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SIMULATION OF PEAT ACCUMULATION: AN AID IN CARBON CYCLING RESEARCH?

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Some preliminary results of a technique used to compare primary production and peat accumulation data mainly from published sources and the results of a peat accumulation simulation model are presented. Emphasis is on differences among micro-sites (hummock, lawn, hollow and pool) and among various *Sphagnum* species (*S. fuscum, S. magellanicum, S. cuspidatum* and *S. balticum*) associated with raised bogs. The primary production of lawns and pools were significantly greater than those of hummocks and hollows. *Sphagnum balticum* had the highest primary production (mean = 339 g $m^{-2}a^{-1}$). Over 90% of the primary production of *Sphagnum fuscum* is accumulated while for the other *Sphagnum* species, the value is <50%. The data are used in a simulation model to show the influence on primary production of a doubling of rainfall over a 50-year period.

Keywords: Meta-analysis, peatland, primary production, *Sphagnum*

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INTRODUCTION

Approximately 1.5–2% of the Earth's land surface is covered by peat (Clymo 1984), much being concentrated in the Northern Hemisphere. In Europe, peatlands occur primarily in Scandinavia and Finland with only fragments of former peatlands being left in countries such as The Netherlands, Germany and Denmark.

Increasing our understanding of the processes involved in peat accumulation will contribute to our general understanding of decay processes and the flow of carbon through the biosphere, particularly in terms of climatic change. There are no reasons to suppose that the decomposition processes in peat-forming ecosystems operate differently in different climatic areas. Therefore general models of decomposition and peat accumulation ought to be applicable over a wide range of peatlands (Nils Malmer, pers. comm.).

The rate at which peat accumulates at a certain site is dependent on many factors, including the production, composition and structure of the peat-forming vegetation, the environmental circumstances, and the period of time the organic matter — formed by the vegetation and deposited as litter — is allowed to decompose in the aerobic surface layer of a peatland. It is also dependent on the anaerobic decomposition and compaction that takes place in the anaerobic peat below the surface layer. However, these processes are very slow compared to those in the upper layer, and so less important when analysing on a time scale of decades. The intrinsic characteristics of a species sets the limits for its primary production, carbon flow, biofragmentation and decomposition. These characteristics are quantitatively and qualitatively influenced by the biotic and abiotic environment; for example, other species in the community, and fluctuations in water table movement, hydraulic conductivity or micro- and macro-climate.

Because peat accumulation is very slow and difficult to measure, these processes have been modelled using simulation techniques. By describing the processes mathematically, it is possible to predict the outcome of long-term field experiments (Clymo 1984, 1992). With simulation models, several important factors involved in the processes can be altered to determine their effect and assumptions in the model can be evaluated. In this way, the most important field data that needs to be collected can be identified.

In this paper, I present some preliminary results of a technique used to compare primary production and peat accumulation data mainly from published sources and the results of a peat accumulation simulation model using this data.

MATERIALS AND METHODS

The database and meta-analysis

As much information as possible concerning the process of peat accumulation were retrieved from published sources to build up a database. Scientists from several countries also kindly provided unpublished data for the database. The database includes literature references, keywords and abstracts for general accessibility, as well as specific information concerning species, vegetation type, type of bog, name of bog, country, longitude and latitude (not complete yet), climatic region, phytogeographic region (according to Tuhkanen 1984), measurement methods, and — if possible — details such as height above water table, dating, depth and degree of decomposition.

All the data were transformed into a standard format (measurement unit) for each type of data (e.g. primary production in g $m^{-2}a^{-1}$, bulk density in g dm^{-3}). Meta-analysis, a statistical technique used in medicine, was adapted and used to compare the primary production and peat accumulation data (van Dierendonck, in prep.). Meta-analysis allows the researcher to compare the results of separate but similar experiments (Mullen 1989). Because the database is very detailed, we can lump or split the data as much as is needed for a particular simulation run. In this paper, I have not taken into account the effects of differences in climatic area, geographic region or date of peat accumulation, i.e. it is a lumped approach. Differences among the micro-sites and species were tested using ANOVA and t-test according to Sokal and Rohlf (1980). The 95% confidence levels are used for all statistical tests.

Simulation of peat accumulation

The peat bed (Fig. 1) is divided in the acrotelm and the catotelm layers. As peat accumulation mainly depends on the rapid processes in the acrotelm, this layer is divided in five sub-layers. In the catotelm, the slow but gradual anaerobic decomposition and compaction processes are simulated.

The Apple program, STELLA II was used for the simulations. The frequency distribution characteristics of primary production and peat accumulation data were used as input variables or validating variables in the simulation model. The simulation were run for a period of 250 years. The effect of doubling rainfall during 50 years was also evaluated.

PRELIMINARY RESULTS

Meta-analysis of micro-site data

A preliminary comparison among *Sphagna* and vascular plant data for each micro-site (hummock, lawn, hollow, pool) are presented separately in Table 1. A high number of records were found in the literature for each micro-site. Significant differences existed between the micro-sites (unpaired t-tests and ANOVA). Each micro-site clearly has its own growth characteristics.

Meta-analysis of some *Sphagnum* species data

The preliminary results of the meta-analysis of the primary production and peat accumulation data of a hummock species (*S. fuscum*), a lawn

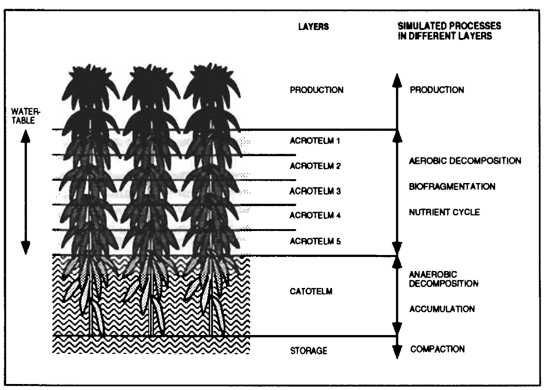

Fig. 1. Layers and processes as simulated in the peat-accumulation model.

Table 1. Frequency distribution characteristics of data from literature on primary production of different groups after meta-analysis. The means followed by common letters are not significantly different at the 5% level (t-test and ANOVA). The number of observations (n) is the number of records/elements used.

Vegetation type/species	n	Mean, g $m^{-2}a^{-1}$	S.D., g $m^{-2}a^{-1}$	Skewness	Kurtosis
Hummock *Sphagna*	112/329	222.0	137.3	1.09	1.26
Lawn *Sphagna*	95/433	379.4a	345.9	1.36	0.97
Hollow *Sphagna*	48/279	267.7	183.8	0.85	0.16
Pool *Sphagna*	9/27	348.0a	85.9	1.58	2.27
Hummock vasculars	75/690	32.9	23.0	1.07	0.71
Lawn vasculars	51/229	24.4a	21.1	1.84	3.89
Hollow vasculars	48/272	20.2a	19.5	0.97	–0.31
Pool vasculars	–	–	–	–	–

Table 2. Frequency distribution characteristics of data from literature on primary production and peat accumulation of different *Sphagnum* species after meta-analysis. The means followed by common letters are not significantly different at the 5% level (t-test and ANOVA). The number of observations (n) is the number of records/elements used.

Vegetation type/species	n	Mean, g $m^{-2}a^{-1}$	S.D., g $m^{-2}a^{-1}$	Skewness	Kurtosis
Primary production					
Sphagnum fuscum	79/267	223.5	107.4	0.30	0.07
S. magellanicum	59/228	174.5a	133.6	1.17	1.16
S. cuspidatum	35/236	147.3a	142.1	2.96	10.62
S. balticum	18/169	339.0	168.6	0.58	–0.06
Peat accumulation					
Sphagnum fuscum	31/117	205.4a	167.7	0.34	–0.67
S. magellanicum	16/16	60.6b	39.3	2.04	4.34
S. cuspidatum	7/7	52.1b	33.0	0.60	–1.25
S. balticum	2/2	160.0a	162.6	0	–2.00

species (*S. magellanicum*), and two hollow species (*S. cuspidatum* and *S. balticum*) are presented in Table 2. The primary production and peat accumulation of most of the species differ significantly.

There was a significant difference (p = 95%) between the peat accumulation data for *S. fuscum* and *S. magellanicum*, and between *S. fuscum* and *S. cuspidatum*. The hollow species, *S. balticum* had the highest gross primary production (339 g $m^{-2}yr^{-1}$), but it looses 52.8% during the peat-forming process. *Sphagnum fuscum*, on the other hand, lost only 8.1% of its annual biomass production.

A simulation run

The *Sphagnum balticum* data were used to illustrate how the simulation technique works (Fig. 2). If the amount of rainfall is doubled, primary production is increased more than the organic matter accumulation in the acrotelm. This is mainly due to the higher evapotranspiration. With these parameters, the model calculated peat accumulation rate is low (Fig. 2).

DISCUSSION

In a raised bog there is a limited number of plant species capable of forming peat. The hypothesis was that the intrinsic characteristics of species as well as the taphonomic processes after dying are mainly responsible for this. The presence or absence of a particular species at a certain spot on the bog is also strongly related to abiotic and biotic features. So the combination of these features influences the process of peat accumulation. Unlike other soils, peat is almost entirely made

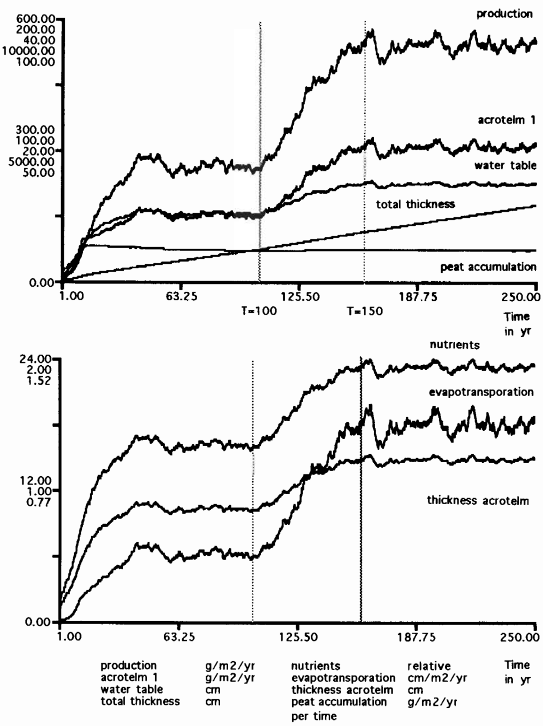

Fig. 2. Results of a peat-accumulation simulation run of *Sphagnum balticum* with 'random' rain and doubling of the amount of rain between T = 100 and T = 150 yr.

of organic material, mostly carbon. There is thus a strong relationship between species, the peat-forming processes and the carbon cycle in peat. If we are able to simulate the most important processes, we can also say something about the carbon cycle in peat. As simulation is a relative cheap and fast method we can also calculate what will happen if we change some environmental or biotic factors.

Because primary production is the most important biotic input parameter, emphasis in this paper is on primary production. The results after the meta-analysis show that most of the comparable groups of vegetation types and *Sphagnum* species are statistically significantly different. This suggests that the different vegetation types need to be treated separately during simulation runs. Notable is the higher mean primary production rate for the lawn than for the other vegetation types which is only due to the higher primary production of the lawn *Sphagnum* species. The primary production of the vascular raised bog plants is, in all cases, ten times smaller than for the *Sphagnum* species. Within the *Sphagnum* species, it is notable that there is a difference between the hollow species *S. cuspidatum* and *S. balticum*. It is not totally clear what causes this difference. In the data set of *Sphagnum cuspidatum* some outliers had to be removed. Also *S. balticum* is a 'Scandinavian' species, so it is restricted to certain specific phytogeographic regions. Other preliminary analysis so far point in the direction that the data has to be divided in the different phytogeographic zones as well as temperature and humidity zones as suggested by Tuhkanen (1984), to make them more comparable. Using all peat accumulation data (not split in different ages) can also have caused some errors. This needs to be analysed in more detail.

The test simulation was exemplified using the *Sphagnum balticum* data. Doubling the amount of precipitation during 50 years doubled the primary production and the amount of organic matter in the first acrotelm layer, but there was only a relatively small increase in the total thickness of the acrotelm, mainly due to the relatively higher evapotranspiration (more growth, higher use of energy). The rate of peat accumulation, however, was low compared with the meta-analysis results of *S. balticum*. Clearly the model is not fully valid at this stage. Further research is needed to work out the difference equations and better parameterization.

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