# VEGETATION SYNTAXONOMY AND LAND MANAGEMENT EFFECT ON METHANE AND CARBON DIOXIDE EMISSIONS FROM WETLANDS: A CASE STUDY FROM TIDAL SALT AND BRACKISH MARSH

## Efek Sintaksonomi Vegetasi dan Jenis Tata Kelola Lahan terhadap Emisi Gas Karbondioksida dan Metana dari Ekosistem Rawa Pasang Surut dan Rawa Payau

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## Abstrak

Kontribusi emisi gas rumah kaca, yakni karbondioksida ($CO_2$) dan terutama methana ($CH_4$) dari ekosistem lahan basah (*wetlands*) termasuk yang terbesar. Interaksi antara tipe vegetasi, faktor abiotik, dan pengelolaan lahan adalah penting dalam penghitungan fluks karbondioksida dan methana dari suatu ekosistem. Dalam penelitian ini, pengukuran terhadap fluks gas karbondioksida, methana, karakter tanah, kelembaban udara dan suhu serta komposisi vegetasi di ekosistem rawa pasang surut asin (*salt marsh*) dan rawa payau (*brackish marsh*) dilakukan di Pulau Terschelling, Belanda. Penelitian ini bertujuan untuk mengetahui pengaruh komposisi tumbuhan model pengelolaan (a.l. penggembalaan/*grazing* atau pembabatan/*mowing*) terhadap emisi gas karbondioksida dan methana dari ekosistem rawa. Komposisi vegetasi di dua tipe rawa berbeda. Keragaman jenis dipengaruhi oleh kegiatan penggembalaan; jumlah jenis di tapak rawa payau yang mengalami penggembalaan adalah 39 jenis sedangkan yang tidak mengalami penggembalaan adalah 31 jenis. Fluks karbondioksida di rawa asin hampir sama besarnya dengan yang ada di rawa payau. Fluks methana rawa asin lebih rendah dibanding fluks methana rawa payau. Di daerah rawa payau, penggembalaan meningkatkan emisi gas methana

**Kata kunci: fluks $CO_2$ dan $CH_4$, lahan basah, penggembalaan, rawa pasang surut asin dan payau, vegetasi**

## *Abstract*

Carbon dioxide ($CO_2$) and methane ($CH_4$) emission from wetlands significantly contribute to climate change and global warming. The interaction between among vegetation type, various environmental factors, and management regimes such as grazing and mowing is considered important in the calculation of $CO_2$ and $CH_4$ gas flux for an ecosystem. In this study, vegetation composition, $CH_4$ and $CO_2$ flux, soil characteristics, air temperature and humidity from the brackish marsh and salt marsh wetland ecosystems on Terschelling Island in Northern Holland were measured. We aimed to investigate the relationship between vegetation composition, grazing, and mowing on $CH_4$ and $CO_2$ emission. The abundance and number of plant species were higher in brackish than in salt marsh. Grazing was found to influence species richness, 39 species being found in a grazed site of brackish marsh compared to 31 species in a similar ungrazed site. $CO_2$ fluxes in salt and brackish marsh were found to be similar while $CH_4$ flux in the salt marsh was found to be lower than in the brackish marsh. Within the brackish marsh, a higher methane emission was recorded in the grazed zone. However the overall effect of grazing and mowing was found to be negligible for $CH_4$ flux but is suggested to clearly reduce $CO_2$ flux in both the salt and brackish marsh.

**Keywords: $CO_2$ and $CH_4$ flux, wetlands, grazing, salt and brackish marsh, vegetation**

## INTRODUCTION

Greenhouse gases (GHGs), particularly those from wetlands (Mitsch *et al*., 2012), are known to play an important role in climate change and global warming (e.g. Solomon *et al*., 2007; Forster *et al*., 2007). Different plant communities and vegetation types can influence GHGs, with the ability to act as either a sink or source for these gases. Certain vegetation types, such as wetlands, are known to exert a particularly strong influence on emissions, such as carbon dioxide ($CO_2$) and methane ($CH_4$) emission (Keppler *et al*., 2007; Whiting and Chanton, 2001; Segers, 1998). Wetlands cover only 1% of the earth, but $CH_4$ release from wetlands is suggested to contribute around 20% of total global methane emissions annually (Houghton *et al*., 1995; 2001). Emission from wetlands is a significant component of the atmospheric methane budget, releasing 145 Tg methane annually to the atmosphere, or about 25% of total emissions from all anthropogenic and natural sources (Whalen, 2005).

In wetland soils, methane flux depends on a number of factors, such as the production of methane in anaerobic soils, consumption of methane by methanotrophic bacteria in the aerobic soil layer above the water table, as well as the transport pathway of methane to the atmosphere through the soil or vegetation (Walter, 2000). The level of the water table has the most influence on carbondioxide flux in wetlands, a high water table (as from flooding) decreases the amount of carbondioxide flux, while drainage of water is known to increase carbondioxide production due to a greater rate of organic matter decomposition (van Huissteden *et al*., 2005).

The flux of carbondioxide and methane in tidal salt and brackish marsh is influenced by exposure to varying lengths of time under both aerobic and anaerobic conditions (Poffenbarger *et al*., 2011). Differences in fluxes were predicted to exist between the two wetland ecosystems, as flooding occurs daily from a tidal action in the salt marsh, but only periodically in the brackish marsh (van der Nat and Middelburg, 2000). This fact indicated the possibility of finding a higher methane flux in the salt marsh, due to more anaerobic soil conditions, while carbondioxide flux was expected to be greater in the brackish marsh due to higher rates of organic matter decomposition (Bartlett *et al*., 1987). Other parameters such as plant community composition (Whalen, 2005; Bernal and Mitsch, 2012), soil pH, and both soil and air temperature and humidity are related to GHG flux level.

It has been suggested that grazing may have an effect on GHG emission in both of these wetland vegetations. Grazing acts in different ways to influence emissions of these gases, both directly through defoliation and indirectly through influencing soil temperature and organic matter, as well as damaging plant roots (Redmann, 1978; Bremer *et al*., 1998). Besides that, grazing or mowing may facilitate the emission of methane by direct exposure of aerenchyma tissue parts to the air. The potential influence of aerenchyma is highlighted in the case of *Oryza sativa*, as it is thought that the primary passageway of methane from anaerobic soils to the atmosphere takes place through the aerenchyma of the plant, in cultivated environments (Inubushi *et al*., 2001; Colmer, 2002).

In this experiment two types of wetland vegetation composition, tidal salt marsh and brackish marsh (a mixture of fresh and salt water), were studied on Terschelling Island, northern Netherlands. Hypotheses were formulated to address different vegetation syntaxonomy among wetland vegetation; grazing effect on brackish marsh carbondioxide and methane fluxes; and clipping effect in carbondioxide and methane fluxes of salt and brackish marsh. The first hypothesis is that there is a difference in species composition and association in marsh vegetation (salt and brackish marshes). The second hypothesis is that grazing affects brackish marsh vegetation composition. The third hypothesis is that carbondioxide flux is higher at brackish marsh due to a higher rate of organic matter decomposition, whereas methane flux is higher at the salt marsh due to more anaerobic soil conditions, created by flooding. The fourth hypothesis is that grazing will lead to different levels of carbondioxide and methane flux in the brackish marsh; and the fifth is that clipping will affect the carbondioxide and methane flux.

## METHODS

### Study site

On Terschelling Island, a brackish marsh and a salt marsh site were selected to measure the gas flux of different vegetation communities. The brackish area is situated in a meadow close to a dike of the Green Beach (*Groene Strand*) and the salt marsh is located at the Wadden Sea in the Midsland area, northern Holland.

The brackish marsh, principally characterized by poor sand with the top soil layer consisting of peat and organic matter, is divided into two different zones: high intensity of grazing (grazed) and low intensity of grazing (ungrazed). These grazed and ungrazed zones are situated between the dike and the dunes with a very low difference in elevation and were delineated by fences that were already in permanent existence. Eight relevés for vegetation analyses were made in both zones.

The tidal salt marsh site, characterized by saline clay, was divided into three zones of five relevés each, based on different sub-vegetation type dominance: Salicornietum, Spartinetum and Limonietum. Five relevés were established in each sub-vegetation type. These zones are regularly flooded twice in 36 hours.

### Data collection

Data collected comprised of vegetation composition, gas (methane and carbondioxide) emission, soil characteristics (pH, moisture, temperature, and organic matter), and air temperature and water vapour.

Vegetation data were collected by establishing transects in each sub-vegetation. In each transect, relevés were established with a size of 2 x 2 m (four square meters), resulting in fifteen relevés in the salt marsh; eight relevés for grazed brackish marsh, and eight relevés for the ungrazed brackish marsh. The cover abundance of each species per plot was considered according to the Braun–Blanquet scale and the ordination scale modified by Barkman. A PDA handheld computer with PocketVeg and VegDat program was used to record vegetation data in the field and conduct analysis in the lab.

Gas analyses and water vapour measurement were done with an Innova 1412 photo acoustic gas monitor. As the chamber is closed and dark, only the respiration of the plant is taken into account without the interference of gas from photosynthetic mechanisms. To simulate the immediate effect of grazing, clipping treatment was applied for salt marsh and brackish marsh vegetation to measure the possible influence on carbondioxide and methane flux.

Ten gas relevés were made for the brackish marsh; with each relevé being measured twice, before and after clipping. Five relevés were randomly chosen within the eight plots of the grazed brackish marsh and five randomly chosen within the eight plots of the ungrazed brackish marsh. In the saltmarsh, gas measurements were applied in all fifteen relevés, but the clipping treatment was only applied for the Spartinetum zone in order to see possible effects of aerenchyma on gas emission flux.

The gas measurement procedure was initiated by settling the gas chamber onto rings previously placed into the ground. During the duration of eight minutes, gas concentration figures were then recorded from the air tight chamber. The clipping was done immediately after this measurement and the procedure was reapplied to obtain the figures of gas concentration right after vegetation removal. This enabled comparison between before and after measurements in order to highlight the immediate effects that grazing or mowing may have on gas flux.

Besides vegetation and gas measurements, abiotic conditions (soil temperature, moisture and pH, organic mater) were also measured, as these are known to be important parameters indicative for both gas and vegetation. For each relevé in which a gas measurement was completed, soil samples were taken for lab analysis to indicate soil pH and organic matter, with air temperature and soil temperature and moisture also being recorded in the field at each gas measurement site. The above ground biomass (from clipping) was also obtained for weighing.

**Analysis of vegetation types, greenhouse gases, and soil parameters**

Soil pH and organic matter were analysed in the laboratory by using a pH meter. Organic matter was measured by placing the soil inside an oven with a temperature of 110°C for three days and then continued with 50°C for the subsequent four hours. Soil moisture was measured in the field with a Theta Probe and soil and the air temperature was measured in the field with a digital thermometer. These measurements allowed quantification of the important abiotic parameters in each vegetation relevé. The vegetation relevés and cover abundance were analysed using VegDat and furthermore dendrograms were made with PC-Ord. The associations were classified with TWINSPAN, and plant community descriptions were indicated by SynBioSys.

Carbondioxide and methane fluxes were analysed further to investigate the relationship between the gas fluxes with vegetation types and abiotic factors. $N_2O$ data, which was also measured in the gas chamber, was left out from any analysis due to “unclear” trends of flux with respect to time-scale, vegetation types, and abiotic factors. The gas flux differences were analysed by univariate analysis (one-way ANOVA with Tukey Post-hoc test, match paired t-test, bivariate correlation, and regression) with SPSS version 15.0. The vegetation, gas flux, and abiotic parameter relationships were analyzed using multivariate analysis with CANOCO software (results not shown in this paper).

## RESULTS

### Vegetation

***Classification of the species in communities***

Vegetation of the two sites was classified first by numerical classification and secondly by syntaxonomic classification. The combination of both of these classifications and calculation of a percentage of cover of each association and sub association, and the different plant community’s syntaxon were apparent. The ungrazed part of the brackish marsh was divided into two communities: Ranunculo–Senecionetum aquatici and Calthion–Parvo–caricetea and grazed brackish marsh communities were observed to be: Triglochino–Agrostietum/Calthion and Triglochino–Agrostietum/Calthion/Parvocaricetea. The salt marsh was observed to be divided into three different community zones: *Spartina*, *Limonium*, and *Salicornia*. The *Spartina* zone was distinguished by Halimionetum/Spartinetum and Spartinetum/Asteretea communities. The *Limonium* part was represented by the Plantagini–Limonietum/

Halimionietum portucaloides community. The *Salicornia* part include Puccinellietum maritimae Salicornietum and Salicornietum (Table 1).

The ungrazed brackish marsh is mainly characterized by marshy hay meadows, base rich, wet soil slightly acid, which is confirmed by an average of 6.18 of soil pH. A mowing regime here is important to prevent scrub and woodland development. Ranunculo–Senecionetum aquatici and Calthion also characterize the soil type which is peat-sand on this site. The grazed brackish marsh soil moisture was higher than in the ungrazed part. This is assumed as the effect of cattle and other large grazers on the soil. Their presence causes compression in the soil resulting in water emerging and remaining on top of the soil, whereas in the lower grazed part, the water (rainwater) can circulate better in the soil, and result in a less wet top soil layer.

The flora in the salt marsh were all strictly halophytes, meaning that they require support from a high concentration of Na+ or other alkaline metals. Thus, the soil is rather alkaline which was confirmed by the measure of pH of 7.38 in average. All of these communities require an aerated substrate. *Salicornia*, the pioneer communities of the saline sites grow on an anaerobic substrate, which has a darker coloration from the presence of iron-sulphide. This was observed during the soil profile analysis, with the colour and soil properties of the *Salicornia* also being darker and having a strong sulphur odour.

***Correlations between the different groups of vegetations***

In the salt marsh, the *Spartina* and *Limonium* communities are the most closely related (50%), whereas the *Salicornia* part is connected to the two others only by 30%. This is explained by the fact that in the *Spartina* and *Limonium* most of the species overlap, whereas in the *Salicornia*, only three species were observed. In the brackish marsh, a significant difference was observed between the grazed and ungrazed zone, with vegetation correlation only at 40%. This highlights the influence of grazing that might affect vegetation composition in this type of wetland ecosystem.

***Species abundance***

In the salt marsh ecosystem, three species were distinguished in the *Salicornia* part with a maximum of three and a minimum of two species per plot, seven in the Spartinetum association part with a maximum seven and a minimum three species per plot, and ten in the *Limonium* part with a maximum of ten and a minimum of seven species per plot. From the brackish marsh relevés, 39 species were indicated in the grazed brackish marsh with a maximum of 28 species and a minimum of 20 species per relevé. In the ungrazed part, 31 species were distinguished, with a maximum of 22 species and a minimum of 16 species per plot.

Grazing hence led to an effect on species diversity; the grazed brackish marsh showing a greater species richness. A possible explanation for this could be from how grazing increases organic matter, and thus soil fertility (Bremer *et al.*, 1998). Moreover, trampling creates disturbances in the soil, allowing more germination to occur from seed banks. Thus, the possibility is created for more species to germinate, emerge and grow.

The difference of species abundance observed amongst relevés within the same sub-vegetation and under the same grazing intensity could arise from differential levels of various abiotic factors as the relevé plots were not placed along specific gradients.

The soil of the brackish marsh is less alkaline than the soil of salt marsh. Soil pH was 6.15 and 7.38 for brackish marsh and salt marsh, respectively. This finding was in line with the observation that occurring seepage acted to decrease salinity and hence soil pH in the brackish marsh. In the salt marsh more cations, such as sodium and potassium are present from the sea water, whereas in the brackish marsh, rainfall leaches cations and leads to more acid soil compared to the salt marsh.

**Table 1.** Plant communities clustering based on the different sub-vegetations and syntaxonomical orders. Values underlined to indicate the dominant plant community most distinctive of each measurement.

| Associations and sub-associations | Brackish Marsh | | | | | | | | | | | | | | | | Saltmarsh | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Non Grazed | | | | | | | | Grazed | | | | | | | | Spartina | | | | | Limonium | | | | | Salicornia | | | | |
| Releveés | 1 | 4 | 2 | 3 | 6 | 7 | 5 | 8 | 1 | 3 | 2 | 6 | 7 | 8 | 4 | 5 | 5 | 2 | 3 | 4 | 1 | 1 | 2 | 3 | 4 | 5 | 5 | 4 | 2 | 1 | 3 |
| **Phragmitetea** | | | | **16** | | | | **16** | | | | | | **20** | | **22** | | | | | | | | | | | | | | | |
| **Parvocaricetea** | | | | **28** | | | | **24** | | | | | | **21** | | **19** | | | | | | | | | | | | | | | |
| **Plantaginetea** | | | | **16** | | | | **21** | | | | | | **<u>32</u>** | | **<u>26</u>** | | | | | | | | | | | | | | | |
| Ranunculo-Alopecuretum | | | | 2 | | | | 9 | | | | | | 9 | | 12 | | | | | | | | | | | | | | | |
| Trichlochino-Agrostietum | | | | 98 | | | | 91 | | | | | | 91 | | 88 | | | | | | | | | | | | | | | |
| **Molinio-Arrhenatheretea** | | | | **<u>41</u>** | | | | **<u>39</u>** | | | | | | **27** | | **22** | | | | | | | | | | | | | | | |
| sum Molinietalia-Calthion | | | | 79 | | | | 80 | | | | | | 87 | | 84 | | | | | | | | | | | | | | | |
| Molinietalia 16A | | | | 51 | | | | 44 | | | | | | 44 | | 43 | | | | | | | | | | | | | | | |
| Calthionpalustris | | | | 49 | | | | 56 | | | | | | 56 | | 57 | | | | | | | | | | | | | | | |
| sum Arrhenatheretalia | | | | 22 | | | | 20 | | | | | | 13 | | 16 | | | | | | | | | | | | | | | |
| **Asteretea** | | | | | | | | | | | | | | | | | | | | **<u>43</u>** | **<u>49</u>** | | | | | **<u>68</u>** | **<u>42</u>** | **0** | | | **0** |
| **Spartinetea** | | | | | | | | | | | | | | | | | | | | **29** | **26** | | | | | **9** | **21** | **<u>50</u>** | | | **30** |
| **Thero-Salicornietea** | | | | | | | | | | | | | | | | | | | | **28** | **26** | | | | | **22** | **37** | **<u>50</u>** | | | **<u>70</u>** |
| | | | **A** | | | | **B** | | | | **C** | | | | **D** | | | | **E** | | **F** | | | | | **G** | **H** | | | **I** | |

**Syntaxonomical order:** A = Ranunculo—Senecionetum aquatici; B = Calthion/Parvocaricetea; C = Calthion/Parvocaricetea/Triglochino Agrostietum; D = Triglochino—Agrostietum ; E = Halimionetum/Spartinetum ; F = Spartinetum/Asteretea ; G = Plantagini—Limonoietum/Halimionetum portucalodis; H = Puccinellietum maritimae—Salicornietum; I = Salicornietum

### Greenhouse gases

#### Carbondioxide Flux

Carbondioxide flux did not differ between the salt marsh and brackish marsh (one-way ANOVA, df = 2; $F_{3085.733}$ = 2.446; p = 0.129). Moreover, grazing effect on the brackish marsh was not pronounced for carbondioxide fluxes (one-way ANOVA, df = 1; $F_{2331.729}$ = 1.238; p = 0.298).

The immediate effect of grazing which was simulated by the clipping of each community separately was tested by a match paired t-test. Statistically, the effect of clipping to carbondioxide flux was found to be pronounced for *Spartina* salt marsh (paired t-test; t = 3.089; p = 0.037) but not for grazed brackish marsh (paired t-test; t = 1.885; p = 0.133) and ungrazed brackish marsh (paired t-test; t = 2.337; p = 0.080).

Nevertheless, there was a clear trend that carbondioxide flux always decreased about 20–30% after clipping (Figure 1). Each relevé from the salt marsh and brackish marsh experienced decreased carbondioxide flux after clipping (Figure 2).

#### Methane Flux

Methane flux differed among the three sites. The highest methane flux was that from the grazed brackish marsh. Methane emission and flux from Spartinetum salt marsh and ungrazed brackish marsh were similar and significantly lower than methane flux from the grazed brackish marsh (one-way ANOVA, df = 2; $F_{19.486}$ = 5.911; p = 0.016; Tukey Post-hoc test). Grazing effect on the brackish marsh was pronounced for methane flux (one-way ANOVA; df = 1; $F_{28.863}$ = 5.849; p = 0.042). Moreover, the methane flux in the ungrazed brackish marsh and the salt marsh were close to zero and sometimes become negative (uptake of methane). The effect of clipping for methane flux was not found to be significant in any of the communities (Figure 1).

There was a distinct trend for each relevé that clipping reduces carbondioxide flux (Figure 2), but does not show a clear effect for methane (Figure 2). Thus, grazing might not have an immediate effect on methane flux in a wetland ecosystem, particularly for salt and brackish marsh vegetation.

#### *Gas Flux and Environmental Analysis*

Besides being closely influenced by vegetation, brackish and salt marsh carbondioxide and methane flux, could also be altered by environmental variables like soil moisture, soil temperature, soil organic matter, aboveground biomass, or pH. Therefore, correlation and regression analysis were conducted to test for a possible relationship between gas flux and individual parameters.

From all the measured environmental variables, only a correlation between carbondioxide and the dry weight of biomass in the grazed brackish marsh was found (Pearson correlation r = 0.939*; n = 5; p = 0.018). A possible explanation for this could be from the fact that a higher value of plant biomass results in higher carbondioxide fluxes, once conduction in a dark chamber has been measured to exclude the influence of photosynthetic carbondioxide mechanisms.

As the majority of the measured environmental parameters showed no significant trend correlated to measured carbondioxide and methane flux, the results instead suggest that the gas flux was less relied on specific parameters related to gas, and more to a result of the combination and interaction of these environmental parameters.

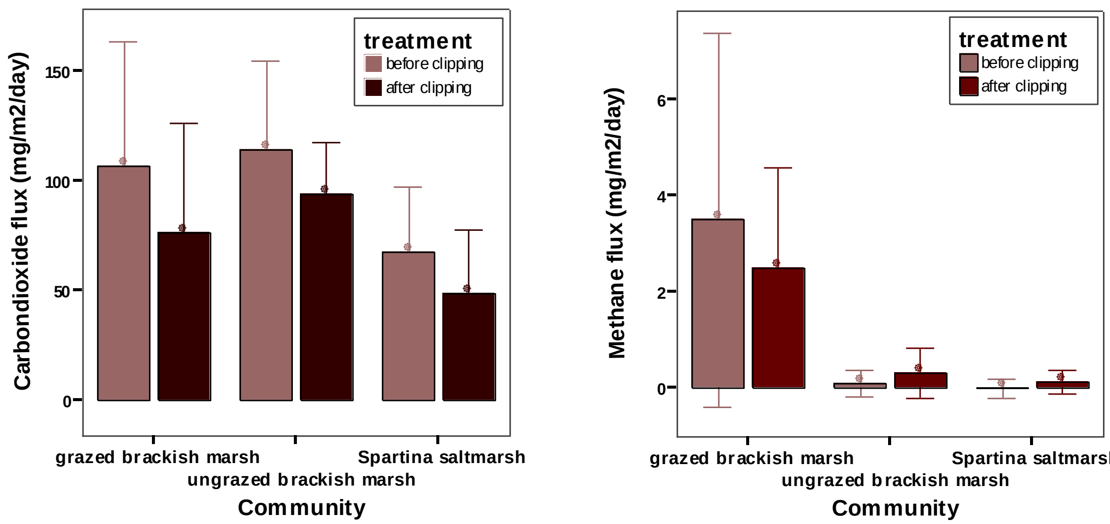


**Figure1.** Carbondioxide and methane fluxes from Terschelling wetlands–brackish marshes and *Spartina*-dominated saltmarshes. Artificial clipping consistently reduced the Carbondioxide fluxes and methane fluxes in grazed brackish marsh, but it led to a slight increase in methane fluxes of ungrazed brackish marsh and salt marsh.

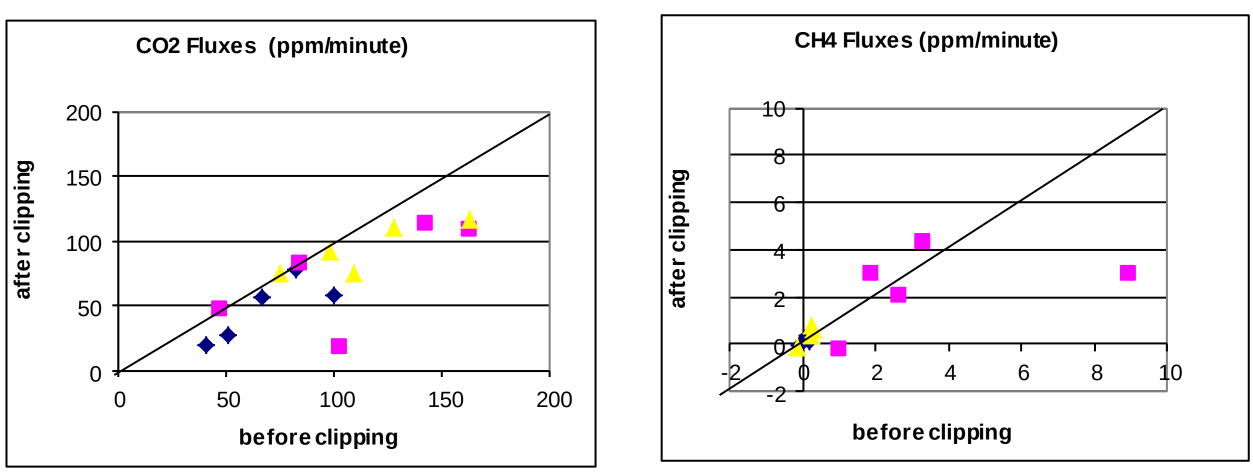


**Figure 2.** Carbondioxide and methane fluxes in different types of Terschelling wetlands (♦: *Spartina* Saltmarsh; ■: Grazed brackish marsh; ▲: Ungrazed brackishmarsh)

## DISCUSSION

The conclusion drawn is that brackish marsh and salt marsh vegetation emit considerable emission of carbondioxide and methane. Plant community structure, function and composition influence GHG emissions by altering nutrient cycling (Hooper and Vitousek, 1997). Methane flux from the salt marsh ranged from -5.29 mg $^{m-2}$ day$^{-1}$ (from *Limonium* zone) to 11 mg/m2/day (from Salicornia zone). This range is considered to be high compared to methane flux from salt marsh in Germany with an average of 100µg/m2/day from June measurement (Giani *et al*., 1996).

Compared to methane flux from the salt marsh, brackish marsh emits at a higher rate. Methane flux found in the brackish marsh range from

1.13 $mg/m^2$/day (from ungrazed brackish marsh) to 142.8 $mg/m^2$/day (from grazed brackish marsh). Higher iron-sulphide concentration in salt marsh soil may explain this, because methanogenesis is generally less intense or inactive in soils containing much sulphate (van Breemen and Feijtel, 1990).

The clipping was proven to decrease the carbondioxide flux in both salt and brackish marsh. This may due to the removal of aboveground biomass and hence reduction of carbondioxide from aboveground biomass respiration. Methane was not proven to decrease with clipping. It is expected that clipping will facilitate methane transport from belowground biomass and root exudates as described by Sebacher *et al*. (1985) and Chanton & Dacey (1991) that methane transport through aerenchymatic plants is usually much greater than diffusion in sediments and ebullitive transport.

Methane flux was found significantly higher in the grazed brackish marsh. Defoliation by grazing alters GHG patterns directly through droppings (Vermoesen *et al*., 1997; Yamulki *et al*., 1998) and indirectly by altering the plant community, which influences the microbial environment and GHG flux (Franzluebbers and Stuedemann, 2003), soil temperature (Ruz-Jerez *et al*., 1994), and soil water (Thurow, 1991).

After tidal flooding, carbondioxide and methane fluxes in *Limonium* salt marsh were all negative (ranging from -5.25 $mg/m^2$/hr to -0.61 $mg/m^2$/hr). This is in accordance with the previous finding that flooding reduced methane emission, probably by blocking the primary sites of methane release in the lower part of the plant stems (van der Nat and Middelburg, 2000).

Carbondioxide fluxes in salt and brackish marsh are statistically not different. Grazing and mowing (clipping) also were not proven to influence the carbondioxide flux. Soil moisture was higher in the grazed brackish marsh while soil temperature was higher in the ungrazed part. A previous study by Kantrud *et al*. (1989) stated carbondioxide respiration appears more responsive to changes in soil water than to changes in soil temperature. Soil humidity may lead to greater plant production but also possible increase in tissue decomposition.

The rings on which the gas chamber stands were inserted into the ground only a maximum of one day before measurements. A period of two weeks is recommended for gas measurement after ring insertion (Arina Schrier, pers. comm.). The act of inserting rings into the ground within the short duration would therefore have influenced the gas content in the soil and vegetation. It was also difficult to maintain the exact standard of the height of clipping in each ring for gas measurement. These plant parts remaining unclipped above ground may have had an influence on the gas flux measured, as it is known, for example, that the primary source for release of methane in *Phragmites* and *Scirpus* species is the lower 20 to 30 cm of stems above sediment (van der Nat *et al*., 1998).

Various other factors that have a differential influence on overall gas flux are important to consider when examining particular environments. Such factors range from the time of year, temperature and hydrological conditions (Bartlett *et al*., 1987; Kelley *et al*., 1995). For this reason it is difficult to state the exact relevance of the results obtained, as the experiment focused only on one particular period of time. It is known that wetlands often show individualistic qualities for methane production within spatial and temporal variations, and is documented that wetland methane flux shows strong seasonality (van der Nat *et al*., 1998). In this study focus fell on the dominant vegetation types of the brackish and salt marsh (as previously described), however, a better indication of gas flux would also require a more thorough scale of investigation of plant communities that together make-up these wetland ecosystems, as well as a broader time scale for investigation.

Despite some questions as to what extent grazing intensity or clipping was homogenous to all plots, as well as other moderate inconsistencies and notes, the results of gas flux obtained throughout the experiment are still regarded to be, to a large extent, truly indicative for these wetland types on Terschelling during the period of measurement.

## CONCLUSIONS

Species composition and association difference were pronounced between salt and brackish marsh vegetation. Vegetation associations in the salt marsh were Asteretea, Spartinetea and Thero-Salicornietea, whereas they were Molinio-Arrhenatheretea dominated by Calthion-/Plantaginetea in the brackish marsh. Grazing in brackish marsh resulted in a difference in floristic species richness. With regards to greenhouse gas fluxes, carbondioxide flux between salt and brackish marsh were similar. Grazing did not affect carbondioxide fluxes but led to an increase in methane flux from brackish marsh which was also correlated with higher soil moisture in the grazed plots. Carbondioxide fluxes decreased immediately after clipping, but the methane does not show any clear overall trend.

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