REVIEW ARTICLE

Transformation of methane in peatland environments

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Abstract. Wetlands and particularly peatlands are the main natural source of methane. Data indicate that 10–45% of methane emission comes from these sources. Methane emission from wetlands is the result of the balance between methanogenesis and methanotrophic processes and is actively affected by the wetland plant community composition. There are many factors affecting the balance of CH_4: for instance, vegetation has a strong effect on CH_4 emissions from wetland ecosystems by influencing methane production, consumption and transport in the soil. The effects of plants on methane fluxes may be mediated by: molecular diffusion, internal transport through plant aerenchyma tissues and ebullition. Methane is formed in the process of methanogenesis under anaerobic conditions. It may then be emitted into the atmosphere directly from the soil or by internal transport through the plant. Alternatively, it may undergo methane oxidation by methanotrophic bacteria, both free-living in the root zone and associated with the host plant in symbiosis. *Sphagnum* moss is of particular importance for this processes as it contains methanotrophic bacteria in its endophytic system. Methanotrophic bacteria live inside the dead hyaline cells or on the surface of *Sphagnum* leaves and are able to oxidise methane produced in the soil during methanogenesis, making peatlands a natural biofilter for methane, one of the main greenhouse gases.

Key words: peatlands, methane, methanotrophic bacteria

1. Introduction

The relationships between climate and peatland ecosystems including forest-bog areas are bi-directional: the climatic conditions affect peatland and, *vice versa,* peatland actively influences the climatic parameters. This relationship is stronger than might be expected from the small share of peatlands covering merely 3% of the Earth's total surface area. It is based mainly on carbon cycling in the environment taking place for the most part in peatlands and is directly associated with carbon cycling in the atmosphere. Peatlands accumulate a huge amount, about a third, of organic carbon contained in soils, which is equal to the volume of carbon contained in the atmosphere or in the entire terrestri-

al biomass amounting to about 400–600 Pg (Gorham 1991). Most peatlands in Poland are located in forest areas. The occurrence of peatlands in forest areas is of great ecological importance because, such forests, unlike those growing on non-peat soils, show a high ability to accumulate organic matter. Peatlands in forest areas are therefore specific reservoirs of biogenic sediments (Tobolski 2003).

Wetlands, including peatlands, are considered to be the largest natural source of methane emissions; they emit 100–231 Tg CH_4 into the atmosphere annually, which accounts for 10%–45% of the total emissions of this gas (IPCC 2007). Through the process of methanogenesis, these areas contribute to the intensification of the so-called greenhouse effect, while at the same time

effectively capturing and retaining CO_2, accumulating it as photosynthesis products. Therefore, the emission of methane from peatland is the net effect of methanogenesis and methanotrophy (Le Mer and Roger 2001).

The total methane emissions from a variety of wetlands are difficult to estimate. There are high temporal and spatial variations of CH_4 fluxes in the air over these areas. Methane emissions are dependent upon more factors than just the activity of methanogenic and methanotrophic microorganisms. Even in ecologically homogeneous research areas, the coefficient of spatial variation can range from 30% to 100% over short distances (Bartlett and Harris, 1993). The differences in methane emission levels are attributable to the diversity of peatlands both in terms of their climatic conditions and plant species composition that differ significantly both globally and regionally. It may also be the effect of a strong microbiological activity in the peat that is usually caused by high seasonal variations (Ding et al. 2004).

The present study attempts to elucidate the factors influencing the net emissions of methane in peatlands. The presented publications from recent literature allow showing, in some detail, the pathway of methane release in peatland ecosystems, starting from its production by methanogenic bacteria through to its transport and oxidation by methanotrophic bacteria. In discussing the last two issues, particular attention is paid to peat-forming vegetation, including vascular plants and sphagnum mosses.

## 2. Methane in peatlands

Production and oxidation

The methane balance is affected by many factors, such as temperature that determines the microbial activity (the optimal temperature for both methanogens and methanotrophs is 20–30°C) (Dunfield et al. 1993; Le Mer and Roger 2001); water table (Moore and Roulet 1993; Ding et al. 2002) that determines the depth of aerobic and anaerobic zones, as well as the redox potential in peat soils (methanogenesis occurs at a low potential Eh < 200 mV) (Stralis-Pavese et al. 2006); and the type of peat (Christensen et al. 2003), content of organic matter and plant species composition (Whiting and Chanton 1993; Ding et al. 2004) that influence soil properties, *i.e.* the quantity and quality of organic matter and oxygenation (Bartlett and Harris 1993; Ström et al. 2003). Peatland vegetation has a crucial effect on methane emissions from these areas as it is involved in methane formation, transport and oxidation (Fig. 1).

CH₄ production

Under anaerobic conditions, the organic matter accumulated in peatlands with the low sulphate and nitrate content is converted to CH_4 and CO_2 by methanogenic bacteria, which can be expressed as a simple equation:

$$C_6H_{12}O_{6(s)} \rightarrow 3CO_{2(g)} + 3CH_{4(g)} \ (\Delta H= +1795 \text{ kJ/mol}).$$

The matter conversion reactions are endoergic. An appropriate amount of energy needed for this process must therefore be supplied from the exoergic *i.e.* methane-producing reactions. This process (methanogenesis) involves four types of microorganisms: (1) microorganisms that hydrolyse polymerised, insoluble organic compounds (proteins, carbohydrates, lipids) aided by extracellular enzymes, (2) acidogenes – microorganisms that decompose hydrolysis products, (3) acetogenes – microorganisms that transform metabolites from the previous phase and (4) methanogens – microorganisms that use the obtained products (mainly acetates and CO_2/H_2) for the synthesis of methane. Only 14% of the methanogenic bacteria species use acetates as a carbon and energy source. Acetotrophes are responsible for two-thirds of the produced methane (Le Mer and Roger 2001) according to the reaction:

$$CH_3COOH_{(s)} \rightarrow CH_{4(g)} + CO_{2(g)} \ (\Delta H= +18 \text{ kJ/mol}).$$
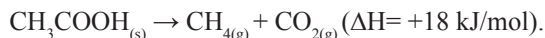
A third of the methane produced is derived from the reduction of carbon dioxide with hydrogen:
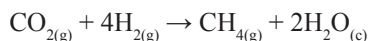
$$CO_{2(g)} + 4H_{2(g)} \rightarrow CH_{4(g)} + 2H_2O_{(c)}$$
$$(\Delta H= -253 \text{ kJ/mol}).$$

According to Houweling et al. (2006), the amount of methane released from the plant to the atmosphere is 85 Tg annually (according to other researchers, peatland vegetation is responsible for the emission of less than 46 Tg CH_4 annually; Ferretti et al. 2007). This controversy is worth discussing because exact estimates of methane release are important while drawing up a balance of emissions and planning the activities aimed at reducing the emission of methane as one of the major greenhouse gases.

Transport

In all, 55%–85% of methane that is liberated from peatlands and transported to the atmosphere is mediated by plants (Waddington et al., 1996). According to Chanton (2005), Berrittella and Huissteden (2011), and Green and Baird (2012), methane transport from the soil to the atmosphere can take place in the form of:
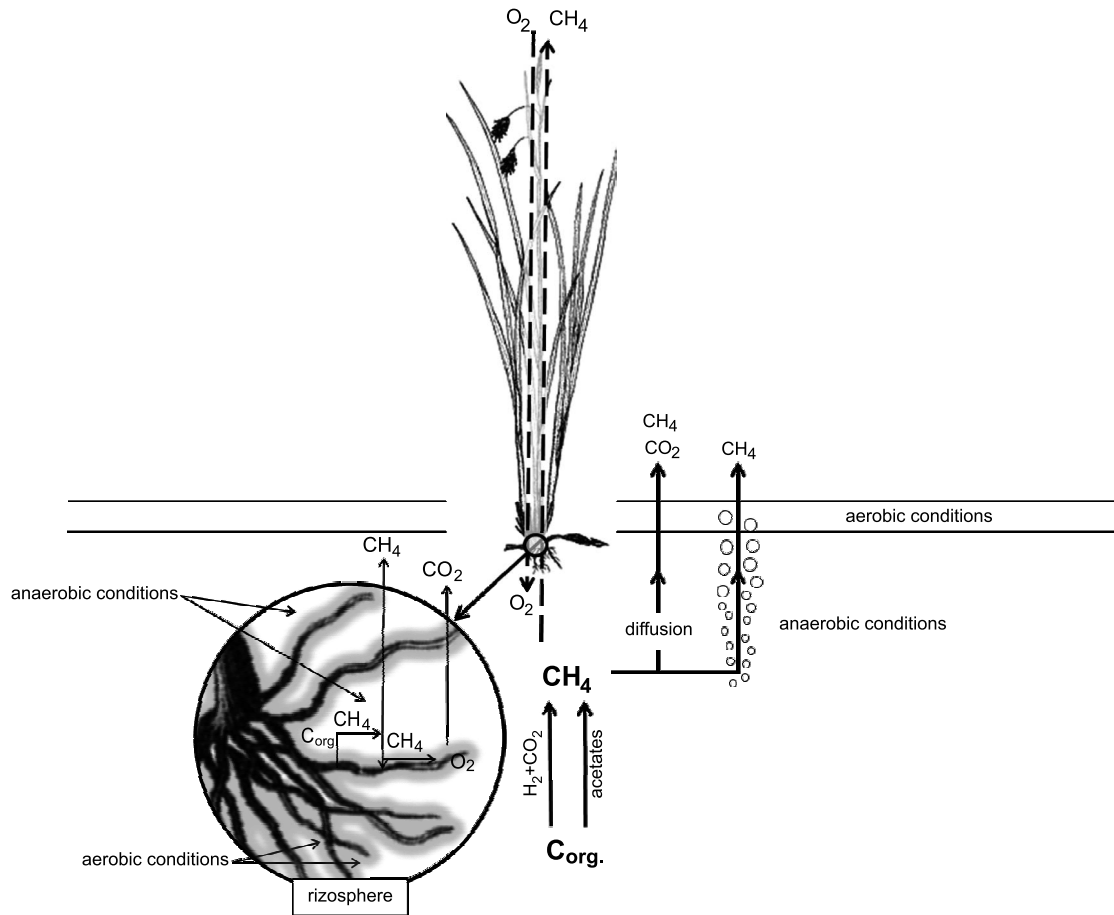
Figure 1. CH_4 production, transport and consumption in soil-plant-atmosphere system (Kiene 1991, Le Mer and Roger 2001 with own modification).

1) a flux resulting from the gradient of concentrations between the soil and atmospheric air – diffusion dependent on soil properties, such as porosity and permeability. Methane oxidation by methanotrophic bacteria can occur during diffusion in the oxygenated soil zone;

2) the so-called internal transport (plant-mediated transport) when plant is an intermediate element in the emission of methane from the soil. The gas from the root zone of plants is released into the atmosphere *via* aerenchyma. This type of transport allows bypassing the oxygenated soil zone in which oxidation of methane by methanotrophic bacteria can take place ('soil–plant–atmosphere' system);

3) a rapid release of methane bubbles from the soil – pressure-induced gradient (ebullition). This is a viscous flow, taking place under the influence of a pressure gradient, temperature fluctuations and humidity of the soil. This flow can be caused by rainfall, spraying, evap-oration, groundwater movement or wind. Recent studies compiled by Coulthard and co-authors (2009) suggest that this pathway of CH_4 may be the most important way of methane release from peatlands, even more important than diffusion and plant-mediated transport.

Oxidation

In the aerobic environment, methane is oxidised by methanotrophic bacteria employing either (1) high affinity for oxidation (CH_4 concentration < 12 ppm) responsible for 10% of the total methane consumption or (2) low affinity oxidation (CH_4 concentration > 40 ppm) (Whalen et al. 1990).

Methane oxidation is an exoergic process – the released energy may be used for the synthesis of cellular material, such as assimilation of carbohydrates. The total amount of

the energy produced during methane oxidation is the sum of the energy released at various stages of the process:

$$CH_{4(g)} \rightarrow CH_3OH_{(c)} \rightarrow HCOH_{(g)} \rightarrow HCOOH_{(s)} \rightarrow CO_{2(g)}.$$

A simplified record of the CH_4 oxidation reaction, which is expressed in the balance of substrates and products, is as follows:

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(c)}$$
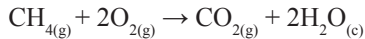
(ΔH = -890kJ/mol).

Methanotrophs can occur in the oxygenated soil layer, in the rhizosphere of plants with aerenchyma, as well as inside plant tissues (Le Mer and Roger 2001; Raghoebarsing et al. 2005). Chen and Murrell (2010) additionally indicated that the share of vegetation in reducing the total CH_4 emission is 30%–35%. They demonstrated that the inside of plants acts as an ecological niche for the methanotrophic bacteria oxidising the methane transported through the plant, thus drastically reducing its emission to the atmosphere.

Vascular plants influence the dynamics of methane in the peatland (Fig. 2) through:
1) carbon release to the rhizosphere;
2) morphology – structure of aerenchyma;
3) oxygen transport to the rhizosphere;
4) methane production.

The release of carbon to the rhizosphere is a stimulating factor in the process of methanogenesis as it increases the availability of C substrate. Vascular plants release a broad range of carbon compounds to the rhizosphere such as organic acids, sugars, ectoenzymes, phenols and amino acids. It is believed that the functions of these components are related to the interactions with other plants and microorganisms (Bais et al. 2006). Some authors suggest that the acetates produced in the fermentation process of organic compounds (e.g. released by plants) are an important substrate for methanogenesis (Ferry 1997; Avery et al. 2003). This is confirmed by isotopic studies using ^{14}C-labelled acetate (Ström et al. 2003, 2005). Although peatlands represent a large pool of carbon, they are less available for methanogens than the carbon derived from the compounds secreted by vascular plants. The amount of carbon released by plants varies and depends on the species – it may account for 10%–44% of the assimilated carbon. The secretion of the substance by roots also depends on the availability of nutrients, particularly of phosphorus (Bais et al. 2006). The qualitative and quantitative composition of carbon compounds secreted by acidophilic and alkalophilic plants is different, for example the latter secrete greater amounts of citric acid (Ström 1997).

The presence of aerenchyma (spaces or air channels) allows creating a system of ventilation channels in the
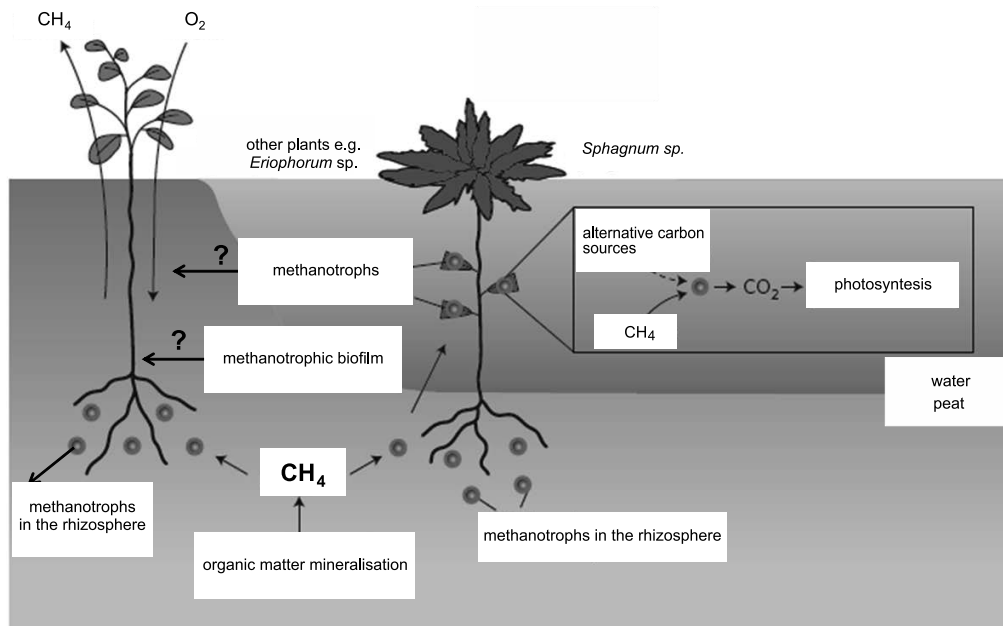

Figure 2. Methane oxidation (Chen and Murrell 2010 with own modification).

plant, which in vascular species also serves as a pathway for CH_4 transport. This system plays an important role in the transport of methane and other gases in different ecosystems, as documented by various earlier studies (e.g. Aulakh et al. 2000; Henneberg et al. 2012). The roots of many (but not all) plants growing in flooded areas have a substantial amount of aerenchyma. The studies by Sun and colleagues (2012) show that 38% of the total methane emissions in the growing season are transported through plant aerenchyma. This figure is lower compared with that reported in earlier studies (e.g., Morrissey and Livingston 1992; Schimel 1995; Ding et al. 2004). In their studies on the emission from the same locations, Ding et al. (2005) pointed out that *Carex lasiocarpa* (slender sedge) transports 72%–82% of the emitted CH_4. As reported by Ding and co-authors (2005), such large differences in the proportion of plants involved in CH_4 transport can be due, in this case, to a very large difference, about 4.5-fold, in the above-ground biomass. A positive correlation between methane emission and plant biomass is also confirmed by other authors (Whiting and Chanton 1993; Joabsson and Christensen 2001).

The oxidation of methane in the rhizosphere occurs through the diffusion of oxygen, as opposite to methane, to the root zone. More than 30%–40% of oxygen transported through aerenchyma can diffuse into the soil (Armstrong 1979). As a result, a substrate is provided allowing the methanotrophic bacteria living in the root zone to oxidise CH_4 before it is emitted into the atmosphere. Oxygen incorporated into the rhizosphere is also found to be a protection against phytotoxins frequently present in wetland soils, such as sulphides, reduced iron and manganese, as well as volatile fatty acids (Pedersen et al. 2004). The transformation of these compounds to less toxic forms involves aerobic microorganisms. The oxidation ability of methane by rhizosphere depends on many factors, in particular the availability of oxygen; however, it is conditioned by the plant species and degree of root development.

Association of plants with methanotrophic bacteria

The analysis of methane cycling requires considering plant associations with methanotrophic bacteria. It is an innovative approach to the subject showing the possibility of methane oxidation *via* the soil–plant–atmosphere system. Numerous bacteria from the rhizosphere colonise not only the rhizosphere and/or rhizoplane but also the internal tissues of plants often stimulating plant growth (Hallmann 2001; Hallmann and Berg 2007; Compant et

al. 2008). As early as 1887, Victor Galippe claimed that soil microorganisms could penetrate healthy tissue of plants and postulated that the mechanisms of colonisation should be well examined (Galippe 1887).

As regards methane oxidation, particular importance should be given to wetland vegetation considered so far the 'channel' for gas flux (including methane). World studies on this phenomenon show that methanotrophic bacteria play a significant role in CH_4 emissions, both those free-living in the rhizosphere attached to the root surface in the form of a biofilm (rhyzoplane) and those living inside host tissues (endophytes) colonising both the underground and the above-ground parts of plants (mainly *Sphagnum* sp.). Methanotrophs capable of oxidising methane, their source of carbon and energy, belong to the gram-negative methylotrophs. The occurrence of methanotrophs was confirmed in different ecosystems. For over 30 years, many researchers studied the methane-oxidising bacteria. The result of the studies was the isolation of methanotrophs inhabiting different environments, such as fresh water, sediments, soil, sea water, peatlands and hot springs (Le Mer and Roger 2001; Knief et al. 2003; Bodelier and Laanbroek 2004; Regina et al. 2007).

Methane-oxidising microorganisms have been known since 1906 when Söhngen for the first time isolated an organism able to grow on methane, a source of carbon and energy, called *Bacillus methanicus* (Söhngen 1906). Whittenbury and colleagues isolated more than 100 new methanotrophic bacteria and created their first classification that served as a basis for further research (Whittenbury et al. 1970; Bussmann et al. 2004). Associations of bacteria with other organisms were recognised on the basis of *inter alia* the symbiosis with mussels (Fisher et al. 1987; Cavanaugh et al. 1987; Robinson et al. 1998; Barry et al. 2002; Duperron et al. 2005), sponges (Vacelet et al. 1996) and *Sphagnum* sp. (Raghoebarsing et al. 2005). Also, associations of endosymbionts oxidising methane and sulphur with the species *Riftia pachyptial* of the polychaete family were reported. This endosymbiosis discovered in hydrothermal vents at the bottom of the sea is the best model for the studies of chemosynthetic symbiosis (Stewart et al. 2005).

The presence of microorganisms was found in various parts of the plant – in the roots, stems and leaves, as well as fruits, seeds and even flowers. There are different methods by which microorganisms enter into associations with plants. Some of them are the result of direct interactions between microorganisms and plant tissues, while others are indirect in nature and result from the modifications of the soil environment (Kalama 2004). It

should be noted that each type of association is unique, depending on the morphology of the interacting partners. The methanotrophic bacteria can colonise various higher organisms, and their methane-oxidising ability sufficiently justifies further studies thereon.

The endophytic bacteria inside plant cells were identified over 120 years ago (Hardoim et al. 2008). The first descriptions of endophytes at the turn of the nineteenth century concerned fungal endophytes living in darnel seeds (Freeman 1904). In 1926, the growth of endophytes inside plants was described as a particular stage in the life of bacteria, an advanced stage of infection and as having a close relationship with mutualistic symbiosis (Perotti 1926). Later, endophytes were defined as microorganisms that can be isolated from the surface of plant organs (Henning and Villforth 1940). The occurrence of the populations of plant-accompanying bacteria indicates that healthy plants hold associations of endophytic bacteria for which they are a specific niche. A number of recent studies seem to confirm the hypothesis that there are no species in the world of plants that would be free of specific endophytic microflora (Strzelczyk 2001).

The mechanism of associations of methanotrophs with peat-forming vegetation is poorly recognised and currently is the subject of studies of many researchers throughout the world. No data concerning the identification of methanotrophic endophytes are available in Poland except for the studies by Stępniewska and colleagues (2013). The review of world literature confirms the presence of extremophilic bacteria in a variety of environments. For the first time, the acidophilic methanotrophs (of the genus *Methylocella* and *Methylocapsa*) were isolated from the peatlands of Eastern Siberia and northern Russia (Dedysh et al. 1998, 2004). The studies on forest soils conducted in Germany led to the isolation of the strain *Methylocella silvestris* (Dunfield et al. 2003). The strain *Methylocella tundrae* was discovered later and was isolated from the acidic tundra peatlands in the northern part of Eurasia and North America (Dedysh et al. 2004). Dedysh and co-authors also identified the bacteria of the genus *Methylosinus* and *Methylocystis* on the material collected in the tundra (Dedysh et al. 2003). Earlier studies reported on the isolation of the bacteria of the genus *Methylosinus* in the acidic-bog lake (Heyer and Suckow 1985). Aquatic plants (Trotsenko and Khmelenina 2001) and embryophytes (*Sphagnum* sp. – Raghoebarsing et al. 2005; Heyer et al. 2002) were also studied.

The enzyme responsible for CH_4 oxidation in methanotrophs is methane monooxygenase that can exist in two forms: pMMO and sMMO. The sMMO enzyme present in the cytosol is activated only when the copper concentration in the biomass is low. The sMMO takes part in the processes of biotransformation and bioremediation of substances such as alkanes, aliphatic and aromatic substances. The pMMO enzyme associated with cell membrane is activated only when the copper concentration in the biomass is high. This enzyme, with a relatively high substrate activity, is capable of oxidising alkanes and alkenes containing more than 5 of C in the carbon chain. Thus, it can be effective in bioremediation (Muller 2000; Semrau 2011). These two forms of monooxygenase may occur concurrently and their activity is directly related to the concentration of copper ions (Cu^{2+}).

The oxidation of methane by an endophytic association 'methanotrophs-plant'

In recent years, researchers have given special attention to the role of peatlands with the dominance of *Sphagnum* sp. in methane emissions. The interaction between the methanotrophic bacteria and plant was discovered by Raghoebarsing et al. (2005) who showed that methanotrophic bacteria occur as endosymbionts and epibionts both inside and outside the cells of *Sphagnum* sp. They effectively capture the methane produced in peatland, thus limiting its emissions. However, in our opinion, the endophytic interaction between methanotrophic bacteria and vascular plants of peatland has so far not been identified.

The analysis of methanotrophic activity of *Sphagnum* sp. collected from peatlands in Siberia showed methane oxidation at a level of 80 $\mu mol \times g_{dw}^{-1}$ per day, while the daily methanotrophic activity in the Finnish sphagnum peatland ranged from 0 to 62 μmol $CH_4 \times g_{dw}^{-1}$ (Larmola et al. 2010). Other researchers have reported the daily consumption of methane at 23.5 ± 20 $\mu mol \times g_{dw}^{-1}$ at 10°C and more than twice this (46.7 ± 39 $\mu mol \times g_{dw}^{-1}$) at 20°C (Kip et al. 2010).

In their studies on the oxidising ability of methane by methanotrophic bacteria associated with *Sphagnum* mosses growing on peatlands of the Poleski National Park, Stępniewska and co-authors (2013) pointed to a relationship between the methanotrophic activity and the water level in the peatland. Submerged plants indicated a higher CH_4 oxidising ability to 77.6 ± 0.1 $\mu mol \times g_{dw}^{-1}$ per day than the non-submerged plants (2.5 ± 0.1 $\mu mol \times g_{dw}^{-1}$).

Raghoebarsing and co-authors (2005) also observed this relationship, and reported the level of methane oxidation at 0.5–30 $\mu mol \times g_{dw}^{-1}$ per day.

Stępniewska and her team also analysed the methane oxidation ability by the complex 'Sphagnum sp.–methanotrophic bacteria' incubated at different temperatures and concentrations of the substrate (CH_4). The analysis showed a proportional increase in the activity of methanotrophs with temperature within 10–30°C and a positive correlation between the ability for methane oxidising and CH_4 concentration in the range of 1%–10%, while at a CH_4 concentration of 20%, a decrease in the activity of methanotrophs associated with oxygen depletion was observed. The greatest ability for methane oxidising was noticed in the samples incubated at a temperature of 30°C and 10% of CH_4 concentration (Stępniewska et al. 2013).

The studies conducted by Kölbener and co-authors (2010) in the peatlands in southern Sweden showed the relationship between methane emissions and vegetation covering the study area. It was shown that the total daily CH_4 efflux from *Eriophorum* sp. was 7.42×10^{-3} g m^{-2}, while the CH_4 emission associated with *Sphagnum* sp. was only 2.204×10^{-3} g m^{-2}. They recorded that the methane emissions from an area covered with *Eriophorum latifolium* (broad-leaved cotton grass), *Potentilla palustris* (marsh cinquefoil), *Carex rostrata* (beaked sedge), *Anthoxanthum odoratum* (sweet vernal grass), *Carex elata* (tufted-sedge) and *Carex acutiformis* (lesser pond sedge) were five times higher when compared with the control area without plants (Kölbener et al. 2010).

Chen et al. (2008) demonstrated that the removal of *Calluna* (heather) plants from the studied area caused a decline in the methane-uptake capacity from the soil and a five-fold decline in the soil methanotrophic microorganisms. Methane emissions from peatland areas described by Goraj and her colleagues (2013) indicate an increased net emission of methane into the atmosphere from the areas where vegetation was dominated by *Vaccinium* sp. (bilberry) and *Carex* sp. (sedge). Emissions from these areas were higher by, respectively, 26% and 2%, compared with the emissions from the areas after removal of plants. The opposite trend was observed in the areas dominated by *Eriophorum* sp. (cotton grass) and *Sphagnum* sp. where a decline in methane net emission was recorded, and the emission was lower by, respectively, 25% and 10%, compared with the areas without vegetation.

Also, changes in the emission level in individual seasons of the year were recorded. In spring, the process of methane oxidation in all studied areas was more intense (except for *Carex* sp.), while in summer and autumn the intensity of methanogenesis and methanotrophy in the same areas varied. The seasonal changes in plant species composition were related to the reduction of methane emissions from peatlands and were influenced not only by the lower temperature, but also by the physiological condition of plants. Due to the poorer plant conditions resulting from the end of the growing season, the functioning of methanotrophic bacteria associated with plants was less favourable, and thus limitation of the transport of gases through the plant was noted (Goraj et al. 2013).

3. Summary

The conversion of methane in peatland ecosystems is complex. Net emission of this gas depends on the intensity of methanogenesis and methanotrophic processes, as well as on the floristic composition and association of methanotrophs with peatland vegetation. A comprehensive approach to the issue of the impact of wetland vegetation, especially peatland, on methane emissions will allow highlighting their significance and at the same time providing a more accurate assessment of peatland plant communities as natural reducers of methane. The presented issues are indispensably linked with the global problem of an increased greenhouse effect, which is particularly important for environmental protection. The studies conducted in this direction may be useful for the calculation of a carbon emission balance from peatlands and assessment of the role of the vegetation cover in reducing of methane concentrations in the atmosphere. An increase in the concentration of greenhouse gases such as CH_4, causes an increase in temperature (one molecule of methane has the same radiation effect as 21 carbon dioxide particles) that, in turn, increases the activity of methanotrophs. Peatlands, therefore, can function as natural CH_4 reservoirs with a high methane and carbon dioxide fixing ability. Due to a steady increase in the concentration of greenhouse gases resulting from human activity, the protection of peatland ecosystems appears to be justified and necessary. It appears that not only vegetation but also the associated microorganisms play a significant role here. Specific associations intensifying the CH_4 to CO_2 oxidation effect and fixing of carbon in the process of photosynthesis are one of the important factors emphasising the role of peatlands in climate change. The relationships between peatland vegetation and the identification of vast biodiversity of methanotrophic bacteria contribute to the knowledge of natural capabilities of those valuable areas. In addition, the natural 'plant–methanotrophs' systems decide on

the applicability of wetland vegetation as reducers of methane concentrations in environmental cleanup technologies such as phytoremediation systems, especially rhizofiltration, in *inter alia* wastewater treatment plants, on waste dumps or land earmarked for re-cultivation of mainly the post-mining areas. The knowledge of both the 'plants–methanotrophs' endophytic symbionts and methanotrophic bacteria in the form of a biofilm on the root surface as well as of the colonisation of the root zone of plants by methane-oxidising bacteria can lead to various possibilities of application.

Acknowledgements

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Contributions

Z.S. – An idea to take the topic of study and substantive care of the whole text. W. G. – review of the literature, collecting data, and preparation of the manuscript. A.K. – Co-author of the idea and review of the literature contained in the article.

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