



A Brief Review in Effect Factors on Peatland Ecosystem

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Abstract

Peatland ecosystem plays an important role in the global climate change because they act as a pool or sink of the gasses. There are several factors which influence the environmental consequences of peatland especially in relation to climate change. The main influences are: 1) carbon dioxide, 2) methane flux, 3) nitrous oxide (N₂O) and 4) others environmental factors. These atmospheric gases concentrates constitute roughly 73 percent of the overall positive energy flux variation. Carbon dioxide is the greenhouse gas considered most consequential in Anthropocene climate change. Methane is a potent greenhouse gas with a global warming potential 34 times greater than carbon dioxide in natural wetlands and the majority of these emissions are from peatlands. Nitrous oxide is one of the main pollutants in the ecosystem of peatlands and can cause eutrophication. This paper is a brief review on environmental factors influences to climate change in peatland ecosystems. It highlights the need for minimizing the negative effects of climate change on wetland ecosystem through proper management of peatlands.

Subject Areas

Environmental Sciences

Keywords

Peatland, Carbon Dioxide, Methane Flux, Evapotranspiration, Climate Change

1. Introduction

Wetland ecosystems cover roughly 6% - 9% of the earth's terrestrial surface. They are present in multiple regions across the globe, but are most abundant in the boreal and subarctic regions, where temperatures are cooler and precipita-

tion amounts are favorable [1]. Wetlands have many characteristics which are notable in the presence of standing water, uniquely soil conditions and species, especially vegetation, that are adapted to and tolerant of saturated soils during the growing season. Hydrological conditions and the role of wetlands as ecotones between land and water systems are unique [2]. In nearly every part of the world, wetlands are located and while many cultures have lived among wetlands for several centuries, and even depended on them, modern wetland history until the 1970s was full of misunderstanding and fear. During the developing world, wetlands were destroyed at alarming rates. The preservation of wetlands in many parts of the world has thus become normal. They are sometimes referred to as landscape kidneys and “supermarkets” for the ecological services and habitat values they provide [2]. Peatlands are wetlands where development levels go above breakdown levels and protected beneath the living plants [3]. The widely accepted definition of a peatland is, “a wetland on which extensive organic material has accumulated” [4]. Peat is a plant material partially decomposed. The most common of the peatlands are in the boreal regions, but also in temperate, tropical and mountainous regions [5] [6] [7]. Peatlands minimum peat mass of 40 cm is required in the United States for classification as a grass, which categorizes it as Histosol. Peatlands with a minimum thickness of 30 cm have been identified internationally [8]. Peatlands Have bogs and fens spread mostly in cold boreal areas throughout the world with ample over moisture. Bogs and fens can be formed in several ways, originating either from aquatic systems, as in flow through succession or quaking bogs, or from terrestrial systems, as with blanket bogs. Although many types of peatlands are identifiable, classification according to chemical conditions usually defines three types: 1) minerotrophic (true fens), 2) ombrotrophic (raised bogs), and 3) transition (poor fens). Features of many peatlands include acidity caused by cation exchange with mosses, oxidation of sulfur compounds, and organic acids, low nutrients and primary productivity, slow decomposition, adaptive nutrient-cycling pathways, and peat accumulation. Peatlands collectively are the largest terrestrial storage of carbon on the planet and are seen as potential sources of carbon to the atmosphere if they are disturbed hydrologically or if climate shifts. Many of these lake basins were formed by the last glaciation, and the peatlands are considered to be a late stage of a filling-in process. The various characteristics of peatlands have been examined in multiple [9] [10]. However, most of the literature tends to be focused on peatland ecosystem function, especially their ability to sequester a large amount of Carbon in the soil [11]. Dead plant material in undisturbed peatlands does not decompose as rapidly as it accumulates as peat; making natural peatlands long term sinks of carbon. Moreover, on shorter time scales, natural peatlands are source or sink of carbon depending on the weather conditions of a given year [12] [13]. The carbon and water budgets of peatlands are intricately linked [14]. Disturbances that impact water storage and flows such as climate change or anthropogenic activities (e.g. peat extraction) lead to changes in peatland carbon cycle processes. The two dominant greenhouse gases exchanged

with the atmosphere from the surface of peatlands are carbon dioxide CO_2 and methane CH_4 , both of which contribute significantly to global warming [15]. Around two thirds of photosynthesis carbon dioxide are produced in cellular respiration [16]. Approximately one third of the carbon is used in cell maintenance and biomass processing. The bio-masses that have been produced contain starch, organic foods, amino acids, polysaccharides, enzymes, lipids and celluloses. When your plant falls or dies biomass, labial carbon compounds can be quickly split up by microbes. Decomposed carbon compounds leave the system in the form of CO_2 , CH_4 or DOC. Recalcitrant carbon compounds such as lignin are harder to decompose and will last a long time in the system. The decomposition rates of the microbial community are highly affected. Under the growing greenery, high water levels provide an anoxic environment. This anoxic zone helps the formation of peat through oxygen reduction during microbial degradation, as an electron acceptor. Bacteria have been found to exploit rich minerals while fungi have occupied ombrotrophic sites [17]. Microbial communities have a stronger tolerance of acidic conditions [18]. Some bacteria can degrade lignin, but its effectiveness is limited. Related, peatlands are thus defined not necessarily by their climate or anyone floristic species, but by the physical and chemical properties that allow the long-term accumulation of incompletely decomposed plant material. Also, the high-water table effect to lowers soil organic carbon decomposition rates by anoxic conditions and the peatland further grows in depth [19]. Here, this review paper illustrated the effects of environmental factors and climate change on peatlands ecosystem, focusing on the effects of variation in carbon dioxide, methane flux, nitrous oxide and changes the environmental factors in atmosphere composition on peatlands ecosystem. It highlights the need for minimizing the negative effects of climate change on wetland ecosystem through proper management of peatlands.

2. Effect of Environmental Factors on the Peatland Ecosystem

The Intergovernmental Panel on Climate Change (IPCC), has continuously analyzed and synthesized thousands of scientific data lines and advanced simulations at different scales, as well as several research teams worldwide, to assert that not only are compelling signs of accelerated climate change, but also that strong evidence of anthropogenic behaviors are responsible for altering global temperature patterns. The IPCC (2013) [20] report indicates that global temperature rise is predicted by 0.3°C to 4.8°C , over 1986-2005 by the end of the century. The ever-increasing additions of gases to the atmosphere from burning of fossil fuels, where atmospheric gases concentrations have increased from 40% above pre-industrial levels, tend to accelerate these patterns [20]. Such atmospheric gases concentrates constitute roughly 73 percent of the overall positive energy flux variation [21] [22], estimated by the latest global climate change of 0.85°C from 1880 to 2012 [20]. The cumulative impacts (temperature, atmospheric gases and precipitation) of these climate change influences are likely to

alter peat environments around the world, disrupting many critical ecological mechanisms and functions [23]. As a result, several research goals for assessing the individual and interactive impact of these climate change influences on specific peatland ecosystem processes [24]. For example, by 2100 high latitude regions are predicted to be up to 11°C warmer than recent averages, about 7°C warmer than the projected global average warming [20]. Accordingly, an important research goal of winter peatlands is to consider the effect of climate change on structure and operation of the peatlands habitats in high-latitude environments [25]. In future climatic conditions, these increased climatic conditions are expected to cause many high latitude habitats to become warmer and drier in an unprecedented way than many other habitats across the globe, particularly in combination.

3. Effect of Carbon Dioxide (CO₂)

Carbon dioxide is the greenhouse gas considered most consequential in Anthropocene climate change [26]. Plants, cyanobacteria, and algae capture and derive energy from atmospheric CO₂ through photosynthesis; all aerobic organisms produce CO₂ through respiration. CO₂ emissions from peatlands as well as that produced through decomposition [27] [28]. The physiological differences in peatlands must be considered. Temperature, water table and availability of organic substrates have been shown to be controlling factors of CO₂ emissions from peatlands [29] [30]. The effect of water table height on CO₂ has been shown in a number of peatland studies. Freeman *et al.* (1993) [31] found that CO₂ emissions increased during a simulated drought in Welsh peatland of Wales. Funk *et al.* (1994) [32] also found that CO₂ emissions tripled when the water table was lowered below the peat surface in microcosm cores of a bog near Fairbanks, Alaska in March 1991. Chimner and Cooper (2003) [30] observed that CO₂ fluxes were highest when temperature was high within the lowest water table in Colorado subalpine fen in early June 1998. They attributed this to increases in mineralization of plant material in the aerobic environment. No high correlations were found between CO₂ fluxes and any variable measured (depth, age, pH, water temperature, wind speed, transparency, etc.) in a number of lakes, rivers in peatlands of Candia [33]. CO₂ flux has consistently increased in atmospheric during the modern era [34], and is critical to Earth's present and future climatic conditions. Related, a previous research demonstrates the variations of CO₂ emissions from peatlands such as Draper *et al.* (2014) [35] has shown in 2014 the variation of carbon dioxide in Amazonian peatlands forests, USA was 3.14 g·C·m⁻²·yr⁻¹ (**Table 1**). Lloyd (2006) [36] in meadow peatland of Tadham, UK between 2000 to 2003 has shown the variation was 59 g·C·m⁻²·yr⁻¹ (**Table 1**). Syed *et al.* (2006) [37] in Boreal fen of Alberta, Canada shows the variation of carbon dioxide between (2002-2003) is -144 g·C·m⁻²·yr⁻¹ (**Table 1**). A number of novel methods, notably the cuvette method, were developed to measure CO₂ exchange in both laboratory settings and *in situ* prior to modern micrometeorological technology [38]. Based on **Table 1**, the emergence of an appreciable body of literature on carbon exchange in fen peatlands using eddy

Table 1. Carbon dioxide observations from peatlands ecosystems around the world.

Year	Country	Site	Type	Value g·C·m ⁻² ·yr ⁻¹	Source
2014	Amazonian peatlands, USA		peatland forests	3.14	Draper <i>et al.</i> (2014) [35]
2002	Tadham, UK	5181202600N, 2849'4300W	meadow	59	Lloyd (2006) [36]
2003-2004	Alberta, Canada	54.95°N, -112.47°E	Boreal fen	-144	Syed <i>et al.</i> (2006) [37]
2014-2016	Newfoundland, Canada	48.26°N, -58.67°E	Boreal bog	-46 ± 35	Wang <i>et al.</i> (2018) [46]
2004-2005	Pirkanmaa, Finland	61.83°N, 24.19°E	Boreal fen	-111	Aurela <i>et al.</i> (2007) [41]
1997-2002	Lapland, Finland	69.13°N, 27.28°E	Subarctic fen	-21.5 ± 19.8	Aurela <i>et al.</i> (2004) [47]
2012-2013	Bavaria, Germany	47.80°N, 11.32°E	Temperate bog pine	-62	Hommeltenberg <i>et al.</i> (2014) [48]
2002-2012	Kerry, Ireland	51.92°N, 9.92°E	Atlantic blanket Bog	-55.7 ± 18.9	McVeigh <i>et al.</i> (2014) [49]
4.5-year record	Norwegian, Norway	69.13°N, 16.01°E	Boreal blanket bog	-19.5 ± 18.3	Lund <i>et al.</i> (2015) [50]
2005-2006	Skåne, Sweden	56.25°N, 13.55°E	Temperate bog	-21 ± 5.4	Lund <i>et al.</i> (2009) [51]
2009-2011	Minnesota, USA	47.51°N, -93.49°E	Temperate poor fen	-19	Olson <i>et al.</i> (2013) [52]
2006-2007	Ontario, Canada	45.41°N, -75.48°E	Cool-temperate bog	-40.2, -104	Strilesky and Humphreys (2012) [53]

covariance techniques in Lapland, Finland in 1997s and 2002s was found $-21.5 \pm 19.8 \text{ g}\cdot\text{C}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$. Related, researchers have elicited several important factors or drivers of peatland CO₂ exchange, including but not limited to plant community structure and composition [38] [39]; weather conditions [40] [41]; volumetric soil moisture [42] [43]; and water table position [44] [45]. **Table 1** illustrated the carbon dioxide has an effect on different kinds of peatland.

4. Effect of Methane Flux (CH₄)

Methane is a potent greenhouse gas with a global warming potential 34 times greater than carbon dioxide in natural wetlands [54] [55] [56]. The majority of these emissions are from tropical wetlands and peatlands [57]. Anaerobic conditions of peatlands as well as accumulation of large amounts of organic matter provide a favorable environment for CH₄ production [58]. Methane production is inhibited by sulfate as sulfate-reducing bacteria out-compete methanogenic bacteria for organic substrates [59]. Global CH₄ cycling is driven naturally by microbial activity underneath the earth's soil surface of the peatland area [60]. If the soil of a wetland is not completely inundated, CH₄ will be consumed via oxidation by methanotrophic bacteria in the aerobic layer (vadose zone) of the soil. Methanogenic *Archaea* convert fermented organic matter into CH₄ through the acetate pathway (acetogenic microorganisms) or the hydrogen pathway (hydrogenic microorganisms); though acetogenesis is more common worldwide and in fens, hydrogenesis tends to dominate in ombrotrophic bogs lacking acetate from

vascular vegetation [60] [61]. Once produced by these anaerobes, CH₄ gas can reach the atmosphere by three processes: direct diffusion through the soil, episodic ebullition events releasing “bubbles” of CH₄ gas; and root transport through the aerenchyma vessels of plants such as *Typha* [55] [62] [63]. Dominant determinants of CH₄ emissions from peatlands are water table position, soil temperature, quality and availability of substrate, and mode of gas transport to the atmosphere [64]. Freeman *et al.* (1993) [31] observed decreased CH₄ flux in peat microcosms during a simulated drought but poor correlations were found between CH₄ flux and water table height. Methanogenesis is the process by which certain *Archaea* produce CH₄ in anaerobic environments, such as in flooded wetlands below the water table. A meta-review of 87 peatland studies by Abdalla *et al.* (2016) [65] found the primary controls of peatland CH₄ flux to be soil pH, vegetation composition, and water table depth. Methane also has secondary impacts on ambient aerosols, ozone and other compounds [66]. **Table 2** demonstrates positive correlations between CH₄ flux and different kinds of peatlands ecosystem, in 1998-2004, the concentration of atmospheric CH₄ is 0.06 - 0.08 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in bog peatland of Canada. In 2005, the concentrations of CH₄ are 0.02 - 0.06 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in Blanket peat of England [67] fluxes in a northern peatland. The various natural CH₄ sinks and sources may significantly contribute to global change in CH₄ abundance. From 2011-2014, the variation of methane flux in Minnesota peatland of USA is 0.3 - 0.5 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ [68].

Table 2. Methane flux observations from peatlands ecosystems around the world.

Year	Country	Site	Type	Value $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$	Source
2006-2007	Scotland	55°480N, 3°14035W	Peatlands	0.10 ± 0.02	Dinsmore <i>et al.</i> (2009) [69]
1995	Scotland	55°050N	Bog	0.01	Clymo <i>et al.</i> (1995) [70]
2003-2005	Ireland	51°550N	Bog	0.2	Laine <i>et al.</i> (2007) [71]
2003-2008	Ireland	51°550N	Bog	0.01	Koehler <i>et al.</i> (2011) [72]
2011-2014	USA	N47°30.4760; W93°27.162	Minnesota peatland	0.3 - 0.5	Hanson <i>et al.</i> (2016) [68]
2009-2011	USA	47.505N, -93.489W	Fen	0.22 - 0.29	Olson <i>et al.</i> (2013) [52]
2008-2011	USA	46°190N, 86°030W	Fen	0.002 - 0.011	Ballantyne <i>et al.</i> (2014) [73]
2002-2003	Canada	45°250N, 75.48°W	Bog	0.7	Moore <i>et al.</i> (2011) [74]
2009-2010	Canada	45.41°N, 75.52°W	Bog	0.6	Lai <i>et al.</i> (2014) [75]
1998-2004	Canada	45.411N, 75.481W	Bog	0.06 - 0.08	Roulet <i>et al.</i> (2007) [12]
2003-2004	Canada	45°410N	Bog	0.01 - 0.03	(Blodau <i>et al.</i> 2007) [76]
1998	Canada	45°330N, 66.49W	fen and bog	0.17	Moore and Knowles (1990) [77]
2005	England	54°650N, 2°45°W	Blanket peat	0.02 - 0.06	McNamara <i>et al.</i> (2008) [67]

5. Effect of Evapotranspiration (ET)

High biodiversity and hydrological functions including flood control, low flux support, nutrient cycling, and ground water recharge have become increasingly recognized in wetlands. Hydrology of peatlands is a key driving force for the environment, its development and its continued existence for water quality assessment, the exact calculation of water loss from ET is quite relevant [78], making proper water resources plans [79]. However, Different types of peatlands are difficult, expensive and seldom available to direct ET measurement. A number of studies have been carried out on peatlands evapotranspiration, due to the different conditions of peatland and the methods used, the results have differed greatly [79] [80] [81]. Researchers explored the available methods for quantifying evapotranspiration and concluded that covariance of eddies is an especially promising instrument. Recent advances in the reliability of eddy covariance devices have allowed long-term eddy covariance data to be collected above several types of vegetation [82] [83], including wetlands [84] [85].

ET is released from molecular diffusion, boiling and plant transportation to the atmosphere [86]. Many factors affect ET flux mechanisms, including water conditions [87] [88], and latent heat flux (LE), the largest consumer of incoming energy [89] [90]. With increasing temperatures and precipitation, peatlands have undergone significant climate change. Environmental factors that increase ET in the atmosphere affect the composition and productivity of plant species [91]. **Figure 1** illustrated the daily variation of ET was 0.028 from January till end of March 2018 in Dajiuhu peatland in central china and agree with a previous study in a bog peatland in southern Ontario of Canada, and the results indicate a number of characteristics of the association of ET ratio for all days was 0.517 mm/hr, this results suggesting there was strong surface control on daily ET at this site [88]. Cao *et al.* (2020) [92] illustrated, the daily ET in growing periods varied from 0.28 to 4.73 mm/hr in the Qinghai Lake basin, of northwest China. ET has flux to the atmospheric due to a variation of environmental variables and peat respiration.

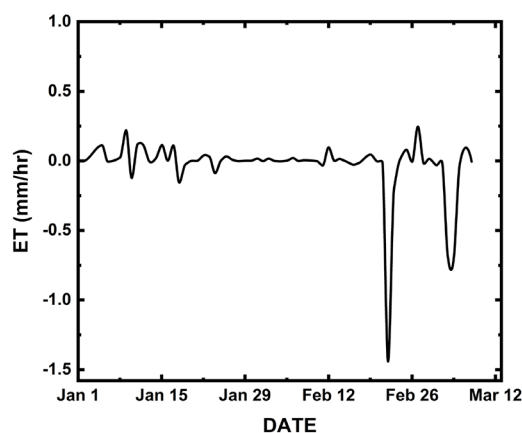


Figure 1. Daily variation of evapotranspiration from January until March of 2018 in peatland of Central China.

6. Effect of Nitrous Oxide (N₂O)

Nitrous oxide is one of the main pollutants in the ecosystem of peatlands and can cause eutrophication, affect water-borne oxygen levels and increase the aquatic species toxicity. Nitrous oxide exists in wetlands ecosystem in inorganic forms and recognized the inadequacy in the number. Groffman *et al.* (1998) [93] studies relating high denitrification rates and N₂O emissions in riparian areas and further suggests that N₂O emissions may be low due to the highly anaerobic conditions found in many riparian zone soils. **Table 3** demonstrated increased in nitrous oxide emissions in permafrost of Finland in 2012 and the values are $2.81 \pm 0.6 \text{ mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ [94]. In a review by Saunders and Kalff (2001) [95] denitrification accounted for 63% of total N₂O removal in lakes. Combined studies of denitrification and N₂O emissions are lacking and the contribution of N₂O emissions from prairie wetlands is not well defined but is expected to be low as the water-saturated environment would promote the formation of N₂ rather than N₂O as N₂ is the dominant gas produced when the waterfilled pore space exceeds 80% [96].

The few existing N₂O estimates from water bodies come from an extensive study by Tremblay *et al.* (2005) [33] in which 125 water bodies were sampled for greenhouse gases N₂O and other nitrogen oxides are formed during nitrification and denitrification processes at suboptimal conditions [97]. Martikainen *et al.* (1993) [98] demonstrate N₂O emission may be affected by various operating parameters and environmental conditions such as Dissolved oxidation, oxidation-reduction potential and water temperature, among other factors in 1992 of Finland peatland. The formation of nitrogen oxides can be avoided by high BOD/N ratio and low O₂/NO_x ratios for denitrification, long denitrification residence time, and avoiding simultaneous NH₄ oxidation and NO₂-reduction [97]. Arai *et al.* (2014) [99] explained the change affects microbial biomass and fluxes of carbon dioxide and nitrous oxide in tropical peatlands of Indonesia and the value is $26.06 \text{ mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ between 2009-2011 (**Table 3**). A previous research by

Table 3. Nitrous Oxide observations from peatlands ecosystems around the world.

Year	Country	Site	Type	Value mg·m ⁻² ·d ⁻¹	Source
1992	Finland	62.51N, 30.53E	peatland	2.5 - 8.6	Martikainen <i>et al.</i> (1993) [98]
1977-2006	Russian	671030N, 621570E	permafrost peatlands	0.9 - 0.1	Marushchak <i>et al.</i> (2011) [101]
1998-1999	Malaysia		Tropical peatlands	1.04	Hadi <i>et al.</i> (2000) [102]
1961-1990	Finland	60°21'N, 25°03'E, -61°23'N, 25°03'E, 125	forest peatlands	0.945 - 0.246	Huttunen <i>et al.</i> (2003) [103]
1991-1996	Finland	61°48'N, 24°19'E,	boreal peatland	1.7	Nykänen <i>et al.</i> (2002) [104]
2012	Finland	68°89'N, 21°05'E	permafrost	2.81 ± 0.6	Voigt <i>et al.</i> (2017) [94]
2009-2011	Indonesia	2°17' - 2°21'S, 113°54' - 114°01'E	tropical peatlands	26.06	Arai <i>et al.</i> (2014) [99]

Khurul *et al.* (2020) [100] approved that the total nitrogen and slightly increased nitrate/nitrite, probably due to the facilitation of microbial degrading activity in the southeast coast of South Korea.

7. Conclusion

This paper is brief review to illustrate the effects of environmental factors and climate change on wetlands ecosystem. Principal processes leading to the production and sinking of carbon dioxide, methane flux and Nitrous oxide in peatland ecosystem of china are presented and discussed mainly. The cumulative impacts atmospheric gases of these climate change influences are likely to alter peat environments around the world, disrupting many critical ecological mechanisms and functions. It is apparent that there is need for continued short and long-term research to better understand peatlands ecosystem and how they affect our climate. This will hopefully provide the basis for predicting better what could happen under various scenarios.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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