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Seasonal Variations in Suspended Sediment Yield in the Baltic Sea Drainage Basin

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The aim of this article is to describe the seasonal fluctuations of suspended sediment yield in the Baltic Sea drainage basin and to quantify the monthly inflow of suspended sediment to the Baltic. The seasonal fluctuations of sediment yield are controlled by rain and snow amounts and by ground thawing. The rhythm of the sediment yield shows great differences between mountainous and lowlandic areas, and also between areas with oceanic and continental climates. The seasonal fluctuations of the total suspended sediment inflow to the different sub-areas of the Baltic Sea imitate the seasonal regimes of the sediment yield within the different catchments. Most of the suspended load is supplied to the sea during snow melting. For the Baltic as a whole, the inflow reaches a maximum value in April (22.2% of the annual inflow) and a minimum value in January (3.7% of the annual inflow).

Introduction

Knowledge of the seasonal fluctuations of suspended sediment yield provides information about the climatic impact on the sediment yield. This impact can be strongly modified by human activity. Man's impact may reduce the suspended load in rivers, as a result of reforestation, more careful land use, and especially as a result of reservoirs. The suspended load can also be increased by human activity (deforestation, regulation works on rivers).

The goal of the paper is to describe and analyse the seasonal fluctuations of sediment yield within the Baltic Sea drainage basin from a large amount of monthly data, and to quantify the seasonal suspended sediment inflow to the sea.

The analysed sediment seasonality has been marginally discussed in the literature (*e.g.* Mikulski 1961, Atlas Mira 1964, Brandt 1982, Lajczak 1989, Hasholt 1990).

Methods

The Study Area

The area draining to the Baltic Sea (Fig. 1) is presented in detail elsewhere (Lajczak and Jansson 1993, p. 32 this issue).

Data Used and Criticism

The same data that were analysed in Lajczak and Jansson (1993) are also used here. In addition to the mean annual values of suspended sediment yield, mean monthly values are used in calculations. The data originate from the gauging stations specified in our earlier paper. Mean annual and mean monthly values of water discharge from the same gauging stations are analysed.

The criticism of the data used, presented in Lajczak and Jansson (1993), is valid also in the present context.

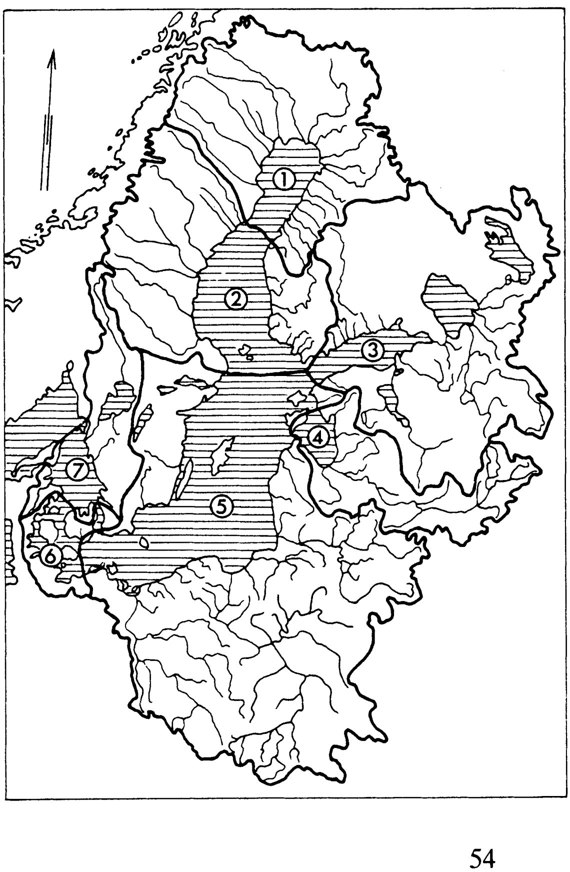

Fig. 1.
The Baltic Sea and its catchment divided into the sub-sea basins and their catchments:

1) Bothnian Bay,
2) Bothnian Sea,
3) Gulf of Finland,
4) Gulf of Riga,
5) Baltic proper,
6) The Sound and the Belts,
7) Kattegat.

Calculations

The seasonal variations of water discharge are presented by the Pardé coefficient: Q_m/Q_{yr}, where Q_m is mean monthly water discharge in m^3/s, and Q_{yr} is mean annual water discharge in m^3/s. The mean monthly inflow of suspended load to the Baltic Sea and the mean annual inflow of material into the Baltic and its sub-areas are calculated to produce a similar coefficient for suspended sediment yield: $R_m/{}^1/_{12}R_{yr}$, where R_m is mean monthly suspended sediment load in t/month, and R_{yr} is mean annual suspended sediment load in t/year. This seasonal variation can also be presented using a coefficient in per cent: 100 R_m/R_{yr}.

Results

Seasonal Fluctuations of Suspended Sediment Yield

The calculated 100 R_m/R_{yr} (%) values for the different months at each gauging station (with catchment areas not larger than 50,000 km^2) made it possible to draw isolines of the monthly part of the annual sediment yield each month. The results are presented in Figs. 2-4. Different climatic and morphological conditions within the large area studied cause differences in the monthly parts of the annual transport.

In January, there is a stable snow cover in the northern and eastern parts of the studied area, and also in the mountains in the south, and the suspended sediment yield reaches very low values there. In contrast, in the lowlandic south-western part of the area, frequent snow melting and relatively high precipitation induce higher values of suspended sediment yield.

In February, the pattern of the sediment yield percentage is similar to that in January. Only in the western part of the area can a decreasing trend in sediment transport be observed.

In March, an increasing trend in the suspended sediment yield is observed. The situation, typical in all the area except in the north, is caused by intensive snow and ground thawing. In large areas the suspended sediment yield reaches 15%, and in the lowland foreland of the Carpathians even more than 25% of the annual value. In the north, the monthly percentage is still lower than 2%, and even 0.5%.

In April, the situation is drastically changed in the central and eastern parts of the studied area. It is caused by rapid snow and ground thawing in these lowland areas. The monthly suspended sediment yield may even exceed 50% of the annual rates. In Poland, in spite of rather low precipitation, moderate values of sediment yield are caused by intensive agricultural work. In northern Scandinavia the suspended sediment yield still reaches very low values.

May is the first month of the warm period in the mountains of southern Poland, producing high sediment yield values caused by increased precipitation. The increasing trend in the yield is independent of the rapidly developing vegetation. The quickest increase in suspended sediment yield is observed in northern and western

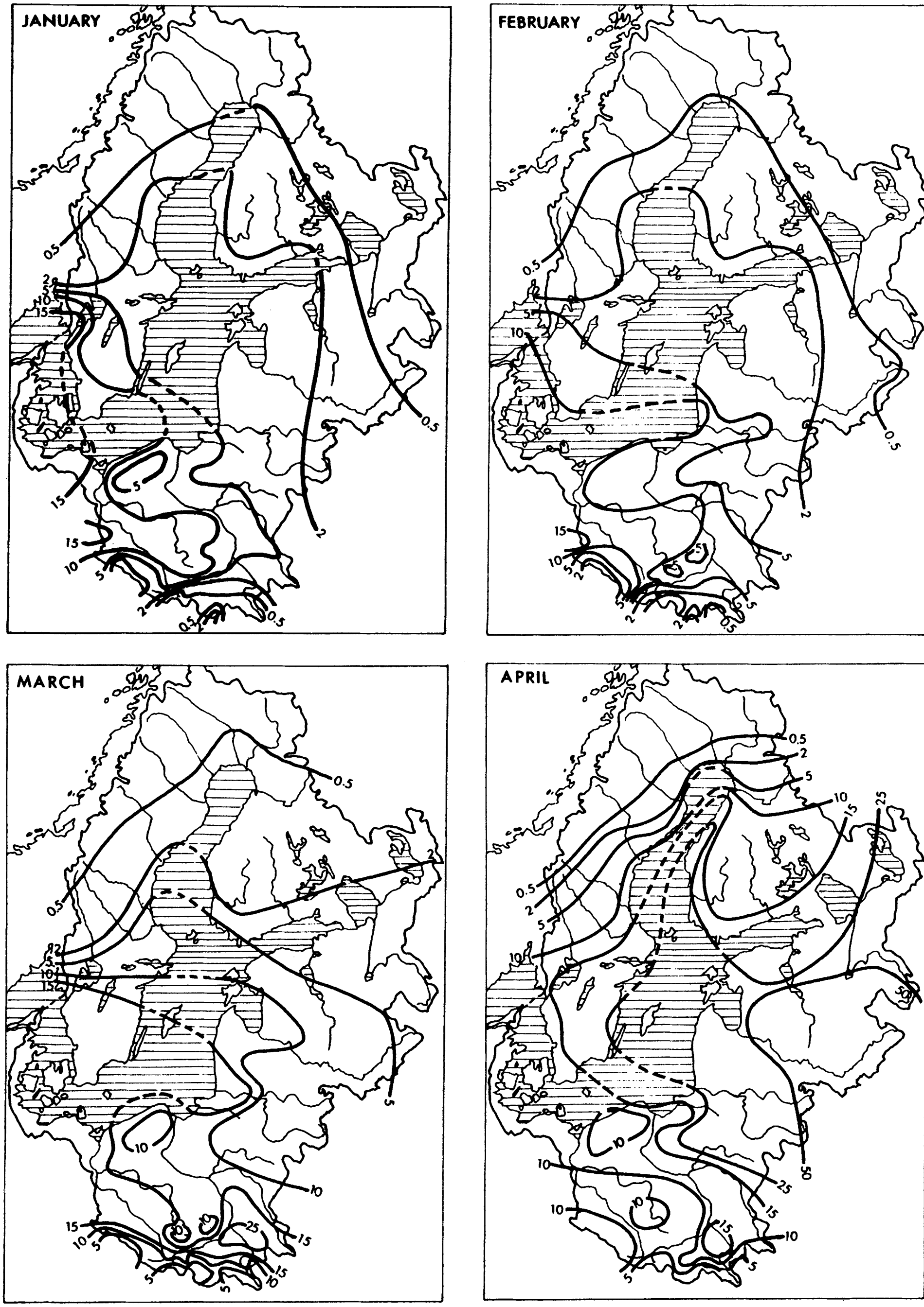

Fig. 2. Isolines of the monthly suspended sediment yield in January, February, March and April as part of the annual yield in %.

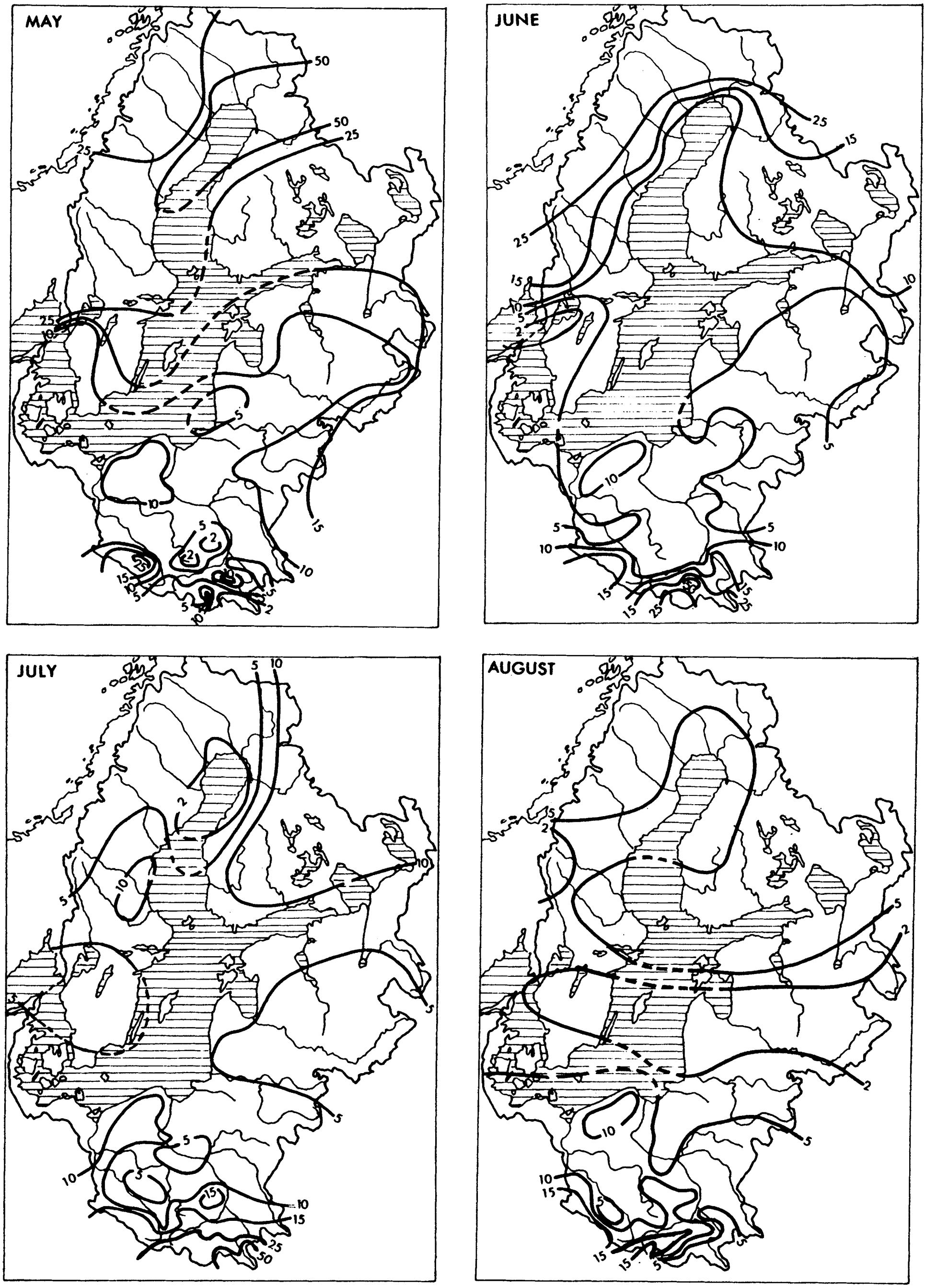

Fig. 3. Isolines of the monthly suspended sediment yield in May, June, July and August as part of the annual yield in %.

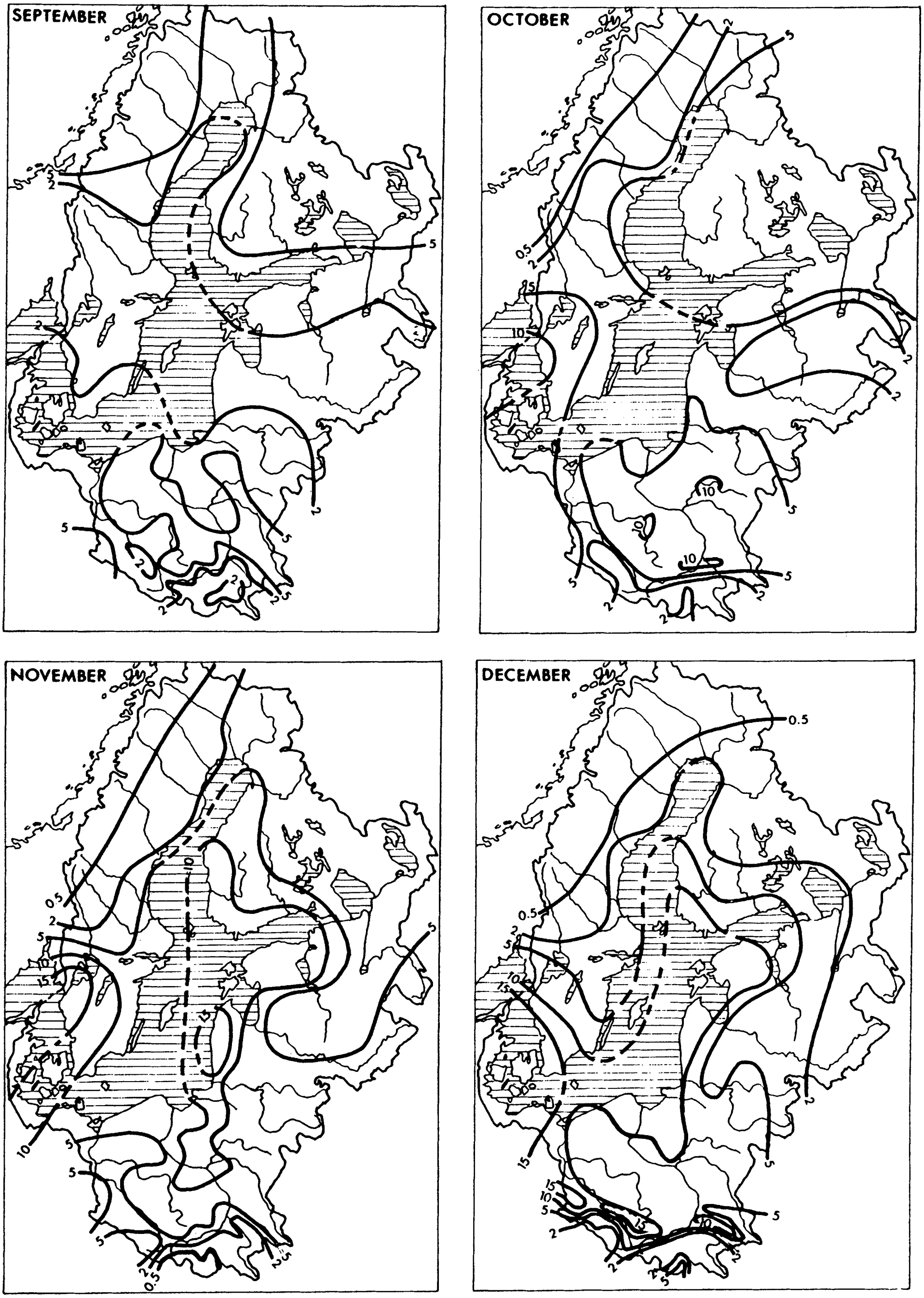

Fig. 4. Isolines of the monthly suspended sediment yield in September, October, November and December as part of the annual yield in %.

Scandinavia, where snow and ground frost are thawing in large areas.

In June, an increasing trend in suspended sediment yield is found in the Carpathian Mountains, locally >50%, caused by heavy rainfall. The suspended sediment yield decreases in the Middle Poland Upland and in the Lowland areas (*cf* Lajczak and Jansson 1993 Fig. 1). Only in northern Scandinavia does continuing snow and ground thawing cause high rates of sediment yield (> 25% of annual values).

In July, the suspended sediment yield decreases in almost all the studied area. Only in the Sudety Mts, and especially in the Carpathian Mts (high precipitation, storms and heavy rainfall), does the suspended sediment yield increase and reach maximum rates in the year (even over 50%).

In August, the amounts of precipitation decrease in the whole area. A clear decreasing trend in the suspended sediment yield is observed in all morphological units of the studied area. The suspended sediment yield is still relatively high in the mountains of southern Poland.

September is characterized by very low rates of suspended sediment yield in all the area. Locally in Poland, in North Sweden and in Finland the monthly values exceed 5% of the annual values.

In October, the suspended sediment yield decreases drastically in the Scandinavian Mts and in the Norrland Plateau. In the rest of the area the yield increases somewhat and exceeds locally 10% of the annual rates. In the mountains in southern Poland, the suspended sediment yield does not reach 2% of the annual values.

In November, the suspended sediment yield still increases in the western and south-western parts of the area and also in an area located along the eastern coast of the Baltic Sea, where it even exceeds 15% of the annual yields. A slightly increasing trend in the sediment yield is observed in the Sudety Mts. The increasing trend described in suspended sediment yield in areas mentioned is caused by increasing precipitation, mainly in the west, and also by thawing of the first snow cover.

In December, snow cover is rather stable in northern and eastern parts of the area, and also in the mountains in southern Poland. The suspended sediment yield does not exceed 2% of its annual value there. In the south-western, western and central regions of the studied area the suspended sediment yield still exceeds 10% of its annual values, and in the lower foreland of the Sudety Mts and also in southwestern Sweden and in Denmark even exceeds 15% of the annual values.

Assessment of Factors Influencing the Seasonal Rhythm of Suspended Sediment Yield

The described spatial distribution of the seasonal rhythm of suspended sediment yield is illustrated by the diagrams in Fig. 5. The seasonal fluctuations in suspended sediment yield and water discharge are presented by the Pardé coefficients in some selected catchments located in different parts of the area studied.

The seasonal fluctuation of the suspended sediment yield is controlled by climatic factors such as amount of rain and snow, and ground thawing. In catchments located in the northern and eastern parts of the studied area, where the climates have typical continental features, the suspended sediment yield is concentrated mainly during snow and ground thawing in spring. The occurrence of the highest value of the suspended sediment yield depends on geographical location (latitude, height a.s.l.).

Late snow and ground thawing in the northernmost part of the Scandinavian Mts and Norrland Plateau induce the maximum rates of the suspended sediment yield during early summer, mainly in May-June (area 1 in Fig. 5).

In the central part of the Scandinavian Mts and in the southern part of Norrland Plateau (area 2), maximum values of the suspended sediment yield occur almost one month earlier and are concentrated mainly in May. The yield in the summer-autumn period is relatively high there.

In northern Finland (area 3), the maximum suspended sediment yield also occurs in May. The suspended load in rivers flowing through only a few lakes is strongly concentrated during one month.

Catchments with a large number of lakes in southern Finland and in Karelia are characterized by very small seasonal fluctuations of the suspended sediment yield (area 4).

Lowland catchments located in the eastern and south-eastern parts of the studied area are characterized by suspended sediment yield strongly concentrated until April, and by relatively high sediment yield during the rest of the year (area 5).

In contrast, southern Sweden and the south-eastern coast of the Baltic Sea (area 6) have a more maritime climate and the seasonal rhythm of suspended sediment yield shows two main equivalent peaks, both caused by unstable snow, which melts very often, and by higher precipitation in late autumn or early winter, and in early spring.

A warmer oceanic climate prevailing along the south-western coast of the Baltic Sea makes the sediment yield more uniform throughout the year (area 7). Relatively high values of the suspended sediment yield caused by frequent snow melting and higher precipitation during the winter are typical of lowland areas influenced by oceanic climate.

Upland catchments in middle Poland (area 8) are characterized by two rather equivalent peaks of the suspended sediment yield in early spring and in summer, and by high sediment yield during the rest of the year.

Catchments located in the mountains in southern Poland are characterized by two dominant peaks of sediment yield. The seasonal fluctuations of sediment yield in the Sudety Mts are mostly influenced by oceanic climate, while the regime in the Carpathians is mostly affected by continental climate.

In the Sudety Mts (area 9), the highest suspended sediment yield is found during snow thawing in early winter or in early spring, and also in the summer due to heavy rainfall.

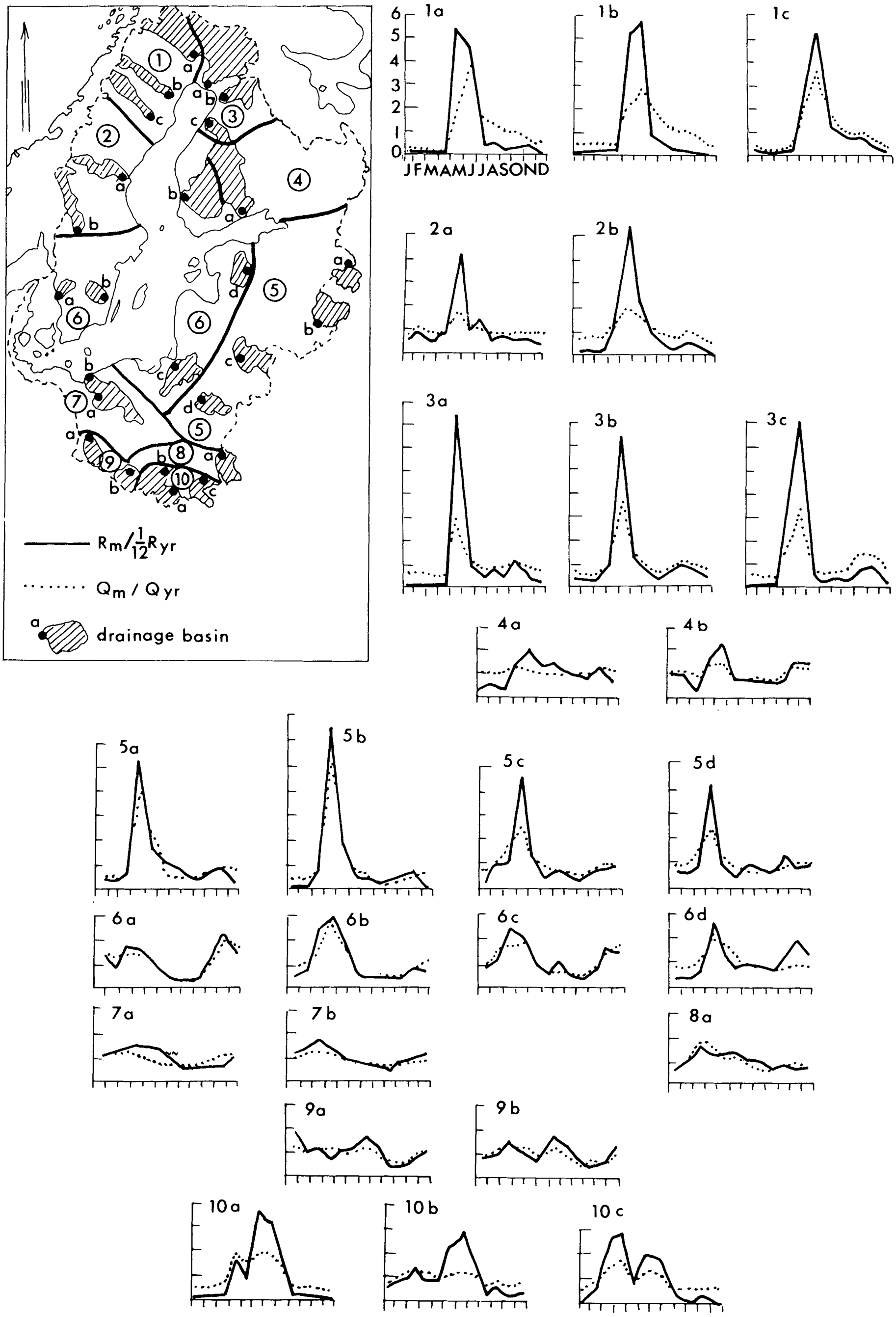

Fig. 5. Examples of seasonal fluctuations of suspended sediment yield in selected catchments in the Baltic Sea drainage basin.

In the Carpathian Mts (area 10), the two peaks of suspended sediment yield are due to thawing of a large amount of snow in early spring (March or April), and by high precipitation in the May-August period. In higher parts of the Carpathians the main culmination of sediment yield is found in the summer, and in their foreland during snow thawing.

It must be stressed that the magnitude of the seasonal fluctuations of the sediment yield as expressed by the Pardé index depends on the absolute values of the yield. In northern Sweden and in Finland, for example, where mean sediment yield is low, a small increase in monthly load gives a high variation while a higher increase in load in the Carpathians can give a low monthly variation.

The area studied can be divided into three relatively homogeneous main regions of suspended sediment regime, where the seasonal fluctuations of sediment yield

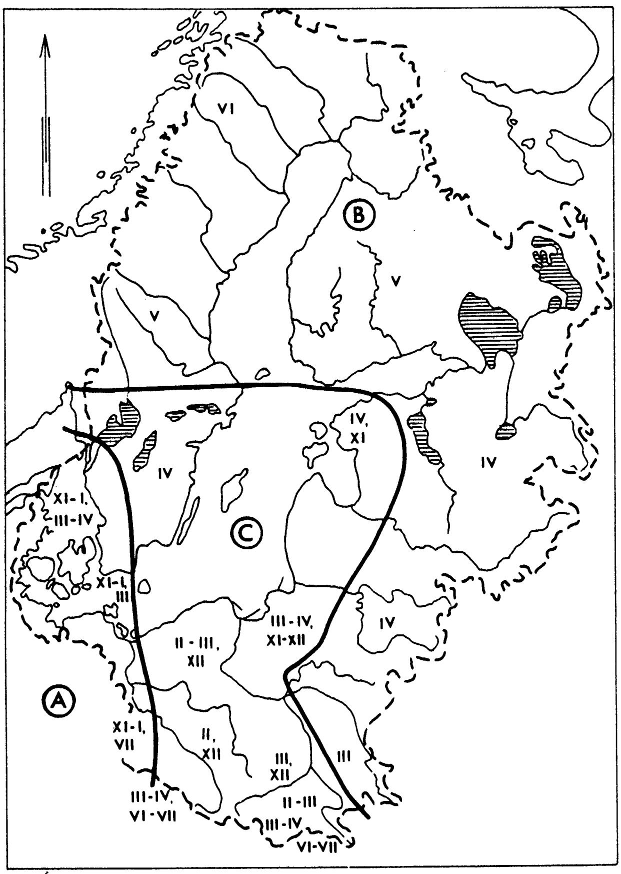

Fig. 6. Main regions with different seasonal regimes of suspended sediment yield in the Baltic Sea drainage basin. The types of sediment yield regimes are: A) oceanic, B) continental, C) both oceanic and continental. Months with the highest suspended sediment yield are marked in roman figures.

are controlled: A) by oceanic climate, B) by continental climate, and C) by both climates (Fig. 6). The oceanic type of sediment yield regime shows two equivalent peaks of the yield in lowland areas in early winter and in early spring, both mainly due to rains. The continental type of sediment yield regime shows one dominant peak of the yield during early spring snow thawing. In the mountains in southern Poland the maximum suspended sediment yields is due to high precipitation in the summer. The months with the highest suspended sediment yield are also presented in Fig. 6.

Seasonal Fluctuations of the Suspended Sediment Inflow to the Sea

Suspended sediment inflow to the Baltic Sea and its sub-basins in successive months of the year are presented in Fig. 7. The seasonal fluctuations of the total suspended sediment inflow to the different sub-basins of the Baltic Sea imitate the seasonal rhythm of the suspended sediment yield in tributary catchments. Most of the suspended load is supplied to the sea during snow thawing in the drainage basin. The highest sediment inflow to Kattegat and to the Sound and the Belts

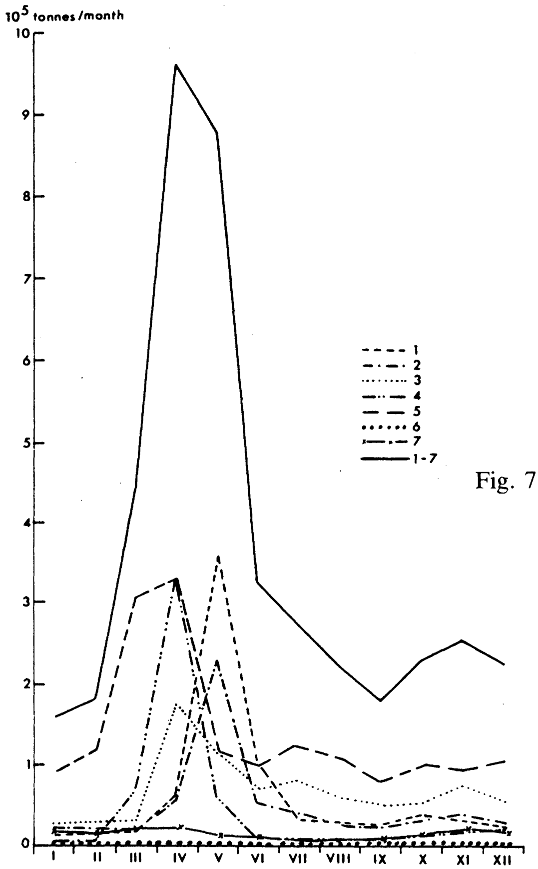

Fig. 7. Mean monthly suspended load inflow to the Baltic Sea (1-7) and to its sub-sea basins:
1) Bothnian Bay,
2) Bothnian Sea,
3) Gulf of Finland,
4) Gulf of Riga,
5) Baltic proper,
6) The Sound and the Belts,
7) Kattegat.

occurs in November and in March-April. The suspended load inflow to the sub-basins mentioned above is fairly uniform during the year. The inflow to Baltic proper is supplied from areas with different climates, and thus is also fairly uniform. The Baltic proper receives the largest amounts of suspended sediment in March and in April. The large increase of suspended sediment yield in the Carpathians during summer months causes only a relatively small increase in suspended load supply to the sea due to intensiv sedimentation processes in the Vistula and the Odra valleys. The suspended sediment inflow to the northern and eastern sub-basins of the Baltic Sea, supplied from areas with continental climate, varies widely during the year. The only uniform supply during the year is that entering the Gulf of Finland, which is a result of the large number of lakes in the Neva, the Kymijoki and the Narva catchments. The Gulf of Riga and the Gulf of Finland receive the highest values of material supply in April, the Bothnian Sea and Bothnian Bay in May. The suspended load inflow to Baltic proper, Bothnian Bay and to Gulf of Riga in the mentioned months, are of similar orders of magnitude.

The suspended load inflow to the Baltic Sea as a whole shows one main maximum in April-May, and a second much smaller maximum in November. The inflow reaches a maximum monthly value in April (958,100 t) and a minimum monthly value in January (159,500 t).

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