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# COMPARISON OF THREE DIFFERENT METHODS FOR THE DETERMINATION OF CLIMATE RELEVANT GAS EXCHANGE OF MIRES

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## SUMMARY

The article compares different methods for determining greenhouse gas emissions of raised bogs in Lower Saxony, Germany. A joint venture project between Volkswagen Leasing GmbH and NABU (German Society Nature Conservation) aims mire protection and the reduction of $CO_2$-emissiones for the climate protection at the same time. In order to reach the aim depleted peat fields and areas previously used for agriculture are rewetted in a mire protection area. Our engineering company for ecology, environmental protection and landscape management, Hofer & Pautz, BGB, analyzed the potential savings of climate relevant gases from three mires:

- Theikenmeer, district Emsland
- Sauerbach, district Gifhorn
- Lichtenmoor, district Nienburg

We applied two types of methods to estimate the annual $CO_2$emission. In the first one the loss of organic matter was quantified based on

1. a comparison between new and ancient peat stratigraphical profiles. In the second one
2. emission factors were defined for each site based on their mire site type and land-use class (Höper, 2007) or based their stage of humidity (Couwenberg et al., 2008)

KEY WORDS: Emission factor, climate protection, $CO_2$-emission, gas exchange of mires, GWP

## INTRODUCTION

Peatland drainage and land use activity results in high $CO_2$ emission caused by the oxidation of the stored carbon. Consequently such sites act as carbon sources to atmosphere.

With projects of nature protection like joint venture between Volkswagen and NABU (German Society Nature Conservation) this development can be made contrariwise by restoration of mire areas. Beside of the aspired aims of mire conservation also the economization of the $CO_2$-emissionen can be achieved.

In order to quantify emissions from peatland sites the following items of climate relevant questions must be considered and cleared:

- Which volume of peat is available?
- Which climate relevant gas exchange happens actually?
- Which emissions of carbon dioxide equivalent in this area can be avoided by future rewetting measures?

Further more framework conditions can be deduced for potential rewetting and the climate relevant gas exchange can be prognosticated. Even prospective scenarios in case of absence rewetting when the peatbody still remains exposed to oxidation can be simulated.

Carbon gas exchange methods are rather complex and the number of direct gas flow measures in mires is limited, therefore indirect procedures are in use (Drösler, 2005; Höper, 2007; Couwenberg et al., 2008). Indirect methods cover different approaches by which the greenhouse gas emission can be determined for a distinguished area:

- emission factors defined for different mire types and land use forms that are derived from various data collections (Höper, 2007)
- emission factors for various stages of humidity (Couwenberg et al. 2008)
- Comparison of peat layer thickness and peat stratigraphy for instance the drilling profiles of the drilling campaign from 1979 and 2011 (Hofer et al. 2009, 2010; Hofer & Witte, 2010; Hofer et al. 2011[1], 2011[2])

## MATERIAL AND METHODS

### Study sites

We applied three types of methods to estimate the annual $CO_2$ emission and the potential savings of climate relevant gases. The studies were conducted at the three sites, "Theikenmeer"(district Emsland) in 2009, "Sauerbach" (district Gifhorn) in 2010 and "Lichtenmoor" (district Nienburg) in 2011. All three areas of investigation were selected because they are characterized by different type of wetland, land use and its stages of degeneration with the corresponding vegetation.

The area *Theikenmeer* (Fig. 1-2) constitutes a large part of the contemporary nature protected area. The area is shaped by forestry, small embedded plotes of grassland which are partly lying fallow and different degenerated raised bog stages side by side. The range of humidity lasts from wet stages up to dry stages which offer the corresponding vegetation like wool grass, peat moss and birch forest. However the main part of this side is characterised by drained areas with a small scaled mix of different raised bog degradation-stages which are attributed by different stages of succession.

After peat mining the area *Sauerbach* (Fig. 5) has been left to natural succession of vegetation on the remaining peat. The surface is structured in lower parts due to former peat cuttings and in between placed remaining peat banks. The southern part is chambered due to peat pools which contain water, whereas the south eastern part after peat mining was taken under cultivation and is used as greenland. The wetter areas are occupied by birch-, osier shrubbery and are specially characterized by the appearance of sphagnum moss (*Sphagnum spec.*), purple moor-grass (*Molinia caerulea*) and different fen-sedges (*Carex spec.*)

The area *Lichtenmoor* (Fig. 3-4) is an ancient peat extraction site with a remaining raised bog peatlayer which shows a thickness of circa 30-50 cm. Deficient outside walls, missing or insufficient water retention of important inner and outside ditches causes drainage of the retained rain water in great parts of this site. A partly falling dry of the peat body in single areas is out coming. Here the appearance of scrub encroachment, birch forest *(Betula pubescens),* island of Scotch Pine (*Pinus sylvestris* ), purple moor grass *(Molinia caerulea),*Cross-leaved Heath *(Erica tetralix),* Common Heather *(Calluna vulgaris)* and isolated appearance of Cotton Grass (*Eriophorum vaginatum)* on moist sites are typical. (Fig.3). Significant occurences of developing floating vegetation mat with *Sphagnum* *cuspidatum* and *Eriophorum vaginatum* are only in the western part of the regenerated bogsite present (Fig. 4)

**Figure 1**. Mosaic of wetter heath degeneration stages and cotton grass-peat moss stages in a peat cutting site (Theikenmeer)

**Figure 2.** Birch fen wood (Theikenmeer)

**Figure 3.** Purple moor grass- birch stage (Lichtenmoor)

**Figure 4.** Developing floating vegetation mat with *Sphagnum cuspidatum* and *Eriophorum vaginatum* (Lichtenmoor)

**Figure 5.** A characteristic occurrence of the birch fen wood. In the foreground you can see the dominance of the purple moor grass (*Molinia caerulea*), which occurs often in this abundance in the region of “Sauerbach”, interrupted by a population of bracken (*Pteridium aquilinum)*

## Stratigraphical recording and construction

Peat sampling in the areas Theikenmeer (2009), Sauerbach (2010) and Lichtenmoor (2011) was conducted with a dutch drilling equipment called “Guts”. From the peat profile sample the type and hydrological characteristics of mineral soil, division of bog and fen peat layers (relevant for C-storage calculation), different types of peat (botanic classification), thickness of peat layers, water content of different depths of dehydrated layers (relevant for peat storage calculation and simulation of oxidation rates) and degree of decomposition by Post, were analyzed referred to the soil survey manual (AG Boden, 1996). The drilling points were GPS calibrated by the RTK (Real Time Coordination) method.

When comparing the thickness of the drilling profiles of ancient bores versus of the actual bores, locations of 40 old drilling points were prospected in the terrain of *Sauerbach* (Fig.6 ). Due to positional inaccuracy of round about 10 m, which results during the prospecting of the ancient bores, normally three test profile drills are taken in the surrounding of each ancient bore. The current average value is used for the confrontation of the old value from 1988 (Table 1). Illogical values, which are shown as red marked points in Table 1 would mean a peat increase and are removed. If there is no sufficient number (< 30) of old bores for a statistic evaluation available, the loss of thickness and the associated $CO_2$-Emission which has taken place over the last years is calculated on the base of values for the respective use, vegeation and/or degradation form, which are indicated in the literature, see Höper (2007), Plagemann (2009).

## Mapping of biotope type and the way of utilisation

Types of biotopes were mapped according to Drachenfels, O.v. (2004). The focus was on the later allocation of different usage intensities for agricultural areas and the classification of humidity grades for the natural states of succession. By the use of emission factors which were defined for each site based on their mire site type and land-use class (Höper, 2007) or based on their stage of humidity (Couwenberg et al., 2008) the actual emissions were calculated.

## Hydrological measurements

Data on the groundwater regime during the inventories.

- Deepness and peat aeration of the drill holes are determined
- Measuring points were established and the bog water levels were determined
- The trench bottom of the drainage system were calibrated

For the evaluation basic maps and digital elevation models (DGM), which were purchased by Survey and Land Registration Office, were additionally embedded in the Geographic Information System (GIS). The hydrological conditions are necessary to assign the volume of peat which concerns the climate relevant gas exchange.

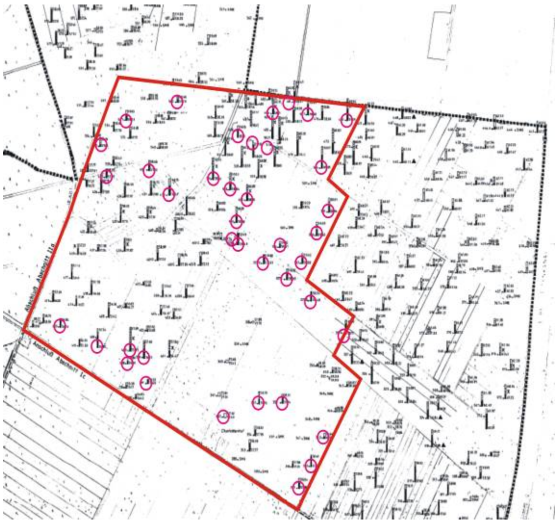

**Figure 6.** Study site “Sauerbach” abridgement of the drilling compaign 1988 (Birkholz). Red dots: 2010 controlled points (Hofer et al. 2010)

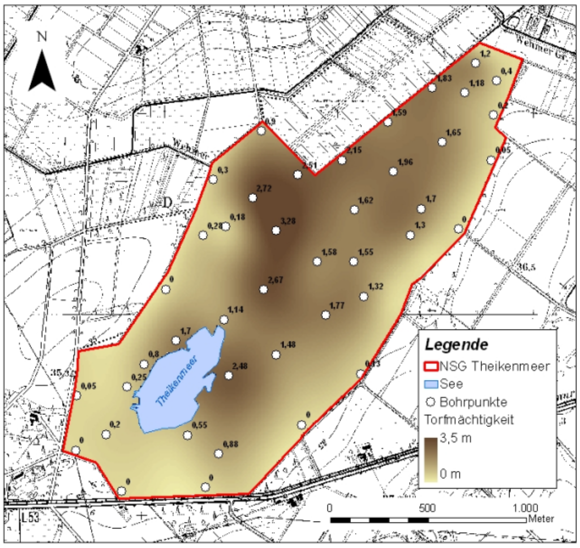


**Figure 7**. Area “Theikenmeer”, actual thickness of the raised bog layer in 2011 (Hofer et al. 2009)

**Table 1.** Comparison of the drill data from 1988 and 2010 of the study site “Sauerbach”. “Illogical values” are red marked an would mean an increase of the peatlayer (Hofer et al. 2010)

| HPH 2010 | Birkholz 1989 | Hm | Hh | Hn | Torf 2010 | Torf 1989 | Diff in m | Diff/a in m | Biotoptyp |
|---|---|---|---|---|---|---|---|---|---|
| BP01 | 397 | 0,15 | 0,00 | 0,39 | 0,39 | 0,40 | 0,01 | 0,0005 | Mol-Bet |
| BP02 | 399 | 0,17 | 0,93 | 0,72 | 1,65 | 1,46 | -0,19 | -0,0090 | Mol-Bet |
| BP03 | 400 | 0,45 | 1,00 | 0,58 | 1,58 | 1,54 | -0,04 | -0,0019 | Mol/Cal |
| BP04 | 398 | 0,10 | 0,00 | 0,46 | 0,46 | 0,60 | 0,14 | 0,0067 | Mol-Bet |
| BP05 | 409 | 0,40 | 0,00 | 1,22 | 1,22 | 1,54 | 0,32 | 0,0152 | Mol-Bet |
| BP06 | 413 | 0,05 | 0,00 | 0,43 | 0,43 | 0,71 | 0,28 | 0,0133 | Mol |
| BP07 | 361 | 0,00 | 0,00 | 0,00 | 0,00 | 0,26 | 0,26 | 0,0124 | GI |
| BP08 | 357 | 0,00 | 0,00 | 0,78 | 0,78 | 1,03 | 0,25 | 0,0119 | Bet-Wald |
| BP09 | 355 | 0,00 | 0,00 | 0,41 | 0,41 | 0,77 | 0,36 | 0,0171 | GI |
| BP10 | 343 | 0,24 | 0,00 | 0,00 | 0,24 | 0,40 | 0,16 | 0,0076 | GI |
| BP11 | 342 | 0,20 | 0,00 | 0,70 | 0,70 | 0,98 | 0,28 | 0,0133 | Mol-Bet |
| BP12 | 291 | 0,20 | 0,00 | 0,72 | 0,72 | 0,86 | 0,14 | 0,0067 | GI |
| BP13 | 518 | 0,12 | 0,22 | 0,40 | 0,62 | 0,95 | 0,33 | 0,0157 | Mol-Bet |
| BP14 | 517 | 0,10 | 0,18 | 0,92 | 1,10 | 1,16 | 0,06 | 0,0029 | Mol |
| BP15 | 516 | 0,30 | 0,00 | 1,22 | 1,22 | 1,62 | 0,40 | 0,0190 | Damm |
| BP16 | 481 | 0,27 | 0,00 | 1,05 | 1,05 | 1,80 | 0,75 | 0,0357 | Damm |
| BP17 | 484 | 0,25 | 0,00 | 1,20 | 1,20 | 1,14 | -0,06 | -0,0029 | Mol |
| BP18 | 477 | 0,15 | 0,00 | 0,87 | 0,87 | 1,12 | 0,25 | 0,0119 | Mol Sph fi |
| BP19 | 470 | 0,35 | 0,00 | 1,44 | 1,44 | 1,73 | 0,29 | 0,0138 | Mol-Bet |
| BP20 | 474 | 0,65 | 0,00 | 1,22 | 1,22 | 1,72 | 0,50 | 0,0238 | Bet-Wald |
| BP21 | 501 | 0,28 | 0,00 | 0,77 | 0,77 | 1,07 | 0,30 | 0,0143 | GI |
| BP22 | 502 | 0,38 | 0,00 | 0,98 | 0,98 | 1,10 | 0,12 | 0,0057 | GI |
| BP23 | 503 | 0,28 | 0,00 | 0,68 | 0,68 | 0,80 | 0,12 | 0,0057 | GI |
| BP24 | 504 | 0,33 | 0,00 | 0,48 | 0,48 | 0,51 | 0,03 | 0,0014 | Bet-Wald |
| BP25 | 327A | 0,24 | 0,00 | 0,86 | 0,86 | 1,29 | 0,43 | 0,0205 | Bet-Wald |
| BP26 | 327B | 0,30 | 0,00 | 0,51 | 0,51 | 0,76 | 0,25 | 0,0119 | Bet-Wald |
| BP27 | 327C | 0,50 | 0,00 | 0,87 | 0,87 | 0,83 | -0,04 | -0,0019 | Bet-Wald |
| BP28 | 327D | 0,25 | 0,00 | 0,53 | 0,53 | 0,77 | 0,24 | 0,0114 | Bet-Wald |
| BP29 | 327E | 0,65 | 0,00 | 0,98 | 0,98 | 1,00 | 0,02 | 0,0010 | Bet-Wald |
| BP30 | 327F | 0,67 | 0,00 | 0,85 | 0,85 | 0,54 | -0,31 | -0,0148 | Bet-Wald |
| BP31 | 525 | 0,45 | 0,00 | 1,52 | 1,52 | 1,26 | -0,26 | -0,0124 | Mol-Bet |
| BP32 | 522 | 0,50 | 0,00 | 1,12 | 1,12 | 1,30 | 0,18 | 0,0086 | Mol-Bet |
| BP33 | 523 | 0,60 | 0,00 | 1,19 | 1,19 | 1,39 | 0,20 | 0,0095 | Mol-Bet |
| BP34 | 524 | 0,98 | 0,00 | 1,20 | 1,20 | 1,72 | 0,52 | 0,0248 | Mol-Bet |
| BP35 | 432 | 0,45 | 0,00 | 0,89 | 0,89 | 1,35 | 0,46 | 0,0219 | Bet-Wald |
| BP36 | 433 | 0,40 | 0,00 | 0,65 | 0,65 | 0,84 | 0,19 | 0,0090 | Bet-Wald |
| BP37 | 425 | 0,38 | 0,00 | 0,63 | 0,63 | 0,74 | 0,11 | 0,0052 | Bet-Wald |
| BP38 | 528 | 0,40 | 0,00 | 0,55 | 0,55 | 0,70 | 0,15 | 0,0071 | Mol-Wiese |
| BP39 | 537 | 0,60 | 0,00 | 0,73 | 0,73 | 0,80 | 0,07 | 0,0033 | Mol-Wiese |
| BP40 | 542 | 0,37 | 0,00 | 0,40 | 0,40 | 0,52 | 0,12 | 0,0057 | Mol-Wiese |
| | | | | | | n=40 | **0,1848** | **0,0088** | Mittel |
| | | | | | | | **-0,3100** | **-0,0148** | Minimum |
| | | | | | | | **0,7500** | **0,0357** | Maximum |
| | | | | | | n=34 | **0,2438** | **0,0111** | **Mittel korr** |

RESULTS

**Calculation based on comparison of thickness of the peat body by time staggered stratigraphical recordings**

By hand of the drilling data the peat body was modelized and the amount of stored carbon was determined (Fig.7).

The next step includes the estimation of mightiness loss of the peat body in comparison between ancient and new drill data. Old peat sampling data were mostly not exactly plotted according to in their position and altitude so that they can't be located exactly. Because of this, significant residual variation can occur, especially over uneven mineral subsoil or in the case of a small scaled relief. Our sampling with a higher number of peat sampling points was adjusted to this situation.

The loss of thickness is the result of *sagging*, *shrinking* and *peat mineralisation* (Höper, 2007). *Sagging* occurs basically in the initial phase after drainage construction and was excluded in these areas of investigation, because there was no change of dewatering during the last decades. *Shrinking* is the consequence of increasing density as a result of dehydration which depends on the specific land-use of the peat land or rather by type of biotope. The shrinking rate for peat can be estimated on average with 30% for wooded situations, 25% for grassland and 25% for purple moor-grass stage.

For the carbon content calculation of the determined peat volume, the mean compactness of 100g/l for bog peat and 150g/l for fen peat was chosen (Hofer and Witte, 2010). The carbon content can be set between 50-55%.By this way determined carbon loss was divided by the intermediate years of the sampling campaigns to obtain the annual carbon loss. As in drained succession stages $CO_2$ emission determines the greater part of the gas exchange, thus it is possible to appraise the $CO_2$ emission.

**Calculation of the climate relevant Gas exchange applying the approachs based on Höper (2007) and Couwenberg et al. (2008)**

The Global Warming Potential (GWP) is the result of the summary of separated climate effective gases ($CO_2$, $CH_4$, und $N_2O$) by quantification with the global warming potential coefficient.

*Calculation according to Höper (2007)*

For the calculation of the actual greenhouse gas emissions according to Höper (2007) the prevailing surface of the peat body is classified by the location categories, type of mire and its land-use. Subsequent different emission factors (GWP), which were determined based on various test series, were assigned to these categories, which were illustrated by the example of "Sauerbach" in Table 2 (Hofer et al. 2010).

*Calculation according Couwenberg et al. (2008)*

Quantification of emission was conducted with the GESTs model (Treibhaus-**G**as-**E**missions-**S**tandort-**T**ypen / Greenhouse-gas-emission-location-types) according to Couwenberg et al. (2008). By means of this method estimations of greenhouse-gas emissions and its acquisition on large-scale level can be made based on vegetation mapping. For the model the areas were mapped and classified to vegetation types according to Drachenfels (2004), Ellenberg (1992), Garve, (2004, 2007). Afterwards sites were sorted according to the degree of humidity (Table 3).

On the classification degrees of biotope types from “wet”, “moderate wet” up to “fresh to dry”, GWP values in $CO_2$-equivalents $ha^{-1}$ $a^{-1}$ similar to Höper (2007) were allocated to the respective percentage of area of which results the emission factors indicated as carbon-equivalents kg $ha^{-1}$ $a^{-1}$ (Table 4).

**Table 2.** Sauerbach, emission factors by type of mire and its land-use (Hofer et al. 2010)

| | **$CO_2$** kg C $ha^{-1}$ $a^{-1}$ | **$CH_4$** kg C $ha^{-1}$ $a^{-1}$ | **$N_2O$** kg N $ha^{-1}$ $a^{-1}$ | **Emissions-factors[b] GWP500** kg C-Äquiv. $ha^{-1}$ $a^{-1}$ |
|---|---|---|---|---|
| Natural / close to nature bog | -337 | 62 | 0 | -189 |
| Natural / close to nature fen | -460 | 236 | 0 | 101 |
| Degenerated bog | 3.770 | 5 | 0 | 3.782 |
| Extensive / unused fen | 4.000 | -0,3 | 6 | 4.415 |
| Grassland fen | 4.600 | -0,3 | 14 | 5.618 |
| Grassland bog | 3.950 | 0 | 0 | 3.950 |

**Table 3.** Application of the humidity degree according to Couwenberg et al. (2008) in the investigation area Sauerbach (Hofer et al. 2010)

| **humidity** | **degree** | **area [ha]** | **area [%]** |
|---|---|---|---|
| flooded | 6+/7+ | 4,9 | 2,8 |
| moderate wet | 5+ | 2,3 | 1,3 |
| very humid | 4+ | 12,7 | 7,3 |
| humid | 3+/4+ | 1,3 | 0,7 |
| semi-humid | 3+ | 84,1 | 50,6 |
| fresh | 2+/3+ | 66,7 | 35,7 |
| moderate dry | 1-/1+ | 2,4 | 1,4 |
| sealed surface | 3-/4- | 0,3 | 0,2 |
| **total** | | **174,7** | **100** |

**Table 4**. Comparison of the methods: average annual emissions of three project areas

| **Time** | **Project area** | **Höper (2007)** | **GEEST Couwenberg et al. (2008)** | **Difference of Layer thickness** |
|---|---|---|---|---|
| 2009 | Theikenmeer | 3.619 kg C/ha/a | | * |
| 2010 | Sauerbach | 4.430 kg C/ha/a | 5.060 kg C/ha/a | 4.852 kg C/ha/a |
| | Differenzen | - 9% | + 4% | |
| 2011 | Lichtenmoor | 3.782 kg C/ha/a | 3.625 kg C/ha/a | 3.500 kg C/ha/a |
| | Difference | + 8% | + 4% | |

** For Theikenmeer there were no ancient drilling data available which were elegible to compare to the actual situation.*

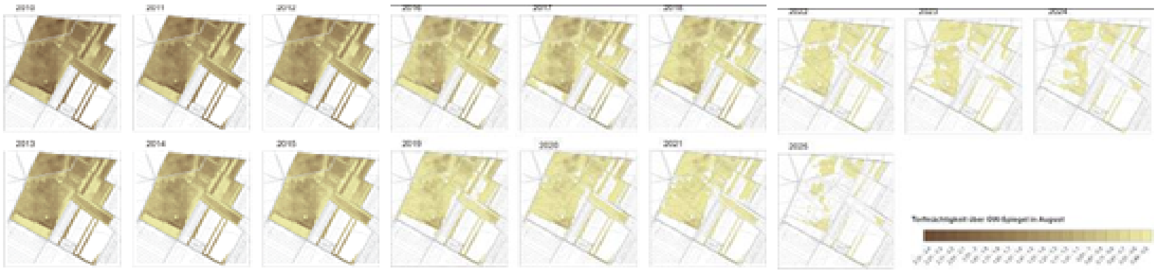

**Figure 8**. Future scenario (2010-2025) of the proceeding peat oxidation for the area "Sauerbach", if no rewetting measures will happen (Hofer et al. 2010)

## CONCLUSION

After calculation of the total amount of the peat body under consideration of the hydrological conditions, the part of the peatbody which is affected by oxidation was designated. On the base of this volume it is possible to determine the emission factors, area and time, the expected behaviour of emission in the respective mire area (Fig. 8).

Table 4 shows the average actual emissions of three project areas. The discrepancy of the absolute altitude between each territory reflects the different degree of humidity. "Sauerbach" was relatively very dry, whereas some parts of "Theikenmeer" have already been rewetted. The comparatively low average emissions of "Lichtenmoor" are constituted due to humid partial areas which were covered with *Sphagnum* comprehensively.

The differences between the emission factors which were determined by the loss of thickness of the peat layer that proceeded during the last years and by the attribution of the actual vegetation / land-use are low and lie between +/- 8%. They are less estimated than the expected inaccuracy of the relatively roughly effected classification into land-use and degrees of humidity. The occurred emission of the past years can be quantitatively well determined by means of the height loss, depending on the quality of peat sampling data.

Owing to the difficult classification of vegetation stages (degrees of purple moor-grass stages) and the pedological classification (transitional peat bogs which are characterized by transition from bog to fen due to peat oxidation) the method of the deduction from the comparison of thickness of the peat body by time staggered stratigraphical recordings -– as far as appropriate peat sampling data are available - is recommended.

## REFERENCES

Ag Boden, Bodenkundliche Kartieranleitung, 4. Aufl., Nachdr., 392 S., 33 Abb., 91 Tab., Hannover 1996

Burrichter, E., R. Pott & H. Furch (1988): Potentielle natürliche Vegetation. - Geogr.-landeskdl. Atlas Westf., 4/1 u. Begleittext, Münster.

Couwenberg, J., Augustin, J., Michaelis, D., Wichtmann, W. & H. Joosten (2008):

Entwicklung von Grundsätzen für eine Bewertung von Niedermooren hinsichtlich ihrer Klimarelevanz. Endbericht des Institut Duene E.V. und der Ernst Moritz Arndt Universität Greifswald

Drachenfels, O.v. (Bearb.) (2004): Kartierschlüssel für Biotoptypen in Niedersachsen unter besonderer Berücksichtigung der nach § 28 a und § 28 b NNatG geschützten Biotope sowie der Lebensraumtypen von Anhang I der FFH-Richtlinie. Stand März 2004. - Natursch. Landschaftspfl. Nieders., A/4, 1-240, Hildesheim.

Drösler, M. (2005): Trace gas exchange and climatic relevance of bog ecosystems, Southern Germany. PhD thesis, Technical Univeresity of Munich, Germany. 179pp.

Eggelsmann, R. (1981): Dränanleitung-für Landbau, Ingenieurbau und Landschaftsbau. 2. bearb. U. erg. Aufl., Parey, Hamburg, Berlin

Ellenberg, H. (1992): Zeigerwerte der Gefäßpflanzen Mitteleuropas. - Scripta Geobot., 9, 3. Aufl., 122 S., Göttingen

Göttlich, K. (1990): Moor- und Torfkunde. 3.Aufl. Hrsg: Göttlich, K., Sigmaringen.E. Schweizbart´sche Verlagsbuchhandlung, Stuttgart

Garve, E. (2004): Rote Liste und Florenliste der Farn- und Blütenpflanzen in Niedersachsen und Bremen, 5. Fassung, Stand 1.3.2004 - Informationsdienst Naturschutz Nieders., Niedersächsisches Landesamt für Ökologie, S. 1-72, Hildesheim.

Garve, E. (2007): Verbreitungsatlas der Farn- und Blütenpflanzen in Niedersachsen und Bremen – Naturschutz Landschaftspflege in Niedersachsen. Heft 43, Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (NLWKN) (Hrsg.), 507 S., Hannover.

Hofer, B.; Langemeyer, J., et al. (2009): Nature Reserve Theikenmeer - Soil study on climate relevant gas exchange of drained peat lands", Hofer & Pautz GbR, Client: NABU - Nature and Biodiversity Conservation Union, Germany

Hofer, B.; Langemeyer, J., et al. (2010) : Nature Reserve Sauerbach - Soil study on climate relevant gas exchange of drained peat lands", Hofer & Pautz GbR, Client: NABU - Nature and Biodiversity Conservation Union, Germany

Hofer & Witte (2010): Massenverlust und Klimarelevanz von Moorböden durch Nutzung, am Beispiel des Großen Uchter Moores

Hofer, B., Lehmann, J., et al. (2011) [1]: Nature Reserve Holtorfer Moor – Avoidance of Co2 emission due to rewetting of a rised bog. Hofer & Pautz GbR, Client: NABU - Nature and Biodiversity Conservation Union, Germany and VW Leasing

Hofer, B., Lehmann, J., et al. (2011)[2]: Nature Reserve Lichtenmoor – Avoidance of Co2 emission in consequenz of improvement meassures in an already effected rewetting process in the early 1970s. Hofer & Pautz GbR, Client: NABU - Nature and Biodiversity Conservation Union, Germany

Höper 2007: Freisetzung von Treibhausgasen aus Deutschen Mooren. In Telma Bd 37, S. 85-116 – Hannover

Ipcc (2007): Climate Change 2007 – The Physical Science Basis. – Intergovernmental Panel on Climate Change. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. University Press, Cambridge. URL: http.//ipcc.ch/ (Aufgerufen am 10.02.2012)

Oberdorfer, E. (2001): Pflanzensoziologische Exkursionsflora. 8. Aufl., 1051 S., Stuttgart. Plagemann, N. (2009): Mass loss and climate relevance of peatlands by the antropogen use by the example of the Great Uchter Bog in Lower Saxony, Institute for landscape ecology, Westphalian-University of Münster.