# Should We Create and Restore Wetlands? Evaluating the Carbon Balance in the Face of Climate Change

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## INTRODUCTION

Wetland functions offer an attractive way to improve habitat, provide for increased flood control, and help facilitate biogeochemical processes for improving water quality and treating runoff (NRC, 2001). Through a process known as carbon sequestration, wetlands also remove carbon dioxide from the atmosphere via photosynthesis. Wetlands then sequester a fraction of that carbon in accumulating peat (Frolking et al., 2006). Constant inundated and anaerobic conditions in the soil lead to slow decomposition rates, and allow carbon to accumulate over long periods of time (Whiting and Chanton, 2001). These conditions also result in the production of various gases. Radiative forcing is the change in energy in the atmosphere from greenhouse gas emissions. The radiative forcing of a greenhouse gas, such as methane, is the difference between incoming solar radiation and outgoing infrared radiation caused by the increased concentration of that gas (CORE, 2011). Wetlands are a main generator of the greenhouse gas methane. Methane is a potent heat-trapping gas with a greater potential for energy absorption than carbon dioxide (Frolking et al., 2006). This results in a positive radiative forcing effect, or warming, as it leads to an increase in Earth’s energy budget (CORE, 2011). How much heat a greenhouse gas traps in the atmosphere is known as the global warming potential (GWP). The GWP of methane compared to carbon dioxide is 25:1 over 100 years (Mitsch et al., 2013). Therefore, for every unit of methane released into the atmosphere, it is equivalent to 25 units of carbon dioxide released.

Recreating wetland functions in areas where conditions are less desirable to offset wetland losses is known as wetland mitigation. Wetland mitigation is a great practice in theory, as its “no net loss” motto has strived to create and restore wetlands to replace wetlands that were impacted (NRC, 2001). The fundamental flaw in this practice is that created and restored wetlands are young compared against the natural wetlands they are replacing. Natural wetlands may have been present for centuries longer and will have a dynamically different ecosystem and biogeochemical cycling then a new wetland (Fennessy et al., 2008). The creation of wetlands for experimentation, regulation, and water quality treatment has since been considered a possible solution to the loss and drainage of wetlands and their functions (NRC, 2001). Wetland creation or restoration typically occurs in areas where previous wetlands have suffered high disturbance. This can mean a large amount of invasive vegetation is present, the hydrology does not function properly, and very likely that there are high levels of nutrients in the area. These conditions encourage newly created and restored wetlands to act as a source of methane. This often leads to newly created and restored wetlands to be a greater source of methane emissions compared to carbon dioxide (Whiting and Chanton, 1993). These processes use the GWP methodology, which determines “the equivalent carbon dioxide annual emission that would have the same integrated radiative forcing impact over a chosen time horizon as the annual methane emission”, as stated by Frolking et al. (2006).

The potential solution to this greenhouse effect can be mitigated by the removal of atmospheric carbon dioxide and storage into peat. The carbon sequestration and storage function of wetlands is an incredibly important process, but it wasn’t until our knowledge of atmospheric gas concentrations and how they influence global temperatures did it become a critical factor that should be considered in wetland creation and restoration (NRC, 2001). As a result, there are concerns that created and restored wetlands are not going to have the same degree of functionality to maintain the carbon balance as natural wetlands.

## THE WETLAND CARBON BALANCE

Wetlands represent the largest component of the terrestrial biological carbon pool, containing about a third of the global terrestrial carbon although only occupying 5–8% of its land surface (Nahlik and Fennessy, 2016). Wetlands typically form in low-lying or depressional areas, where the water table is at the land surface. Water, nutrients, and sediments are transported and accumulate in these areas, allowing vegetation to become highly productive (Fenessey et al., 2008). Carbon is added to the system through peat formation under anaerobic conditions (Frolking et al, 2006). The solubility of oxygen is very low when diffusing through water, and this prevents oxidation and allows large amounts of organic matter to build up. Methanogensis occurs as a result of the constant inundated soil conditions and lack of oxygen, and this process releases methane to the atmosphere (Badiou et al., 2011). Root carbon exudates and litter production within the wetland provide raw material for methanogens to use. They are a product of high primary productivity, which can result from increases in plant biomass (Stefanik and Mitsch, 2013). Therefore, the quantity of vegetation present can lead to increased methane emissions. Chanton et al. (1993) found that emergent vegetation that used a diffusive gas exchange method, did not produce as much methane as vegetation that used bulk flow ventilation, such as *Typha*. The higher amounts of biomass and production led to these elevated methane rates, indicating that methane emissions were under the influence of the amount of vegetative present instead of qualitative differences. In a study performed by Bhullar et al. (2014), plant species composition was identified as an influential factor in determining methane emissions from wetlands. Aquatic vegetation facilitates oxygen exchange and can alter dissolved oxygen concentrations within the water column. When vegetation is submerged it impedes the exchange of oxygen and carbon dioxide between leaves and the environment. The relationship between low amounts of dissolved oxygen in the presence of submerged aquatic vegetation has been noted in numerous studies (Rose, 1996). Elevated rates of carbon dioxide in the atmosphere may also prove to be a serious threat as methane rates have been proven to increase as a result of additional carbon dioxide uptake by plants (Vann and Megonigal, 2003).

Climate conditions directly impact soil formation, as the soil organic carbon pool is influenced by the role of climate and its associated factors. Climates effect on precipitation, temperature, and vegetation correspond with the quantity and quality of biomass and the soil organic carbon pool. Precipitation and temperature can influence the amount of soil organic carbon accumulated, as soil organic carbon was found to be greater in areas with high precipitation and lower temperatures (Lal, 2003). Whiting and Chanton (1993) found a positive correlation between methane emissions and net ecosystem production. Their study emphasized that while temperature and water levels are important factors that can affect the soil microbial activity and the bacteria that produce methane emissions, the net ecosystem production was the main control over the process, with 3% of production going back into the atmosphere as methane daily (Whiting and Chanton, 1993). Net primary productivity in wetlands is the amount of carbon fixed from photosynthesis minus that lost in plant respiration (Fennessy and Cronk, 2016). Carbon dioxide and methane gases are products of this process. Through this process, carbon dioxide is fixed from the atmosphere and is accumulated in the soil as plant inputs, however some carbon dioxide can be released back into the atmosphere as plants and litter decompose (Fennessy et al., 2008). The remaining carbon results in a net soil organic carbon accumulation, however in wetlands, methane gas is also a product of this decomposition process. Thus, although wetlands can act as a carbon sink by storing and accumulating carbon, methane emissions can still result in a positive GWP (Whiting and Chanton, 2001). This is due to methane's greater absorption of infrared radiation over a short time period compared to carbon dioxide (23-25 times). To help maintain the carbon-based GWP balance, soil organic carbon inputs should strive for 23-25 times as much carbon accumulated to account for the amount of methane released.

In their study of Northern peatlands, Frolking et al. (2006), sought to determine where carbon dioxide and methane would have the same radiative forcing impact at different time horizons. As a result of methane's greater energy absorption potential and short lifetime in the atmosphere, methane will initially produce a stronger radiative forcing impact than carbon dioxide. However, as methane dissipates over time, its effect will continue to lessen and will not contribute as much to the warming effect. Figure 1 presented by Whiting and Chanton (2001) shows how the GWP of methane is dependent on time. When methane is emitted the GWP of methane is at its greatest, then as centuries pass and methane concentrations decrease, the GWP of methane decreases as well. This is the rationale Mitsch et al. (2013) uses in his arguments under the support of created wetlands where after the initial methane release, methane concentrations will become less dominant over time.

Numerous studies note what they call a switchover time and why this aspect is so important. The switchover time is where net radiative forcing reaches zero, and the radiative forcing impact of carbon dioxide grows larger than methane's impact, switching from a positive net warming effect, to a negative net cooling (Neubauer, 2014). However, the ratio of methane emissions to carbon dioxide will determine how long it takes for switchover to occur. Figure 2 presented by Frolking et al. (2006) demonstrates this concept, as the ratio of methane emissions relative to carbon dioxide removed increase, the time to switchover increases. When the switchover time occurs depends on the combined dynamics of both carbon dioxide and methane pools. They can constantly change based off of the concentration of greenhouse gases in the atmosphere. According to Neubauer (2014), many natural wetlands have made the transition to lifetime carbon sinks and are demonstrating net negative forcing. "No natural wetlands older than ~250 years can be considered sources of net radiative forcing because their emissions are part of the preindustrial era baseline that is used for climate accounting purposes (Neubauer 2014)." Therefore, any newly created wetlands are not accounted for in this original budget, and as a result they will contribute to additional methane releases to the atmosphere. For example, Bridgham et al. (2006) notes that methane emissions from historical steady state rates of emissions from wetlands have zero net radiative forcing. When wetlands experience impacts to carbon sequestration capacity, increases in methane production, and loss of existing soil carbon, they exhibit positive radiative forcing resulting in a warming effect, and this may negate any benefits previously derived from the wetland (Bridgham et al., 2014).

The average 50 year time period has been proposed more than once, with Frolking et al. (2006) in his model, Mitch et al. (2013) using this rationale in his argument to create more wetlands, and Whiting and Chanton's (2001) study, although they extend this principle over much longer time horizons. While this switchover time is approximate, research suggests that it will happen under the right conditions. Figure 3 presented by Whiting and Chanton (2001) identifies the relationship between the GWP of methane and the ratio of methane emitted to carbon dioxide taken up by a wetland. When the ratio of methane emitted to carbon dioxide removed is low and the GWP of methane is small, the wetland will act as a sink. As the ratio increases but the GWP of methane remains small, the wetland will remain a sink. However, if the GWP of methane increases as the ratio of methane emitted to carbon dioxide removed increases then we start to see a transition to a source. Under a short time span the wetland will function as a source. Methane concentrations will be higher after the initial release creating a greater radiative forcing effect, and the ratio of methane released to carbon dioxide removed is larger in this scenario. When the time period is extended the wetland has a greater ability to act as a sink under higher emission/exchange ratios.

## CREATED AND RESTORED VERSUS NATURAL WETLANDS

Natural wetlands and created or restored wetlands are going to have different structures and functions depending on age, location, and productivity. These factors can influence carbon sequestration, methane emissions, and influence the net rate of carbon accumulation in a system. Fennessy, et al. (2008) determined patterns of plant decomposition between natural and created wetlands. His experiment found litter decomposition rates to be greater in natural wetlands compared to their created counterpart. Throughout the study, decomposition was consistently faster in the natural wetlands. Atkinson and Cairns (2001) reported similar results, with decomposition rates greater in the older wetland of the two created wetlands, and found that decomposition rates fell well below what rates should have been if it were a natural wetland.

Nutrient availability is one of the factors that can affect decomposition rates and is a driver of carbon dynamics. Both restored and created wetlands were found to lack critical plant nutrients that natural wetlands were not limited by. Carbon and nitrogen were determined to be significantly different from the mean, determined Fennessy et al. (2008). Confer and William (1992) reported lower nutrient availability in their created wetland sites. This led to increased quantities of *Typha* when compared to the natural wetland, which had more diverse vegetation. Large amounts of *Typha* present is an indicator of highly productive wetlands, as *Typha* will rapidly colonize mineral soils, which are more common in newly created sites due to their lack of time to develop thick layers of organic matter (Confer and William 1992). Mitch et al. (2012) had similar findings over his 15-year study performed in an experimental wetland, noting *Typha* marshes in the created wetlands were more dominant and less diverse.

Restored and created wetlands tend to be younger on average by many years, decades, or even centuries. As mentioned, mitigation has only been around for a short time compared to natural wetlands, which have contributed to the carbon budget for a much longer time. These young, created and restored wetlands will emit greater methane emissions from higher carbon sequestration, as many landscapes and water bodies have excessive nutrient amounts and will lead to highly productive wetlands (Mitsch et al., 2012). All of these factors play a role in the carbon balance and can effect both carbon sequestration and methane emission rates.

Although numerous studies have identified enhancing carbon sequestration as possible solutions to mitigating for climate change, the amount of time it takes is going to depend on a variety of environmental factors as mentioned above. Carbon sequestration for natural temperate wetlands averaged 174 g C $m^{-2}$ $yr^{-1}$ in a study conducted by Bernal and Mitsch (2012). In comparison with Mitsch et al. (2012) study, these natural wetlands had much greater carbon sequestration rates than the natural freshwater peatlands he studied that were calculated to have a carbon sequestration range of 105-160g C $m^{-2}$ $yr^{-1}$. Roulet (2000) performed a similar study for natural Canadian peatlands and the results show sequestration between 20 and 30 g C $m^{-2}$ $yr^{-1}$ and 29 g C $m^{-2}$ $yr^{-1}$ for North American peatlands. Depending on the type of wetland the sequestration rates may vary. This is important to note, as peatlands for example are known to be less productive than other types of wetlands, and thus may produce the illusion that natural wetlands are not as efficient at sequestration. Carbon sequestration rates in natural wetlands varied between 174 g C $m^{-2}$ $yr^{-1}$ (Bernal and Mitsch, 2012), 105-160 g C $m^{-2}$ $yr^{-1}$ (Mitsch et al., 2012), 29 g C $m^{-2}$ $yr^{-1}$ (Roulet, 2000), and 140 g C $m^{-2}$ $yr^{-1}$ (Bernal and Mitsch, 2013). In comparison, sequestration rates in created and restored wetlands ranged from 212-267 g C $m^{-2}$ $yr^{-1}$ (Bernal and Mitsch, 2013), and 181-266 g C $m^{-2}$ $yr^{-1}$ in the experimental wetland of Mitsch et al. (2012).

Another wetland study focusing on the prairie pothole region performed a similar study comparing newly restored, long-term restored, and natural reference wetlands (Badiou, 2011). In this study they used the change in soil organic carbon density to project if the restored wetlands would become a net sink for carbon dioxide emissions. Their conclusion was that wetland restoration would be more beneficial, even with the increased emissions that would generate from restoration. Badiou assumed a sequestration duration of 33 years, and even after factoring for increased methane emissions that would result from the restoration, the study suggested that wetland restoration resulted in greater carbon sequestration rates. They calculated 90 g C $m^{-2}$ $yr^{-1}$ in restored wetlands after green house gas emissions had already been considered, favoring carbon sequestration enhancement (Bernal and Mitsch, 2013).

METHANE EMISSIONS-CAN WE DETERMINE SUCCESS?

Projecting future methane concentrations through modeling can help scientists and policy makers establish guidelines to help combat global warming. A variety of environmental factors have the ability to change methane emission rates. Potential factors controlling methane emissions include precipitation, saturation, current atmospheric levels of carbon dioxide, inundation, and land use-changes (Paudel et al., 2016). A Community Earth System model was coupled with a methane biogeochemical model and predicted that methane emissions used to be greater by 10% with a preindustrial global wetland emission of 187 Tg $CH_4$ $yr^{-1}$ (Paudel, 2016). The reason methane emissions are not as large now compared to pre-industrial times is the simple fact that wetlands are being lost at an alarming rate. The loss of wetland area is significant, with a shocking loss of over 50% of the worlds wetlands converted to other uses and over 60% of North America's wetlands lost (Bridgham et al., 2006).

Another study introduced a process-based model, under the assumption that methane emissions are tied to the surrounding climate and soil environment (Cao et al., 1998). In their study, Cao et al. (1998) estimated global methane emissions from natural wetlands and calculated emissions at 92 Tg $CH_4$ $yr^{-1}$. Similar to the methane biogeochemical model by Paudel et al. (2016), this model focuses on the complex factors that affect methane emission rates including soil organic matter and vegetation growth rates. Zhanga et al. (2017) calculated mean annual global methane emissions from natural wetlands in climate scenarios RCP2.6, RCP4.5, RCP6.0, and RCP8.5. Regardless of the model chosen, mean global annual methane emissions from natural wetlands were projected to increase from 172 Tg $CH_4$/yr to 221-338 Tg $CH_4$/yr and could account for up to 25% of the change in radiative forcing in the next century.

The results of Mitsch et al. (2012) indicated that methane emissions were reduced in the two created wetlands compared to their natural reference wetland. Their study calculated methane emissions at 57g $CH_4$-C $m^{-2}$ $yr^{-1}$ in the reference wetland, which were double his planted and unplanted wetland of 16g $CH_4$-C $m^{-2}$ $yr^{-1}$ and 31g $CH_4$-C $m^{-2}$ $yr^{-1}$. Shown as the ratio of carbon dioxide sequestered to methane emitted, the Mitch et al. (2012) planted wetland had a ratio of 37:1 and 31:1, indicating that it will act as a sink for carbon. The unplanted wetland in Mitsch et al. (2012) had ratios below the GWP of methane, resulting in 15:1 and 17:1 ratios and revealing that it would act as a source of methane emissions, however they were still significantly better than the reference wetland which only had a ratio of 7:1. The abundance and community of plants made a difference in this case, as the unplanted wetland was more effective at sequestering carbon. Badiou et al. (2011) calculated mean methane emissions at 0.47g $CH_4$-C $m^{-2}$ $yr^{-1}$ for the newly restored wetland, 2.55g $CH_4$-C $m^{-2}$ $yr^{-1}$ in the long-term restored wetland, and 1.53g $CH_4$-C $m^{-2}$ $yr^{-1}$ in the natural reference wetland. While Bridgham et al. (2006) reported a range of 0 to 130g $CH_4$-C $m^{-2}$ $yr^{-1}$ in Canadian peatlands, with the majority ending up emitting less than 10g $CH_4$-C $m^{-2}$ $yr^{-1}$. Freshwater wetlands reported an average of 7.6g $CH_4$-C $m^{-2}$ $yr^{-1}$, and estuarine wetlands 1.3g $CH_4$-C $m^{-2}$ $yr^{-1}$ (Bridgham et al., 2006).

CONCLUSION-SHOULD WE CREATE AND RESTORE WETLANDS

Creating and restoring wetlands has a place in this new era. Wetland's made for nutrient retention, improving water quality, and other specific purposes can be altered to maximize and achieve results. They have allowed for enhanced habitat where wetlands once existed or have not existed before. However, created and restored wetlands are structurally and biogeochemically different than natural wetlands. Organic matter, decomposition, nutrient availability, and vegetation types were all different between the created and restored wetlands versus the natural wetlands. As a result of these differences, created and restored wetlands are not going to function to the same degree of a natural wetland within the near future. Carbon sequestration rates were greater in created and restored wetlands when compared against natural wetlands in the presented studies. Wetlands can be modified to increase carbon sequestration rates by altering factors such as hydrology and vegetation present. With this strategy in mind, most created and restored wetlands will probably show greater rates of carbon sequestration, as planting more highly productive species will lead to more carbon uptake. Over time as the wetland matures, its soil carbon pool increase rates should eventually slow. If the positives obtained from carbon sequestration in wetlands cannot offset the threat of methane emissions, then it may be unwise to use carbon sequestration as the reason for the creation and restoration of wetlands (Bridgham et al., 2006).

With the exception of Mitsch et al.'s (2012) rather large methane emission rates, all of the studies presented had comparable emissions, with the restored wetlands and natural wetlands each demonstrating both can produce competitive methane emissions. It should be noted that Mitsch et al. (2012) methods have undergone criticism, and his high methane emissions may be a result of improper calculations, as "the authors of that study made significant errors that caused them to underestimate the importance of wetland $CH_4$ emissions on climate dynamics" (Neubauer, 2014 and Brigdham et al., 2014). Mitsch's claim suggesting that soil carbon sequestration outweighs the warming effect of methane emissions generated has raised the concern of whether we should be creating and restoring wetlands (Bridgham et al, 2014).

Created and restored wetlands may eventually reach similar functionality that natural wetlands have demonstrated with time. Ultimately, most wetlands will reach a negative net radiative forcing. However, the consequences from increased methane concentrations may not be realized for a long time after the methane has dissipated (Neubauer, 2014). Mitsch et al. (2013) claims to have illustrated that when carbon sequestration is compared to methane emissions from wetlands, methane emissions become unimportant within a few hundred years compared to the positive impact carbon sequestration could make now. However, with each release of methane gas comes net warming for not just the estimated 50 years it takes for the switchover to occur, but centuries longer (Frolking et al., 2006). The composition of the atmosphere is a regulator of how the carbon model will respond. If we manage to have a steady increase in sequestration, then it should eventually lead to a net cooling effect (Bernal and Mitsch 2012, Mitsch et al., 2013, Frolking et al., 2006). However, as we start to see more carbon dioxide in the atmosphere as methane eventually dissipates, this may lead to more ambiguous dynamics in the carbon balance (Frolking et al., 2006).

A net carbon accumulation does not mean a reduction in warming, as methane emissions can still result in a positive GWP. The difference is centered on the misconception that the amounts of carbon stored will equal net carbon accumulation, when in reality the release of methane will set this equation off balance. “The degree to which future expansion of wetlands and $CH_4$ emissions will evolve and consequently drive climate feedbacks is thus a question of major concern,” states Zhanga et al. (2017). As temperatures continue rising at an alarming rate, the need for a solution to help combat warming has grown considerably. Changing climate conditions will result in an impact to soil formation, effecting carbon sequestration capacity, methane production, and existing soil carbon. All of these impacts will result in a positive warming effect, further escalating the problem.

While natural wetlands contribution to the carbon balance has already been factored in, created and restored wetlands have only begun to influence carbon dynamics. Further studies to determine methods to improve switchover time for created and restored wetlands may help reduce the additional amount of radiative forcing that is brought on by increased methane emissions. Other considerations for improvement may include more thought put into where created wetlands are being established. Areas with fewer disturbances will result in fewer emissions generated while the wetland is developing. It is known that created and restored wetlands can act as a carbon sink and effectively store and accumulate carbon. If efficiencies can be improved on the other side of the equation in regards to increased methane production, then created and restored wetlands may be a more feasible option to use to mitigate greenhouse gas accumulation in the atmosphere.

Figures

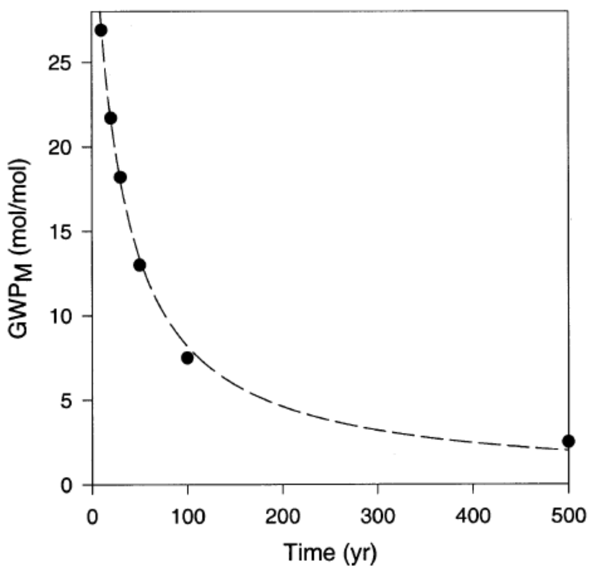


Figure 1. Relationship between integration time and the global warming potential of methane (GWPM). Whiting, G.J. and J.P. Chanton (2001).

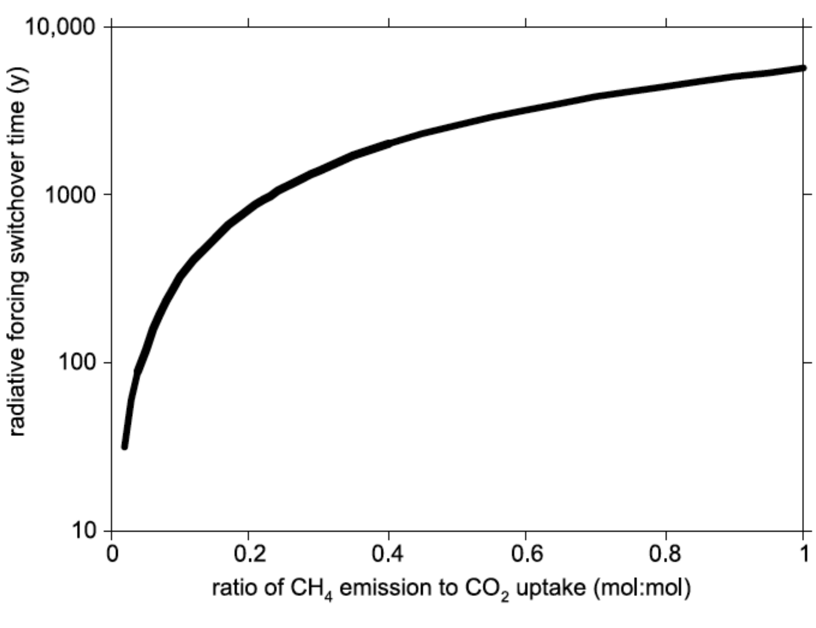


Figure 2. Timing of the instantaneous radiative forcing switchover from net warming to net cooling as a function of the ratio of $CH_4$ emission to $CO_2$ removal for constant fluxes. Frolking et al. (2006).

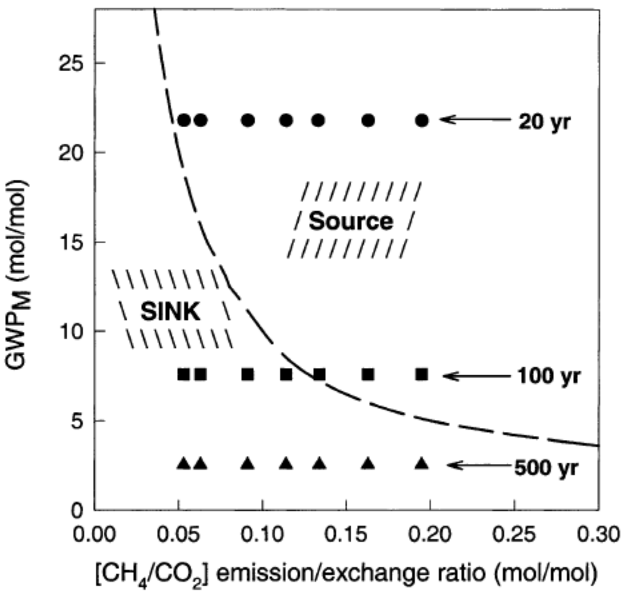


Figure 3. A model of the relationship between the greenhouse warming potential of methane (GWPM), expressed as CO2 equivalents, and the molar ratio of CH4 emitted to CO2 taken up (CH4/CO2) by a wetland. The circles, squares, and triangles represent the sites over 20-year (GWPM=21.8), 100-year (GWPM= 7.6), and 500-year (GWPM=2.6) time horizons, respectively. Whiting, G.J. and J.P. Chanton (2001).

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