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PRIMARY PRODUCTION OF DIFFERENT SPECIES OF ALGAE MEASURED *IN SITU* IN TALLINN AND MUUGA BAYS (1992 - 1994).

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Abstract.

During 1992-1994, a number of *in situ* primary production measurements were carried out with different macroalgal species dominating in algal communities in the coastal waters of Tallinn and Muuga bays.

Photosynthetic and respiratory activities of annual *Enteromorpha intestinalis* and *Cladophora glomerata* (CHLOROPHYTA), *Ceramium tenuicorne* (RHODOPHYTA), *Pilayella littoralis* and perennial *Fucus vesiculosus* (PHAEOPHYTA) were determined by measuring the changes of dissolved oxygen concentration in "light and dark" bottles using the Winkler titration method or an oxygen meter.

The highest production rates were measured for the green algae *E. intestinalis* and *Cl. glomerata*, the lowest rates for the perennial brown algae *F. vesiculosus*.

Comparing the results obtained at experimental stations with different degree of human impact, the maximal net photosynthetic rates for *E. intestinalis* and *Cl. glomerata* were measured at stations with the highest amount of nutrients in the water.

Key Words: Primary production, net photosynthesis, dark respiration, *Enteromorpha intestinalis, Cladophora glomerata, Pilayella littoralis, Ceramium tenuicorne, Fucus vesiculosus*.

Introduction.

This paper summarises the results obtained by measuring the primary production of macroalgae *in situ* during the investigation of Tallinn and Muuga bays in 1992-1994.

During the course of three years, a number of measurements of net photosynthetic and dark respiration rates of different macroalgal species dominating in the algal communities in the Estonian coastal waters of the Gulf of Finland were made.

In 1992, the preliminary study with the intention to prepare experiments for measuring seasonal changes in the primary production of macroalgae was carried out. The oxygen method that has been used for determining the net photosynthetic and dark respiration rates for *Furcellaria lumbricalis* (Paalme, 1994) was adapted and checked on three different macroalgal species: *Pilayella littoralis*, *Cladophora glomerata* and *Fucus vesiculosus*.

In 1993, the main interest was focused on seasonal changes in the primary production of five most abundant algal species in the area: the annual *Enteromorpha intestinalis* and *Cladophora glomerata* (CHLOROPHYTA), *Ceramium tenuicorne* (RHODOPHYTA), *Pilayella littoralis* and the perennial *Fucus vesiculosus* (PHAEOPHYTA). During an 8-month investigation period, weekly measurements of net photosynthetic and dark respiration rates for the above-mentioned species of algae were carried out.

In 1994, an attempt was made to compare during three months (May, June and July) the net photosynthetic rates of the two fast-growing green algae *E. intestinalis* and *Cl. glomerata* at experimental stations with different load of human impact.

Material and methods.

Study area

In 1992, the primary production measurements were carried out at two different experimental sites near the tip of the Viimsi Peninsula, *i.e.* in Tallinn or Muuga Bay, respectively (Fig.1).

In 1993, the production estimates were carried out in Muuga Bay near the tip of the Viimsi Peninsula at one experimental station (in 1994 station 3) where the algal vegetation was dominated by *F. vesiculosus*. In spring and early summer *E. intestinalis* and *P. littoralis* and in July-August *Cl. glomerata* were the most abundant annual algal species growing there.

In 1994, basing on recent investigations of the ecological situation in the coastal waters of Tallinn Bay, as a result of which the geographical distribution of macrophytobenthos according to saprobic level was established (Kukk *et al.* 1994), location of two new experimental stations in this area was chosen. Station 1 was situated near the Port of Tallinn and station 2 in the area between the mole of Merivälja and the Miiduranna harbour, in the vicinity of the outflow of the domestic sewage from the local settlement into the sea. Both stations were prevailed by algal communities, in which *E. intestinalis* and *Cl. glomerata*, the species of green algae favouring eutrophic areas, dominated. At station 3, situated in a relatively undisturbed area in Muuga Bay at the tip of the Viimsi Peninsula, *F. vesiculosus* dominated in algal communities.

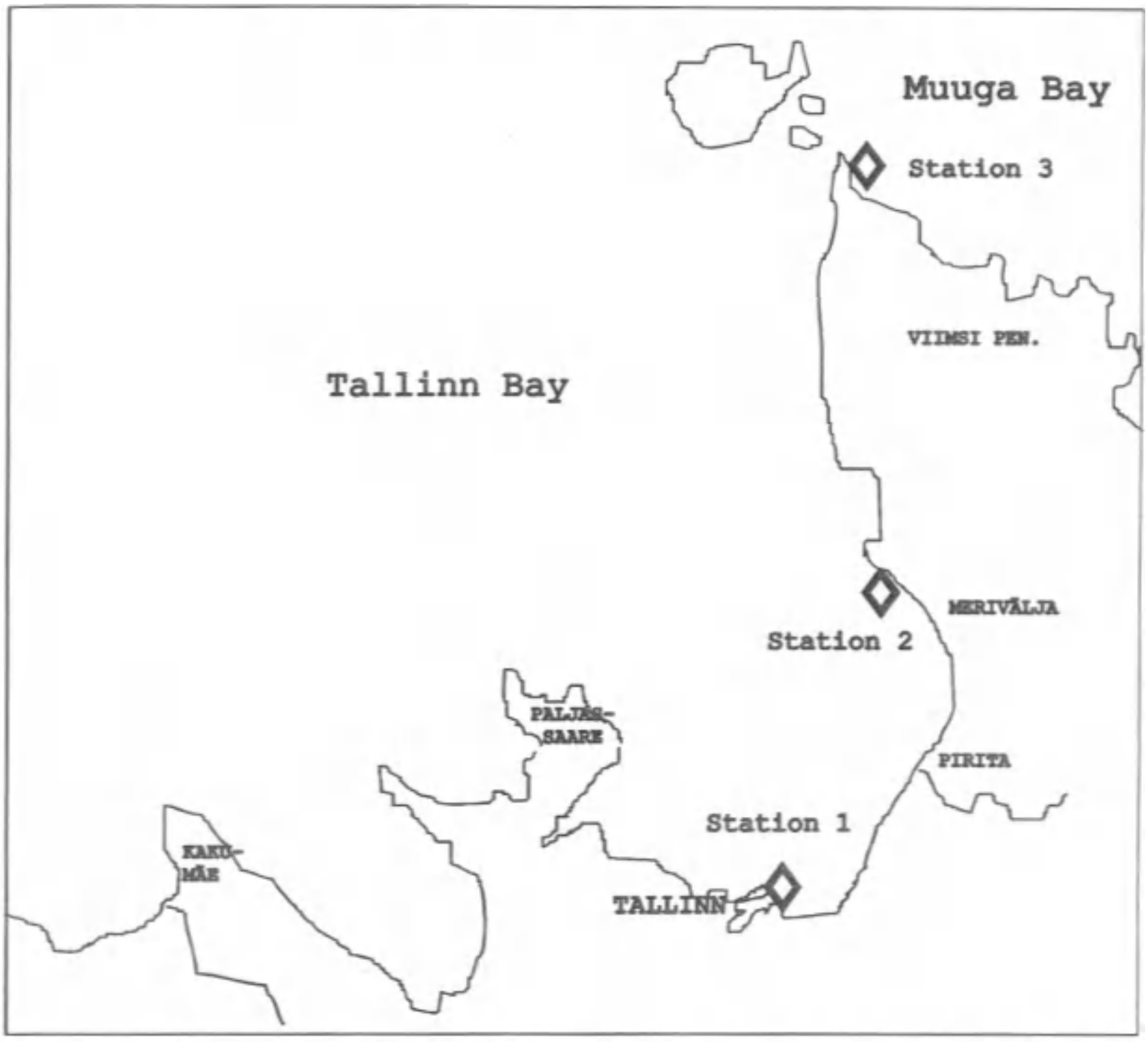

Figure 1. Location of experimental stations.

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Photosynthetic and respiratory activities of algae were determined by measuring changes in dissolved oxygen concentration in "light and dark" bottles employing Winkler titration method in 1992-1993 or using later, in 1994, the oxygen meter (OXI 92, WTW) which also measured the water temperature.

The algal material was collected from natural populations growing in the vicinity of the experimental stations. Depending on species, 0.5 - 3 g wet algal material (corresponding to 0.05 - 0.5 g dry weight) was placed into incubation bottles (300 ml light and 250 ml dark bottles, respectively). The bottles were incubated (dark and light ones separately) horizontally on special trays at a depth of 0.5 m for a period ranging from 1.0 to 1.5 hours.

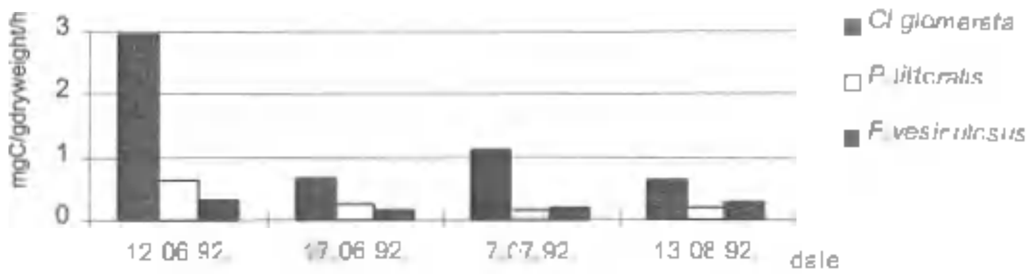

Fig. 2. Net photosynthetic rates of different macroalgal species

Changes in oxygen were converted to mgC•g dry wt^{-1}•h^{-1} by standard methods (Strickland 1960) assuming a photosynthetic quotient of 1.2 and respiratory quotient of 1.0 for expression of rates of net photosynthesis and dark respiration. Each of the results is a mean of at least three replicates.

Dry weight of the algal material was determined after drying at 60°C for 24 hours.

Environmental conditions in the field

The environmental factors measured at the time of the experiment were solar irradiation (kW•m^{-2}) above the water surface and the water temperature (°C). For the further laboratory analysis of the content of nutrients, water samples (250 ml each) were taken.

Results and discussion.

In July-August 1992, four incubation series to measure net photosynthetic (NP) and dark respiration (DR) rates of *Pilayella littoralis, Fucus vesiculosus* and *Cladophora glomerata* were carried out.

During the investigation period, the water temperature varied between 11.7 °C (June) and 18.5 °C (August).

Comparing the results obtained (Fig 2), the highest NP rates - up to 3.0 mgC•g dry wt^{-1}•h^{-1} - were measured for *Cl. glomerata*. Remarkably lower NP rates (below 1 mgC•g dry wt^{-1}•h^{-1}) were obtained for *P. littoralis* and *F. vesiculosus*.

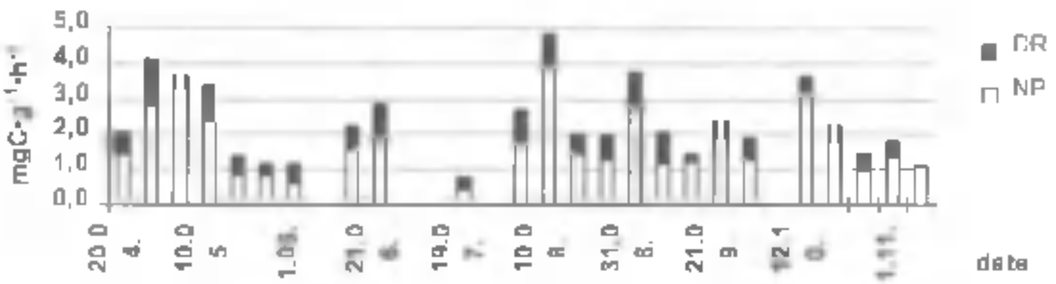

Fig.3. Net photosynthetic and dark respiration rates of *Enteromorpha intestinalis*

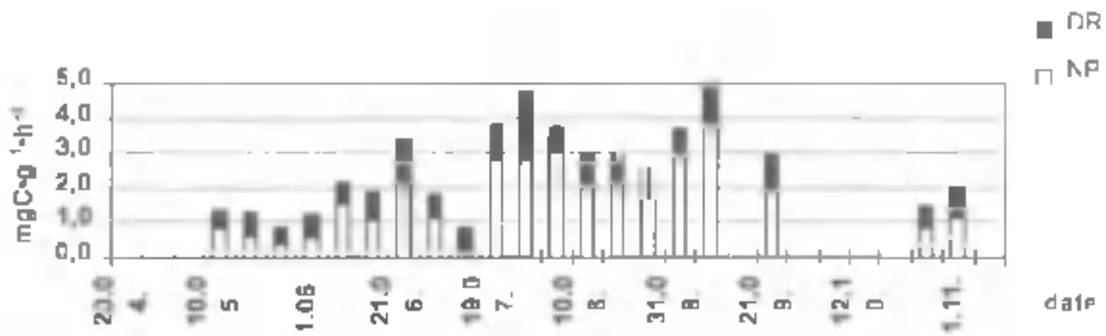

Fig.4. Net photosynthetic and dark respiration rates of *Cladophora glomerata*

In 1993, the experimental station (Station 3 on Fig. 1) was visited altogether 29 times during the investigation period lasting from 20 April until 9 November, and net photosynthetic and dark respiration rates were measured for five most abundant algal species in the area - *Enteromorpha intestinalis, Cladophora glomerata, Pilayella littoralis, Ceramium tenuicorne* and *Fucus vesiculosus*.

The highest NP rates were measured for short-lived annual green algae *E. intestinalis* and *Cl. glomerata*, supporting our earlier results and those of other investigators (Jannson 1974, King and Schramm 1976, Wallentinus 1976,1978). There were little differences in the magnitude of

NP rates between *E. intestinalis* and *Cl. glomerata* (0.4-3.9 and 0.2-3.8 mgC•g dry wt^{-1}•h^{-1}, respectively; Figs. 3 and 4).

Compared with the other algal species in our *in situ* experiments, the above-mentioned green algae had also higher DR rates. In *Cl. glomerata*, DR rates were somewhat higher than in *E. intestinalis*. DR was roughly estimated to be 32 per cent of gross photosynthesis for *Cl. glomerata* and 26 per cent of gross photosynthesis for *E. intestinalis*.

According to our investigation results, *C. tenuicorne* was the third algal species with relatively high NP rates (0.5 - 2.6 mgC•g dry wt^{-1}•h^{-1}), though the maximal NP was a bit lower (Fig. 5).

DR formed 25 per cent of gross photosynthesis.

Significantly lower NP rates (below 0.6 mgC•g dry wt^{-1}•h^{-1}) were obtained for the perennial brown algae *F. vesiculosus* (Fig. 6). In the event of *F. vesiculosus*, the absolute DR rates and the percentage of DR in gross photosynthesis (20 %) were also the lowest.

P. littoralis exhibited unexpectedly low NP rates (below 0.8 mgC•g dry wt^{-1}•h^{-1}) and relatively high DR rates (40 per cent of gross photosynthesis on the average) in 1993, during the study period 27 April - 10 August (Fig. 7).

The NP values we had obtained at the same station in 1994 were considerably higher - up to 1.7 mgC•g dry wt^{-1}•h^{-1} (DR rate 30 per cent of gross photosynthesis), while at station 1 and station 2 (Fig.1) the maximal NP rates measured were accordingly 2.4 and 1.8 mgC•g dry wt^{-1}•h^{-1} (obtained at the end of June). For comparison, I. Wallentinus (1978) reported that the

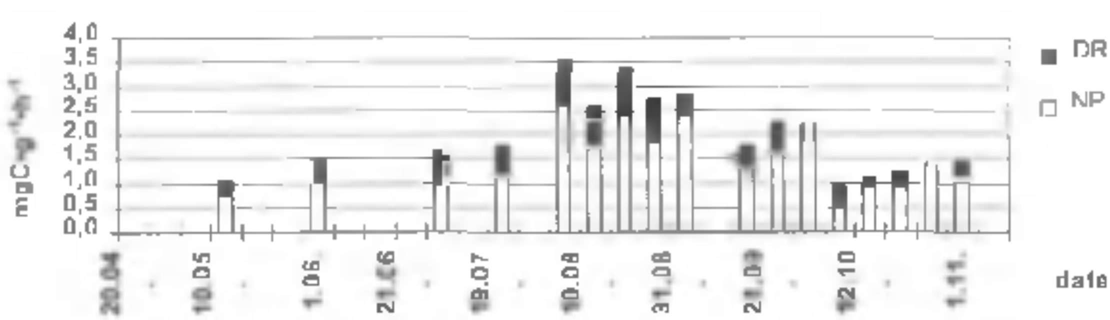

Fig. 5. Net photosynthetic and dark respiration rates of *Ceramium tenuicorne*

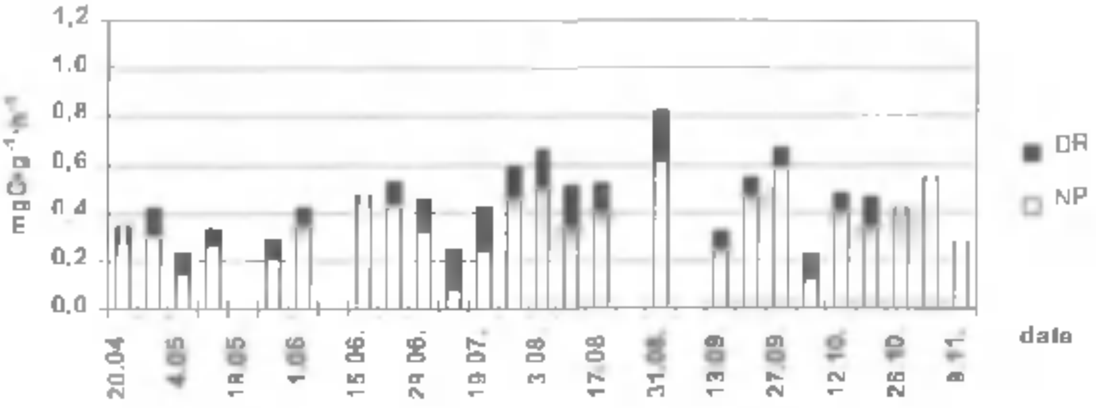

Fig.6. Net photosynthetic and dark respiration rates of *Fucus vesiculosus*

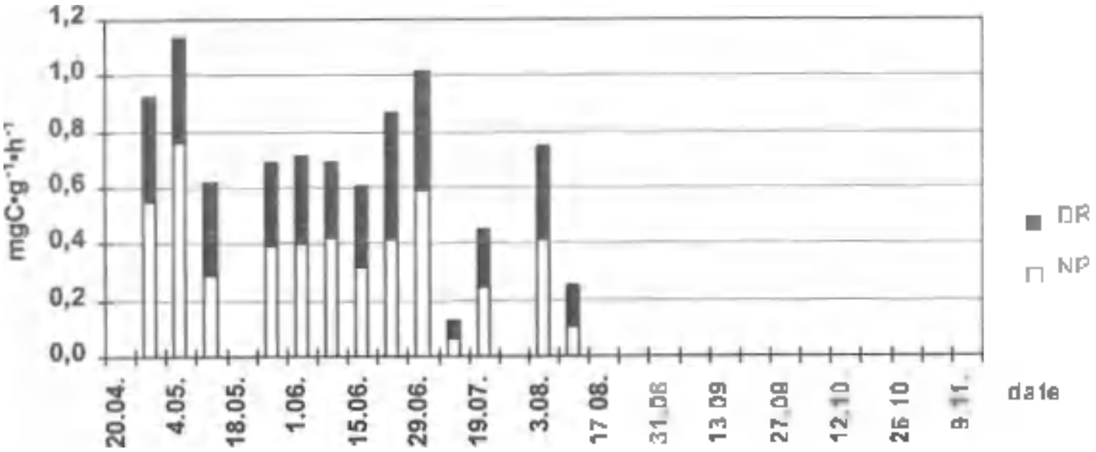

Fig. 7. Net photosynthetic and dark respiration rates of *Pilayella littoralis*

production rate of *P. littoralis* in in situ measurements with ^{14}C ranged between 0.6 and 6.1 mgC•g dry wt^{-1}•h^{-1}.

Higher photosynthetic and respiratory capacity of *E. intestinalis* and *Cl. glomerata* in comparison with the perennial algal species used in our study, could be related first of all with the differences in their thallus morphology (Littler 1980, Leskinen 1992). Compared with *F. vesiculosus* and *C. tenuicorne* nearly, the whole biomass of the thin sheet-like thallus of *E. intestinalis* and finely-branched thallus of *Cl. glomerata* is photosynthetic and much of the structural material is metabolic (resulting in higher absolute rates of respiration).

In all likelihood, the variations in NP rates, observed during the investigation period within the same species, were determined mostly by seasonal changes in environmental conditions (*i.e.* light, water temperature, nutrients).

It is obvious that an important factor controlling the photosynthetic activity of algae during the whole vegetation period is the amount and quality of available light. Differences in NP rates measured for algae in our experiments in the summer months and in late autumn were most probably caused by seasonal changes in light conditions (*i.e.* by decreased solar radiation and decreasing part of photosynthetically active radiation).

Here attention should be paid to the fact that sudden decreases in NP rates could also be caused by temporary unfavourable light conditions (low water transparency or overcast sky, or both during incubation time). For example, the low NP rates obtained for all species at the beginning of July could be explained definitely by the very low water transparency.

On the other hand, in the middle of June when solar radiation was at its highest and clear sky prevailed, the photosynthetic activity of *E. intestinalis* and *Cl. glomerata* was relatively low. As all incubations for measurements of NP rates during the investigation period were made at shallow depths (0.5 m) at noon, the possibility cannot be excluded that the above-mentioned depression of photosynthetic activity was caused by the photo-inhibition effect (Powles 1984). A similar phenomenon has been described by several authors for different algae, among others by Wood (1968) and Leskinen (1992) for *Cl. glomerata*.

The water temperature measured at our experimental station varied during the investigation period between 0.7 and 18.5 °C. The temperature, contrary to the light, seems to play less important role in the variation of NP rates obtained for different algae used in our experiments during the investigation period as Baltic algae are generally well adapted to low water temperature (Russell 1985).

On the other hand, in spring when the light conditions were relatively good but the water temperatures were low, differences in the production rates measured for *Cl. glomerata* and *E. intestinalis* could be due to different optimal temperature required.

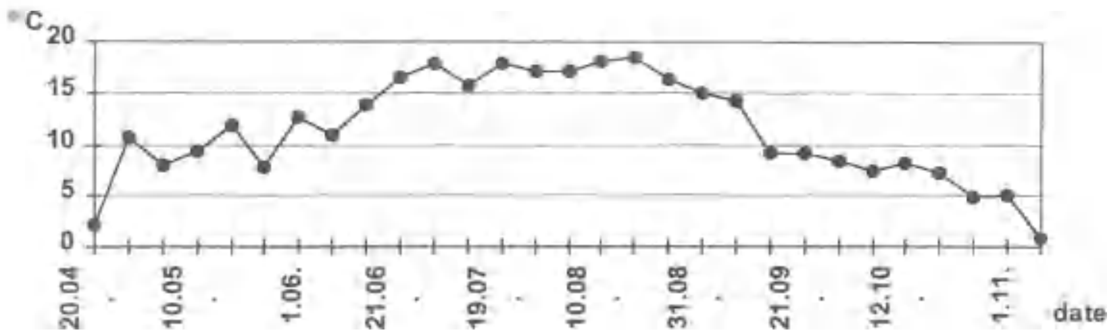

Fig. 8. Water temperature

E. intestinalis was capable of fast growth already in early spring under relatively low-temperature conditions. The highest vernal NP rates for *E. intestinalis* obtained at the temperature of water 8 °C was close to the maximal NP rate measured at 18 °C, while considerable NP rates were observed with water temperatures below 5 °C.

Cl. glomerata seems to prefer somewhat higher temperatures than *E. intestinalis*.

In literature, there are several data available on the direct effects of temperature on the production rates of *Cl. glomerata*. According to Whitton (1967), the maximum growth takes place at temperatures between 15 and 25 °C, the lowermost limit being 6 °C. Jannson (1974) has observed a visible growth of *Cl. glomerata* at the temperature of water not exceeding 4 °C.

As seen from Figure 8, the highest temperatures during our experimental period occurred in July - August when high NP values for *Cl. glomerata* (accompanied with luxuriant growth of this algae in the study area) were obtained, *i.e.* the water temperature was higher than 14 °C. Low NP was observable at water temperature 5 °C.

Besides the above-mentioned environmental factors, temporary variation in NP rates of annual *E. intestinalis* and *Cl. glomerata* could be due to the fact that several generations were growing during the vegetation period (Jannson 1974 , Snoeijs 1992). Thus, the decrease in NP rates of *E. intestinalis* in the second half of May - at the beginning of June compared with high NP rates obtained earlier could be explained by the ageing of algae.

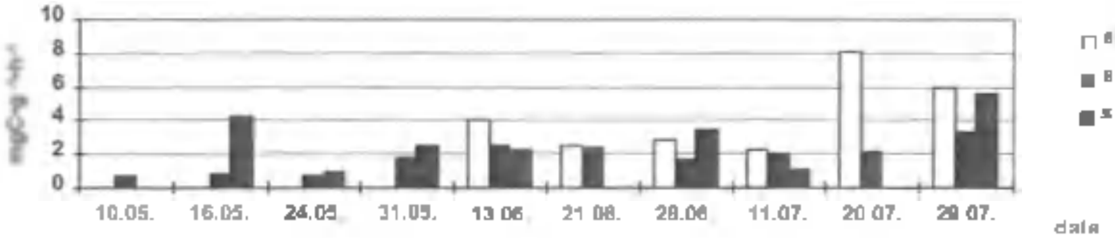

Fig. 9. Net photosynthetic rates of *Cladophora glomerata*

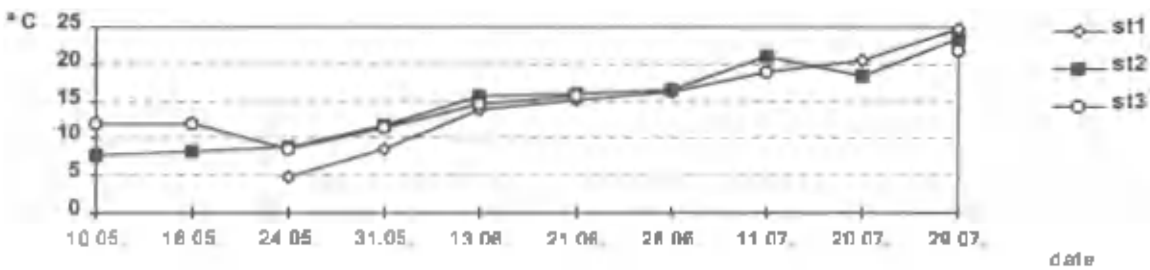

Fig.10. Water temperature at different stations

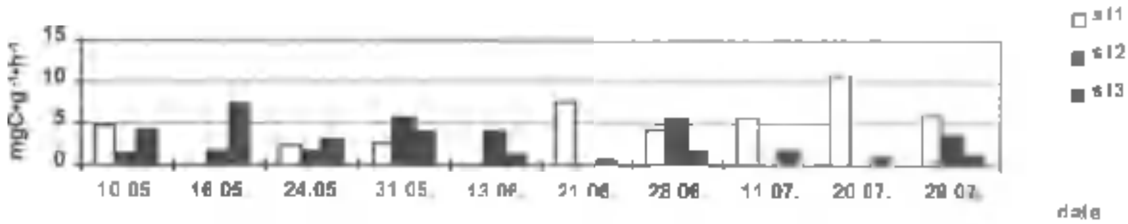

Fig. 11. Net photosynthetic rates of *Enteromorpha intestinalis*

According to the above-presented results, the algal species used in *in situ* experiments in 1992 and 1993 can be divided roughly at least into two groups. The first group will include the species with high net photosynthetic (production) rates, such as *E. intestinalis*, *Cl. glomerata* and *C. tenuicorne*; the second group will comprise the species with low net photosynthetic (production) rates - *P. littoralis* and *F. vesiculosus*.

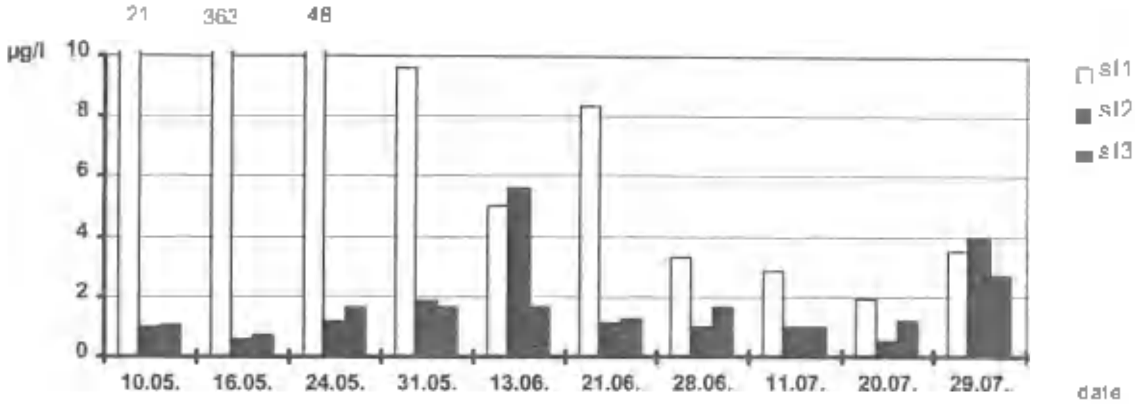

Fig. 12. NO_3^- content of the water at different stations

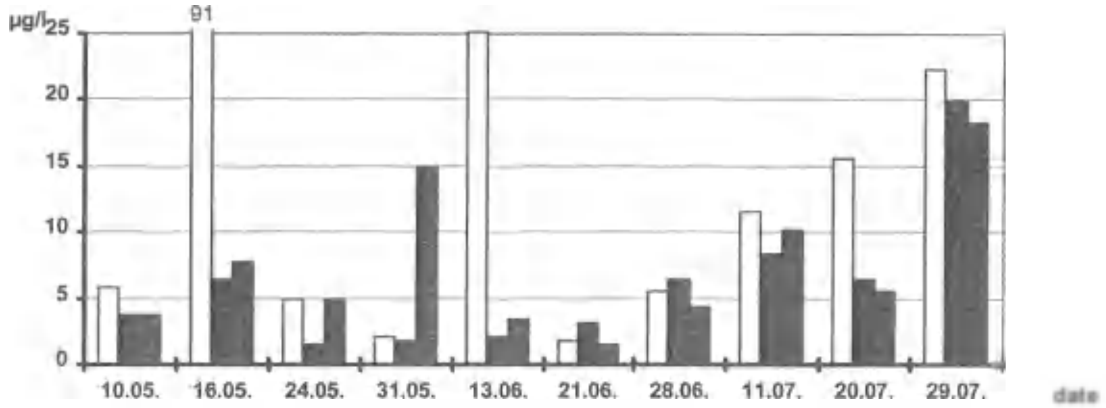

Fig. 13. PO_4^{3-} content of the water at different stations

In 1994, the primary production estimates were concentrated on the primary production of *E. intestinalis* and *Cl. glomerata* , the two fast-growing green algae very common in algal communities of shallow coastal areas. During three months, from May to July, changes in their NP rates were measured altogether ten times and an attempt was made to compare the corresponding values obtained at the same time at different experimental stations (Fig. 1).
Our experimental data in Figures 9 and 11 show differences in NP rates of *E. intestinalis* and *Cl. glomerata* from different stations. At the same time, a certain temporal shift of the occurrence of NP maxima measured for the above-mentioned algae between stations is evident.

Unfortunately, the data available are too scanty and do not allow any definite conclusion to be drawn to explain these differences. In May, the water temperature seems to control the NP rates of algae used in our experiments (Figure 10 shows remarkable differences in water temperature between stations). In June, after levelling of water temperature, other environmental as well as physiological (incl. the age of the algae) factors must be taken into consideration to explain the differences in NP rates between the stations.

It cannot be excluded that besides other factors the differences in the nutrient content in the water of experimental stations are, to a certain extent, responsible for these discrepancies.

The highest rates of net photosynthesis were obtained for both *E. intestinalis* and *Cl.glomerata* at Station 1 where during the investigation period relatively higher concentrations of NO_3^- and PO_4^{3-} were measured (Figs. 12 and 13).

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