursts analysis using CiteSpace from 1991 to 2021. Citation burst illustrates evidence of which keywords have frequently been cited within the literature of a research theme/area, specifically, growing topics or topics associated with surges in citations (Chen, 2014). Using the WOS dataset, 68 keywords had citation bursts, as seen in Fig 4, illustrating the top 25 keywords with the strongest citation bursts. The blue lines in the figure denote the time interval, whereas the red lines represent the time interval during which a subject was found to have a burst, indicating a citation burst event. The citation burst ranges from 5.42 to 2.33. The top five keywords having the strongest citation burst were diversity (burst strength, 5.42; 2014-2016), peatland (burst strength, 3.79; 2013-2016), land use (burst strength, 3.63; 2015-2016), water (burst strength, 3.27; 2006-2012) and drain blocking (burst strength, 3.22; 2014-2018). Furthermore, soil respiration (burst strength, 2.93; 2019-2021) is the most current burst, representing the emerging trend within the RDP research domain.

3.2.2 Research outlet: outlets direct citation analysis

Fig 5 displayed the network of the landmark research outlets in the RDP, consisting of 190 links and a total link strength of 3264. Three clusters were formed, with different colours (red, green and yellow) assigned to differentiate between journal clusters. Cluster 1 (blue) entails research outlets publishing articles focusing on the hydrology of peatland in RDP research. Research outlets found in cluster 1 are science of the total environment, hydrological processes, journal of hydrology and water resources research etc. Cluster 2 coloured green comprises research outlets (restoration ecology, biological conversation, applied vegetation science, and ecology and evolution etc) focusing on vegetation and ecology RDP research. Cluster 3 coloured red is composed of mires and peat, wetlands ecology and management, ecosystem, ecological engineering, biogeoscience etc.

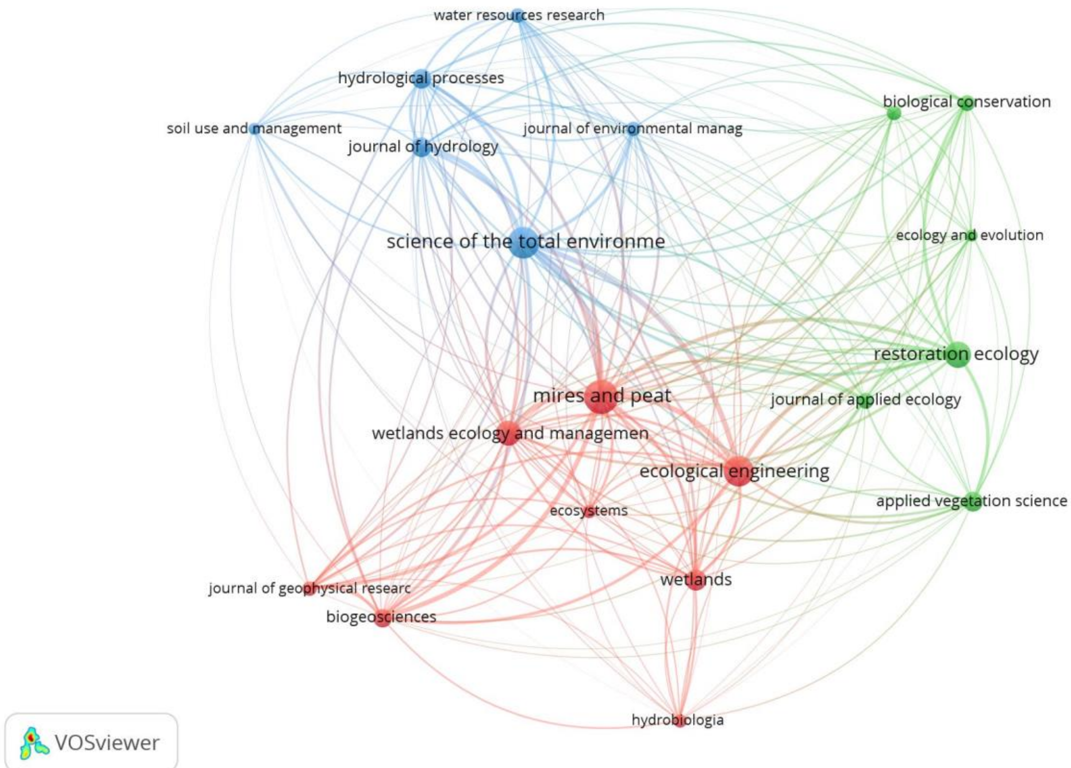

Fig 5: Network of the Landmark Research Outlets in the RDPThe top 20 research outlets with their quantitative measurement are presented in Table 3, with mires and peat recording the highest number of articles (40) in the RDP research domain. Mires and peat is a peer-reviewed internet journal publishing articles on mires, peatlands and peat-related research. It is published jointly by the International Peatland Society (IPS) and the International Mire Conservation Group (IMCG) (http://mires-and-peat.net/)

Table 3: Research Outlets in the Restoration of degraded peatland research.

Research outlet	No. of articles	Average citation	Total citations	Total link strength
Mires and peat	40	8	311	929
Science of the total environment	35	20	683	811
Ecological engineering	30	15	444	646
Restoration ecology	24	14	346	490
Wetlands ecology and management	21	25	517	415
Wetlands	15	16	234	264
Applied vegetation science	14	22	309	215
Hydrological processes	13	13	172	324
Journal of hydrology	13	42	541	391
Biogeosciences	12	38	455	393
Biological conservation	9	12	111	194
Journal of applied ecology	9	37	336	178
Forest ecology and management	8	16	124	152
Journal of environmental management	8	16	129	202
Journal of geophysical research-biogeosciences	7	15	107	247
Water resources research	7	16	110	190
Ecosystems	6	52	314	182
Hydrobiologia	6	42	250	104
Ecology and evolution	5	19	93	109
Soil use and management	5	18	90	92

3.2.3 Document citation networks in RDP research.

The resultant network of the document citation network analysis of RDP research comprises 101 links and 187.50 total links as displayed in Fig 6.

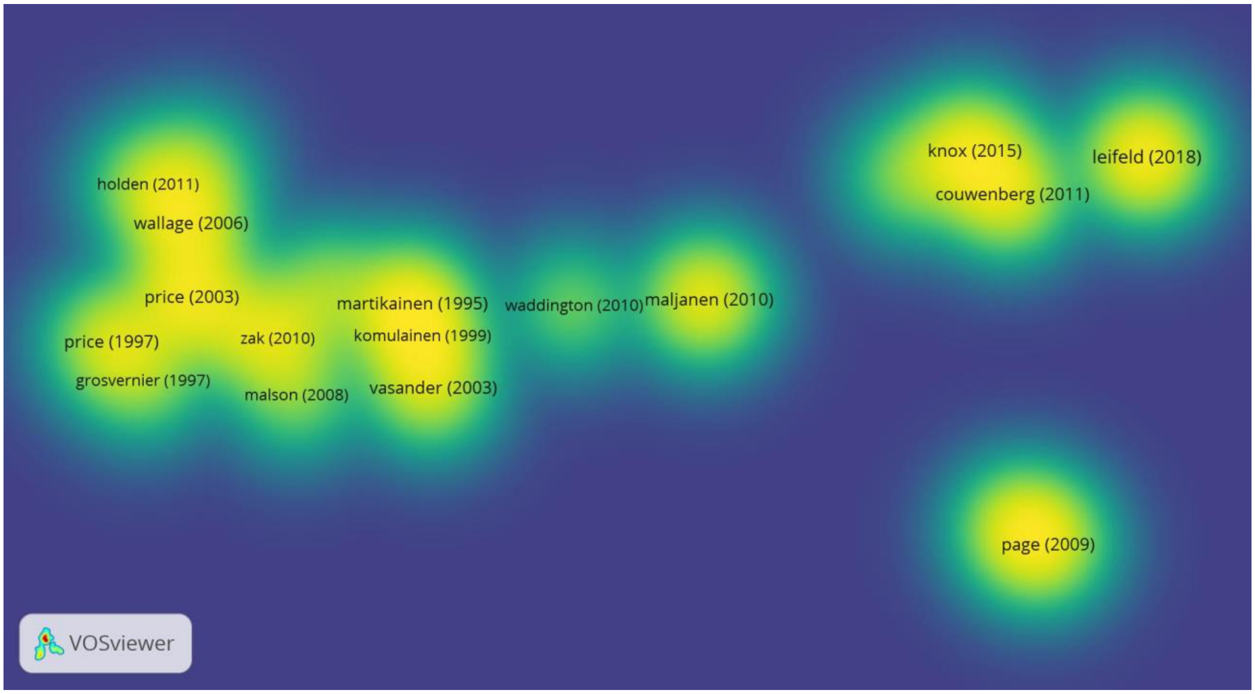

Fig 6: Density map of document citation network analysis

From Fig 6, the top three cited articles include Leifeld (2018) "The underappreciated potential of peatlands in global climate change mitigation strategies". The article revealed that restoration of drained peatland drastically reduces the current annual greenhouse gas emission, which is 3.4 times less nitrogen costly, involving a much smaller land area demand than improving mineral soil carbon sequestration for mitigation of greenhouse gas emissions peat coverage areas. A review article titled "Hydrological processes in abandoned and restored peatlands: An overview of management approaches written by Price (2013), obtained a citation of 183, making them the second most cited article in the RDP research domain. Price (2013) revealed that hydrological management increases hydrological functions such as hydraulic conductivity, water retention capacity, vegetation development, and the specific yield of abandoned land peatland. Lastly, the third most cited article was "greenhouse gas balances of managed peatlands in the Nordic countries – present knowledge and gaps conducted by Maljanen (2010). Another observation made from

Table 4 suggests that the top three influential documents based on the citation index in the RDP research domain were literature review articles. A different trend was observed when evaluating the links among the top 13 articles. It was found that 22, 60, 80 and 60 of the 522 articles have cited Leified (2013), Prince (2003), Maljanen (2010) and Knox (2015) respectively. By analysing the impact of rewetting on drained peatland, Komulainen (1999), found out that two years of rewetting stimulated carbon sequestration such that rewetted minerotrophic fen obtained CO_2-C balance ranged from 162 to 283 g m^{-2}, with dense *E. vaginatum* vegetation and a high-water table while rewetted bog had CO_2-C balance varied from 54 to 101 g m^{-2} having a high-water table and mire vegetation. Wuni et al. (2019) emphasised that the influence of articles can be assessed by their total citations, normalised citations, and links with other articles. Therefore, using the total citation approach, Table 4 summarised the top 13 most influential research articles with key findings, links and citations.

Table 4. Highly cited document in RDP research domain.

Article	Title	Citations	Total Links	Research outlets	Type of articles	Key findings
Leifeld (2018)	The underappreciated potential of peatlands in global climate change mitigation strategies	226	22	Nature communication	Review	Restoration of drained peatland drastically reduces the current annual greenhouse gas emission, which is 3.4 times less nitrogen costly than improving mineral soil carbon sequestration for mitigation of greenhouse gas emission in peat coverage areas.
Price (2003)	Hydrological processes in abandoned and restored peatlands: An overview of management approaches	183	60	Wetlands Ecology and Management	Review	The authors discovered that hydrological management options (blocking ditches, constructing bunds, reconfiguring the surface, and managing microclimate) increase hydrological functions of abandoned land peatland.
Maljanen (2010)	Greenhouse gas balances of managed peatlands in the Nordic countries – present knowledge and gaps	183	80	Biogeosciences	Review	Annual mean GHG balances (CH_4, N_2O and CO_2 emissions) from agriculture managed peatland in the Nordic countries were 2280 and 3140 g CO_2 eq. m^{-2} for areas drained for grass swards, cereals or those left fallow, respectively. The mean net GHG missions in abandoned and

						afforested agricultural peatlands recorded 1580 and 500 g CO_2 eq.m^{-2}, respectively.
Knox (2015)	Agricultural peatland restoration: effects of land-use change on greenhouse gas (CO_2 and CH_4) fluxes in the Sacramento-San Joaquin Delta	178	60	Global Change Biology	Research article	The conventional drained agricultural peatland used for pasture and corn production released 341 g C m^2 yr^1 as CO_2 and 11.4 g C m^2 yr^1 as CH_4, while flooded land-use types (a rice paddy and two restored wetlands) store up to 397 g C m^2 yr^1 but obtained a higher methane emission ranging from 39 to 53 g C m^2 yr^1, suggesting that rewetting of drained agriculture pet soils reduce soil subsidence and GHG emissions.
Martikainen (1995)	Change in fluxes of carbon dioxide, methane and nitrous oxide due to forest drainage of mire sites of different trophy	160	11	Plant and Soil	Research article	Drainage negatively affects the annual CO_2 and N_2O emissions but decreases the emissions of CH_4 in a drained peatland.
Couwenberg (2011)	Assessing greenhouse gas emissions from peatlands using vegetation as a proxy	158	70	Hydrobiologia	Research article	A water-level class, trophic state (C: N ratio), base richness (pH) and vegetation type were used as ‘vegetation forms’ as a comprehensive proxy for estimating baseline and project scenario greenhouse

						emissions from degraded peatland and thus emission reductions from rewetting.
Page (2009)	Restoration Ecology of Lowland Tropical Peatlands in Southeast Asia: Current Knowledge and Future Research Direction	157	23	Ecosystems	Review	The review reported that fire, exacerbated by drainage, is the principal driver of land-use change. In contrast, repeated and high-intensity fires lead to retrogressive succession towards non-forest communities in Kalimantan, Indonesia. Furthermore, the hydrological restoration through rewetting the drained peatland was identified as the key vegetation restoration and protecting the remaining peat carbon stocks.
Wosten (2008)	Peat–water interrelationships in a tropical peatland ecosystem in Southeast Asia	146	4	Catena	Research article	The hydropedological modelling approach was used to generate groundwater level prediction maps to study the peat-water interrelationships in a degraded tropical peatland. The model identified areas with good restoration potential based on predicted flooding depth and duration. The model predicted groundwater levels should be maintained between 40 cm below and 100 cm above the peat surface

						to prevent subsidence and fire during rewetting.
Price (1997)	Soil moisture, water tension, and water table relationships in a managed cutover bog	142	16	Journal of Hydrology	Research Article	The study compared the hydrological indicators between a natural bog, drained and harvested bog, and drained harvested bog with ditches blocked. Ditches block with mulching obtained high water table recessions similar to the natural site. However, the soil moisture obtained at the block site did not differ from the drain site. The site with ditches blocked observed higher greater water tension than the drained bog site
Vasander (2003)	Status and restoration of peatlands in northern Europe	137	41	Wetlands Ecology and Management	Review	Rewetting and ditch or drainage blocking were identified as restoration techniques developed for degraded peatland management in Estonia, Sweden, and Finland, specifically for nutrient-rich peatland
Komulainen (1999)	Restoration of drained peatlands in southern Finland: initial effects on vegetation change and CO2 balance	121	47	Journal of Applied Ecology	Research article	Two years of rewetting stimulate carbon sequestration such that rewetted minerotrophic fen obtained CO^2-C balance ranging from 162 to 283 g m^{-2}, with dense *E. vaginatum* vegetation and a high-water

						table while rewetted bog had CO^{2}-C balance varied from 54 to 101 g m^{-2} having a high-water table and mire vegetation.
Jauhiainen (2008)	Carbon dioxide and methane fluxes in drained tropical peat before and after hydrological restoration.	121	47	Ecology	Research article	After restoration, the drained tropical peat forest showed higher annual minimum soil water table levels. However, the improvement of the peat hydrology did not instantly reduce CO_2 flux rates in forest sites. As a result, the cumulative CO_2 emissions of the tropical peat did not reflect the notable changes in the hydrological conditions before and after restoration. In addition, the methane emission from the rewetted peat did not differ from the drained peat.
Holden (2011)	Water table dynamics in undisturbed drained and restored blanket peat	106	48	Journal of Hydrology	Research article	Water tables in undisturbed drained and restored blanket peats are more variable in order (drained > restored > intact) such that the mean water table depths over 18 months studied period were −5.8 cm at the intact site, −8.9 cm at the restored site and −11.5 cm at the drained sites.

3.3 Co-authorship and Active countries in the RDP research

3.3.1 Co-authorship analysis

Scientific collaboration between researchers and institutions enhances knowledge exchange, innovation and joint funding application (Hosseini et al., 2018). Only two clusters of productive and collaborative researchers were revealed, consisting of 105 links and a total link of 2136 as illustrated in Fig S1. Researchers such as Baird, Andy J., Peacock, Mike, Green, Sophie M., and Evans, Chris D. are found in cluster one (red). Cluster two (red) includes researchers such as Holden, Joseph and Evans, Martin G. Researchers such as Evans, Martin G and Holden, Joseph tends to collaborate more often in the RDP research (Holden et al., 2006; Evans et al., 1999). Fig S1 suggests that Holden, Joseph; Kotiaho, Janne S., Vasander, Harri and Tahvanainen, Teemu are the top collaboratives researchers within the RDP research discourse. Using the citation index to measure the productivity of the top collaborative co-authors, Vasander, Harri and Holden, Joseph emerges as the top-cited authors within the RDP research domain, as seen in Table S1.

3.3.2 Active countries in the RDP research

Fig S2 illustrates the most active countries in the RDP research discourse, with larger nodes indicating a high number of publications. Cluster one (blue) involves the United Kingdom countries such as England, Scotland and Wales, with England possessing the higher nodes. The second cluster (green) consists of Germany, Netherland, Poland, and Sweden, with Germany obtaining the higher nodes. The higher node obtained by Germany isn't surprising since they have degraded more than 85 % of its original peatlands -hence restoration research options are now implemented to restore the degraded peatland to its original state. The last cluster is red, consisting of five countries, with the highest nodes obtained by Finland. Based on the analysis, it can be revealed that about 26 % (51 out of 195) of all countries in the world are involved in RDP research. Regarding the strength of links, the strongest links were between the following pairs (England-Wales; England-Scotland; England-Finland; Germany-USA; Canada-USA).

Table 5: Active countries in the RDP research

Country	Documents	Citations	Av. Citation	Total link strength
Sweden	18	667	37	886
Finland	68	2053	30	1837
Canada	46	1270	28	1875
Netherlands	47	1121	24	1430
England	96	2005	21	3976
Usa	43	794	18	1717
Wales	24	412	17	1262
Germany	88	1498	17	3179
Indonesia	40	675	17	1629
Poland	34	465	14	1480
Scotland	37	426	12	1602
china	24	197	8	561

Table 5 shows the top 12 influential countries based on the number of articles, with England (96) obtaining the higher number of articles. The top three countries are England (96), Germany (88), and Finland (68). However, an inconsistent pattern is observed when ranking based on citations. Under this, Finland (2053), England (2005), and Germany (1498) are the top influential countries in the RDP research domain. A slightly different ranking pattern is observed when using the average citation index such, that Sweden (37), Finland (30) and Canada (28) are the influential countries in the research domain.

4.0 Conclusion

This study reconnoitres the status and the global trends of RDP research using scientometric analysis. RDP research has tremendously increased in the last decade resulting in numerous literature reviews being published. Still, this current study presents the first scientometric review of RDP research using 522 documents (research articles and literature review) retrieved from WOS database. The structure of the body of knowledge in RDP research was evaluated using the research Outlet, keywords co-occurrence analysis and document citation analysis. Specifically, the scientometric analysis of the RDP dataset discovered the following conclusions:

- Annual exponential growth in the number of publications in RDP research was observed
- Four research themes were identified with the co-occurrence of keywords analysis namely; (i) impact of drainage on peatland ecosystem services; (ii) impact of peatland restoration on greenhouse gas emissions (iii) peatland restoration and biogeochemical properties and (iv) peatland restoration and plant species richness.

- The top 3 keywords in RDP research having the strongest citation burst were diversity (burst strength, 5.42; 2014-2016), peatland (burst strength, 3.79; 2010-2013) and land use (burst strength, 3.27; 2014-2018).
- The most contributing research outlets of RDP research are mires and peat and the science of the total environment
- England and Germany are the most active countries in RDP research.
- It was found that 22, 60, 80 and 60 of the 522 articles have cited Leified (2013), Prince (2003), Maljanen (2010) and Knox (2015) respectively.

The current scientometric analysis is limited to certain keywords TS (topic) =('*drained peatland restoration' OR 'drained bog restoration' OR 'drained mire restoration' OR degraded peatland restoration' OR 'degraded bog restoration' OR 'drained peatland reclamation' OR 'drained bog restoration' OR 'degraded peatland reclamation' OR 'degraded bog reclamation' OR 'drained mire restoration' OR 'degraded mire reclamation' OR 'degraded fen restoration' OR 'drained fen reclamation*') and the selected documents were limited to review and research articles only. In addition, only one database (WOS) was used for the extraction of the dataset and this may be pretentious by intrinsic limitations of WOS's coverage of publications. Due to the aforementioned reasons, this study might not fully capture the whole available literature on RDP. However, Scientometric analysis of RDP research provides instinctive graphics for a research hotspot in RDP and valuable information based on a comprehensive analysis of the research theme and future trends

Author Contributions: Conceptualization, S.O.A.; methodology, S.O.A.; software, S.O.A.; validation, S.O.A; formal analysis, S.O.A; investigation, D.M.; resources, D.M; F.T.; data curation, S.O. A.; writing—original draft preparation, S.O.A.; writing—review and editing, M.G; F.T., and D.M.; visualization, S.O.A; supervision, M.G; F.T., and D.M.; project administration, M.G; F.T., and D.M.; funding acquisition, F.T. All authors have read and agreed to the published version of the manuscript.

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Supplement figures

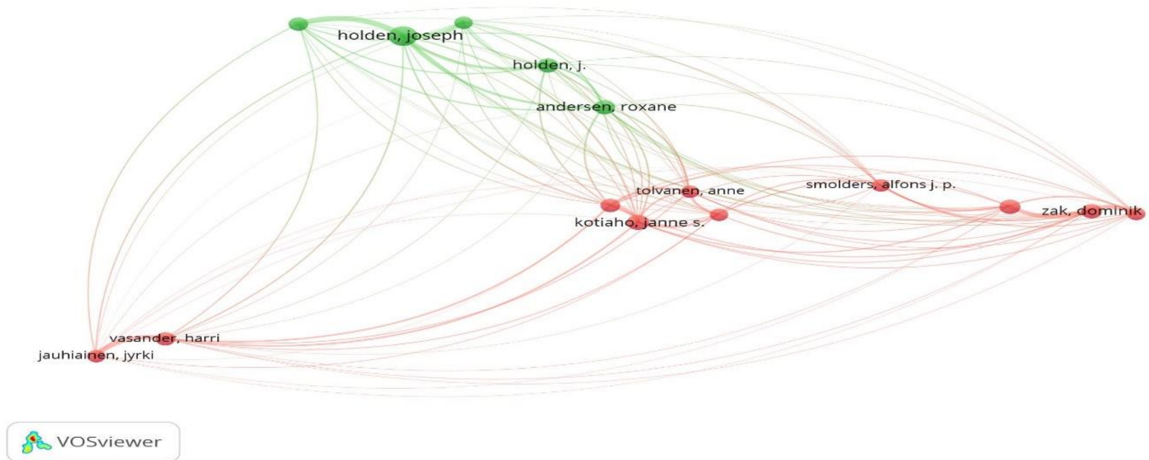

Fig S1. Density Map of Co-Authorship Network

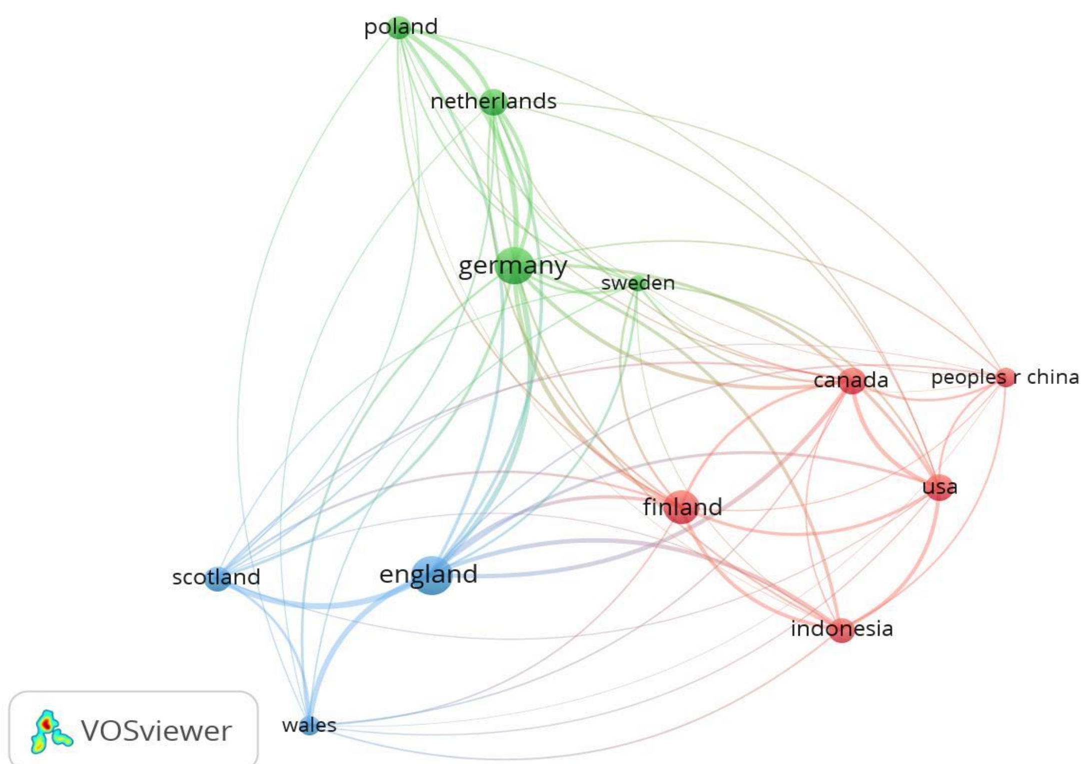

Fig S2 . Network of most contributing countries in the RDP research