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Investigations on the role of bacteria in the food web of the Western Baltic

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Abstract

Scientists of the Institut für Meereskunde at the University of Kiel have for several years been involved in investigations into the role of carbon heterotrophic micro-organisms in the food web of the western Baltic. The aim of this work is to obtain information on the transformation of organic material from the primary producers to bacteria and from these to zooplankton and zoobenthos during the annual cycle. The release of phytoplankton exudates was investigated by use of tracer methods and by the uptake of this material by bacteria. It could be shown that in the Kiel Bight area approximately 15 – 30 % of the yearly primary production was transformed to bacterial biomass. In relation to the phytoplankton development the bacteria population exhibits seasonal changes. The growth of aufwuchs was studied and also the sedimentation of algal detritus. During sedimentation a rather high amount of the easily degradable material is remineralized. The remineralization processes are strongly affected by temperature. Laboratory experiments showed that 35 % of the phytoplankton material was remineralized at 20°C and 3% at 5°C per day. The bacterial aufwuchs is a valuable subtrate for grazing organisms like ciliates and rotifers. These processes continue after sedimentation of the detritus and stimulate bacterial activity in the uppermost zone of the ground. The amount of bacterial biomass production influences the development of the meiofauna. In shallow coastal waters microphytobenthos can provide most of the primary carbon production from which about 50 % were transferred to bacterial biomass.

Introduction

During recent years investigations on the role of the C-heterotrophic microflora in the food web of the western Baltic Sea (Fig. 1) have been carried out in the Institut für Meereskunde at Kiel University. Scientists and graduate students are still involved in this programme. Initially the main focus was upon the conversion of organic substances made by the primary producers into bacterial substance, and the distribution of the bacterial biomass during the course of the year. Also included were sedimentation and the further breakdown of organic compounds in the sediment. Later came studies on the importance of bacteria in the nutrition of the primary consumers in the pelagic and benthic region. The goal of these investigations is to gain an insight into that part of the energy flow involving the bacteria on through to the lower members of the food web.

The bacteria in the western Baltic and their distribution

This work was preceded by investigations which had been carried out on the microflora of the Baltic Sea as compared to other sea areas (RHEINHEIMER 1968, 1971, 1980, AHRENS 1969, MEYER-REIL 1973). Of great importance thereby is the influence

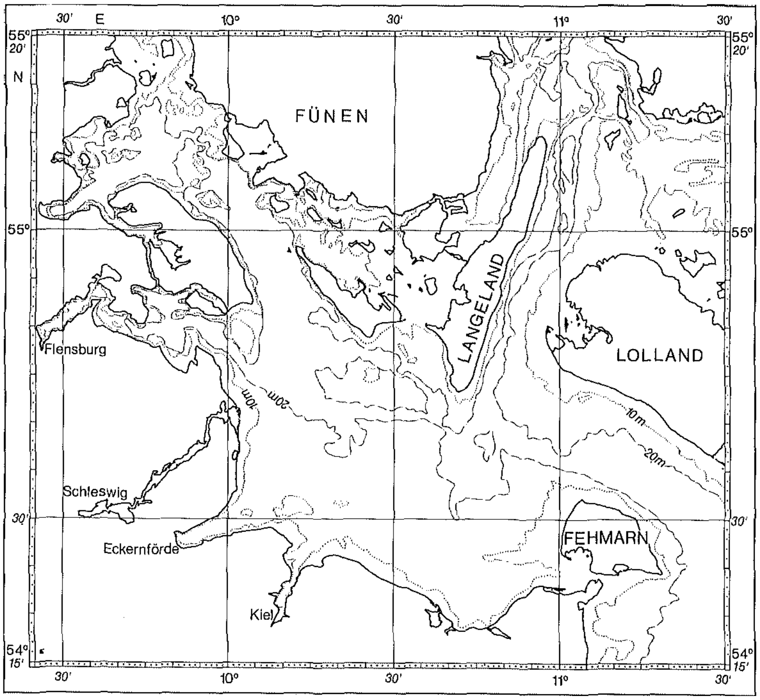

Figure 1
Map of the Kiel Bight (Western Baltic Sea)

of the salinity on the compositon of the bacteria population. The Baltic Sea represents one of the largest brackish water areas of the world, with salinities decreasing from the west to northeast. In the western areas strong nonperiodical fluctuations in the salinity occur, which vary e.g. in the Kiel Bight between 10 and 25‰. This, of course, is not without influence on the microflora. Thus, halophilic brackish water bacteria with salinity optima between 10 and 25‰ are found to dominate here. These are hardly able to develop in freshwater and proper seawater with salinities of around 35‰. In addition to these, there are varying amounts of genuine marine bacteria with salinity optima between 25 and 40‰, as well as freshwater forms with a more or less great salinity tolerance. Their proportion of the saprophyte flora even in the coastal regions remains relatively small since they cannot compete with the halophilic bacteria. A certain role is also played by the osmophilic forms, which do not require NaCl for their development, yet need a corresponding osmotic pressure. Such osmophilic bacteria enter the sea e.g. with wastewater and have relatively high nutritional demands. Therefore, in the comparatively nutrient-poor Baltic Sea, they are unable to compete in the long run and are suppressed by halophilic forms, which are able to utilize very small concentrations of nutrients. These relations are especially evident in the open water. In the nutrient-richer sediments the proportion of non-halophilic bacteria is as a rule greater. This is also the case with the aufwuchs bacteria. The saprophytic bacteria flora of the western Baltic Sea is composed mainly of members of the genera *Micrococcus*, *Achromobacter*, *Flavobacterium*, *Pseudomonas*, *Vibrio*, *Agrobacterium*, *Bacillus* and *Corynebacterium* (BÖLTER 1977).

The quantitative distribution in the Baltic Sea shows seasonally dependent fluctuations. At different stations in the relatively strongly eutrophicated Kiel Fjord and the less polluted Kiel Bight, the yearly cycles of bacteria numbers and bacterial biomass determined demonstrate a connection with the phytoplankton development; maxima occur in the spring or early summer, as well as in late summer or early autumn, whereby a time lag in the bacteria counts can be recognized. The curves of the saprophyte counts show this connection especially clearly, since these react more rapidly to changes in the nutrient concentrations than the total bacterial numbers (Fig. 2).

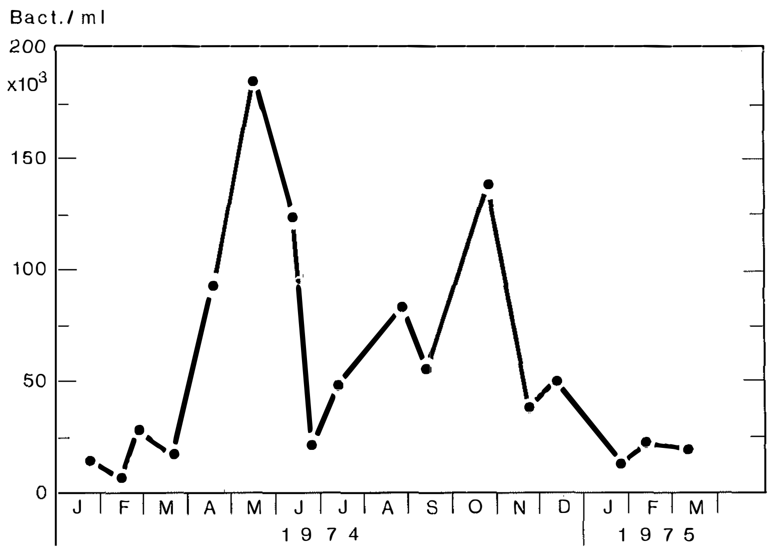

Figure 2
Annual cycle of saprophyte counts in the central Kiel Bight

Bacterial production

MEYER-REIL (1977) calculated for 1974 – 75 an average biomass production in the water of 57 g bacterial carbon per square meter and year in the Kiel Fjord and 9 g in the central Kiel Bight. This is approximately 30 and 15% of the primary production.

Part of the primary production is released by the phytoplankton in the form of exudates and serves the bacteria as easily utilizable nutrients. ITURRIAGA and HOPPE (1977) found that in the Kiel Bight 2 – 21% of the primary production is exuded. The uptake rates of the bacteria for the released substances vary between 8 and 17.5% per hour. According to WOLTER (1980) during an investigation of an annual cycle in 1978 in the inner Kiel Fjord, 0 – 15.6% of the primary production and 0 – 88.7% of the exudates were taken up within 24 hours by the bacteria (see Fig. 3). However, the fact that the various plankton algae behave differently with regard to the release of exudates must also be taken into consideration. It was thus shown, for example, that *Chaetoceros* sp., *Prorocentrum micans* and flagellates give off more exudates than other forms. The bacteria probably also differ with regard to the uptake of exudates; however, under favorable conditions their population can adapt relatively rapidly to the nutrients available. The incorporation of exudates by the bacteria begins in the spring later than the phytoplankton development – but during the further course of the year is subject to similar fluctuations as the primary production. As studies of BÖLTER (1981) show, the uptake of exudates conforms to that of dissolved carbohydrates. With the entry of the algae into the stationary phase of growth, the exudation increases noticeably and finally it comes to a lysis of the cells. At this time the bacterial aufwuchs on the algae strongly increases and a heavier grazing by ciliates and rotifers sets in.

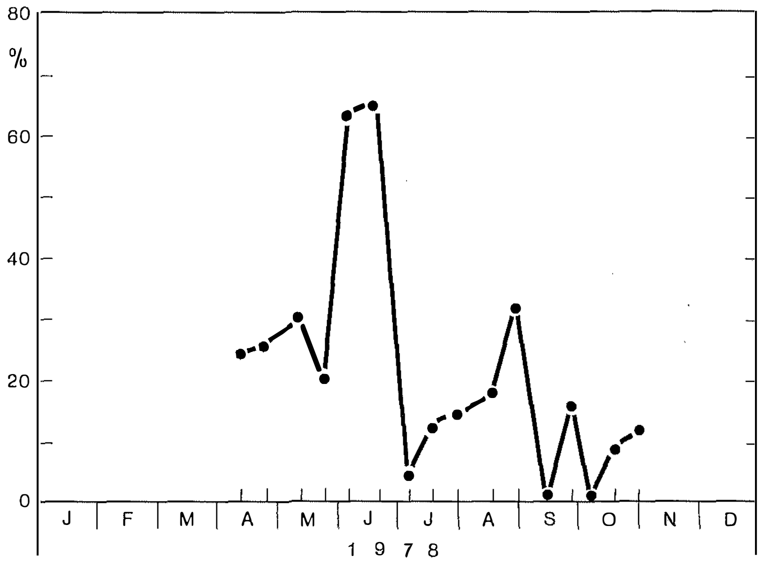

Figure 3

Annual cycle of the bacterial uptake of exudates in the Kiel Fjord (after WOLTER 1980)

Bacterial aufwuchs

There are opposing statements made in the literature with regard to the composition and amount of attached bacteria. This probably comes from the fact that on young cells aufwuchs is lacking among many algae and begins then gradually during the development of a phytoplankton population or thalli of higher benthic algae, and this does not occur by any means in the same manner among different algae. Thus algae whose cells are surrounded by a mucus envelope have a different microflora from those without a mucus envelope. As investigations by RIEPER (1976) in the Schlei Fjord (western Baltic Sea) show, a specific and correspondingly species-poor bacteria population lives e.g. in the slime layer of *Microcystis*, which serves them as a nutrient. As a rule these mucus layers consist of polysaccharides or their sulfuric acid esters. The microflora of the mucus is probably more or less independent of the actual exudates. In contrast, the genuine aufwuchs bacteria which are found directly on the algae cells feed mainly on the nutrients liberated by exudation and lysis. According to the availability of different easily degradable organic compounds such as proteins, amino acids, sugars, etc., a species-richer flora can develop, which represents in turn an especially good nutrient basis for grazers. This is especially noticeable on the older thallus parts of benthic algae. Here also the more solid parts can be utilized, which leads to a further diversification of the aufwuchs flora. Often ciliates and rotifers which feed on bacteria are also found here.

Part of the dissolved organic compounds released by exudation and lysis serves the free-living bacteria as nutrients and leads to their reproduction. Different bacteria populations are able to develop according to their composition and concentration. Noteworthy is e.g. the strong increase of *Agrobacterium* species in the late autumn after the death of a large proportion of the phytoplankton. These can then make up as much as 90 % of the saprophytes on yeast extract-pepton agar – whereas their proportion in the summer generally lies under 10 %. These bacteria are brackish water forms which typically form star shaped aggregates. They show a smaller maximum in the spring after the breakdown of the phytoplankton spring bloom (AHRENS 1969).

In the late summer and autumn polysaccharide-degrading bacteria greatly increase. A connection could be shown here with the development of the benthic algae (LEHNBERG 1972).

Sedimentation and grazing

Of great importance in the food web is also the particulate organic matter, which often occurs in large amounts after the death of the phytoplankton. Immediately after lysis of the cells a rapid growth of bacteria takes place which brings about a remineralization of the easily degradable organic substances. Investigations by ITURRIAGA (1979) showed that during the sedimentation of these substances already a considerable portion is remineralized. This process is, of course influenced to a large extent by the water temperature. Thus, a considerably higher bacterial activity in the summer could be measured than in the winter. Laboratory experiments showed that approximately 35 % of the phytoplankton material was remineralized per day at 20 °C, but only about 3 % at 5 °C.

Because of its bacteria aufwuchs, this phytoplankton detritus represents a valuable substrate for grazers, and many animals prefer it to living phytoplankters (e.g. Cyanophyceae) as food. Observations made by HORSTMANN (personal communication) showed that rotifers and ciliates feed on this substrate in the Baltic Sea.

This process continues after sedimentation. As a result of the rich addition of organic material the bacteria content in the uppermost zone is very high. The total bacteria number varies here between several hundred millions and many billions per cm^3 wet sediment. During monthly investigation of a location with sandy sediment in the central Kiel Bight at approximately 12 m depth, in the time from June to September 1974 682 – 2301 x 10^6 bacteria were counted in 1 cm^3 wet sediment. Among these 36 – 51 % were found in the interstitial water and 49 – 64 % as aufwuchs on the sand grains (WEISE and RHEINHEIMER 1979). Still greater is the bacteria content of muddy sediments, which can be higher by 1 to 3 factors of ten. Thus, in the uppermost zones of the sea floor a very great reservoir of organic matter may be found in the form of bacteria, which can be utilized by the meio- and macrofauna and influences to a great extent their quantity and composition.

In very shallow coastal waters with good illumination on the sea bottom the greatest portion of the organic matter can be produced by the macro- and microbenthos. Investigations by MEYER-REIL et al. (1980) in the summer of 1977 in sandy sediments from the shore area of the Kiel Bight gave a primary production by the microphytobenthos (macrophytobenthos was not present in the study area) of 3.7 mg C per m^2 and hour. From this 1.8 mg C $m^{-2}h^{-1}$ were transformed into bacterial biomass, which corresponds to a proportion of about 50 %. The bacterial biomass of 43 mg C produced daily per m^2 is of about the same order of magnitude as the carbon of the meiofauna present here, which was determined at 35 mg C per m^2. From this it can be seen that the bacterial biomass production in these sediments is high enough to supply sufficient carbon compounds for a daily turnover of the meiofauna carbon.

Investigations of MEYER-REIL and FAUBEL (1980) showed inverse relationships of meiofauna and bacteria carbon. That means high numbers and biomass of meiofauna are correlated with low numbers and biomass of bacteria. Tracer experiments using tritiated glucose revealed different incorporation of organic material by different groups of meiofauna, as detritovore oligochaetes showed the highest incorporation rate, followed by turbellarians and nematodes. Bacteria and their extracellular products seem to be the major part of the organic material taken up by these animals.

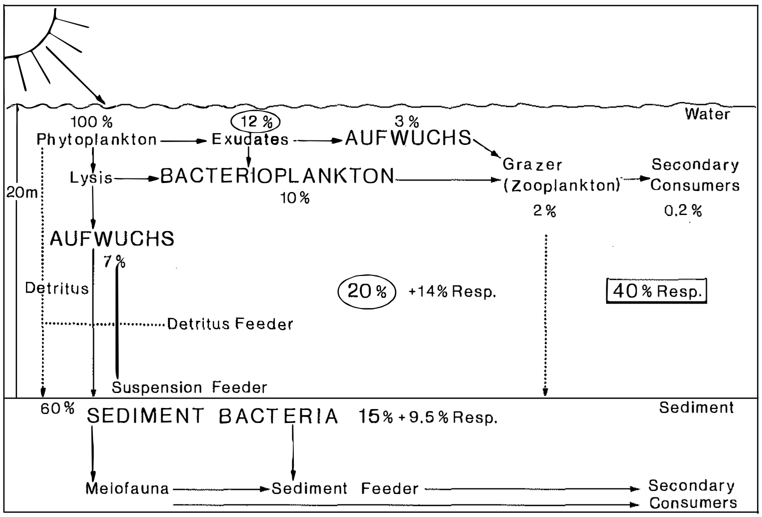

Figure 4

Abstraction of the carbon flux in the food web of the Kiel Bight

Conclusions

Fig. 4 gives a rough sketch of the carbon flux in the food web of the Kiel Bight with special reference to bacteria as can be calculated from the results of our investigations. Without taking into consideration those phytoplankters directly eaten by animals, about 20 % of the produced carbon in the water are transferred to bacterial carbon and up to 60 % sink to the ground of the Kiel Bight which has a mean depth of 20 m. Our future task will be to obtain more detailed data on this bacterial transfer of carbon to the primary consumers.

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