Ödsmål, Kville sn, Bohuslän

Hällristning
Fiskare från
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Rock carving
Bronze age
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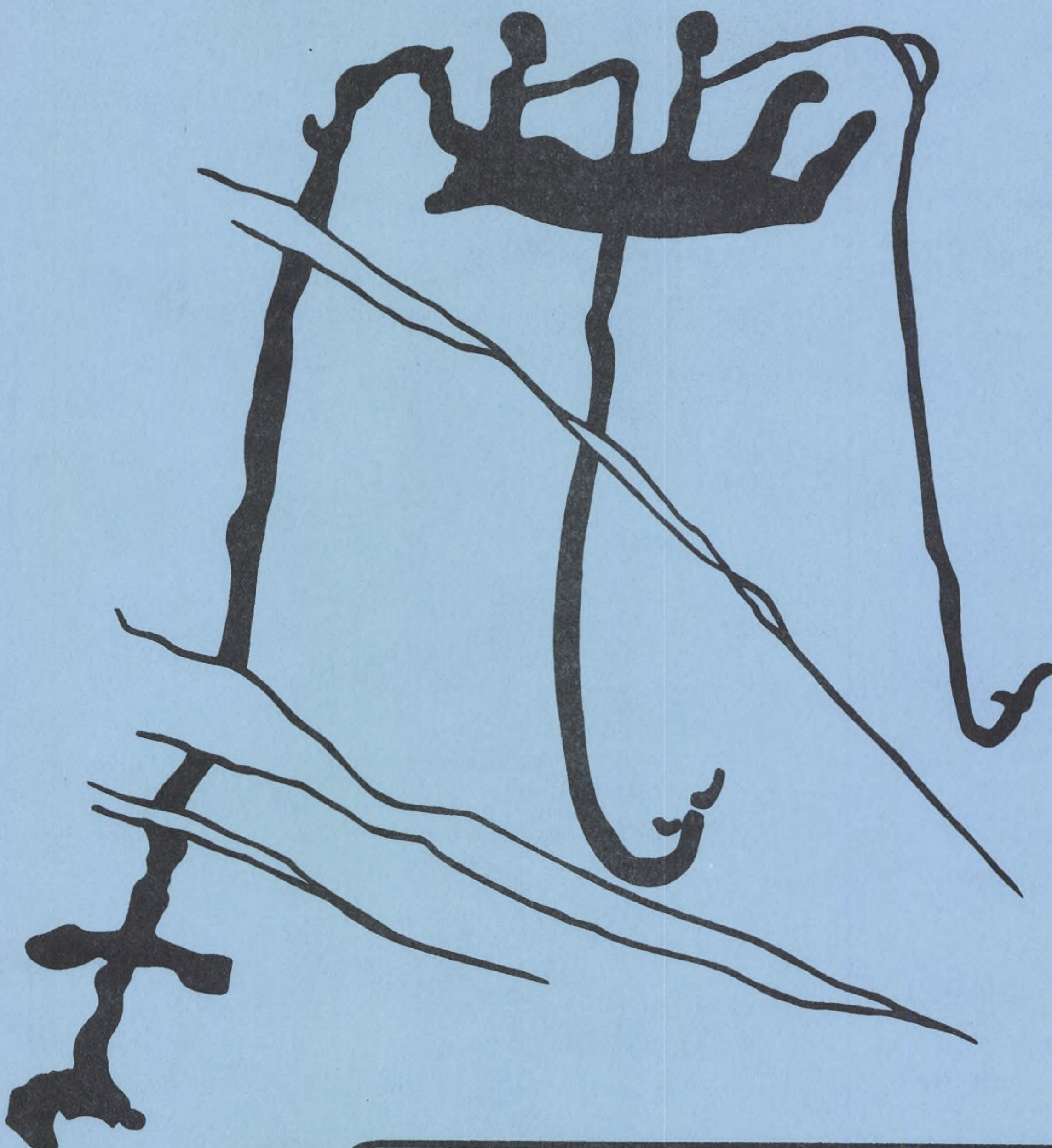

MEDDELANDE från
HAVSFISKELABORATORIET · LYSEKIL
nr 235

Hydrografiska avdelningen, Göteborg

Primary Production in Heated Water

by

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April 1978

PRIMARY PRODUCTION IN HEATED WATER

A presentation of results from measurements at Simpevarp nuclear power plant in the period May 1975 - September 1976.

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SWEDISH SUMMARY

Mätningar har utförts under perioden maj 1975 till september 1976, med en eftersträvad frekvens av en mätomgång varannan vecka, för bestämning av den primära växtplanktonproduktionen, dels i varmvattnet utanför kylvattenutsläppet vid kärnkraftverket i Simpevarp, dels, för jämförelse, på en plats nära intaget av kylvatten.

Den metod som använts är mätning av kolupptaget i växtplanktoncellerna genom märkning av vattnet med radioaktivt kol - 14. Inkubering sker i glasflaskor om 100 ml vilka återplaceras där provvattnet hämtades (in situ inkubering) under $\frac{1}{2}$ soldygn. Växtplanktoncellerna filtreras därefter av och analyseras med avseende på radioaktivitet i Geiger - Müller räknare.

Resultatet är en totalt sett högre produktion i varmvattenregimen jämfört med produktionen vid de naturliga förhållandena i vattnet nära intaget. Under mätperioden ligger varmvattensproduktionen c:a 40% över produktionen i det ej uppvärmda vattnet. Det finns samtidigt en tendens till förstärkning av extremerna så att den allmänt höga sommarproduktionen är ännu mycket högre i varmvattnet, medan under vintern,när produktionen är låg, det uppvärmda vattnet har en lägre produktion än det naturliga. Den högre primärproduktionen i varmvattnet får inte ses som en direkt materiell vinst utan mera som en omfördelning av material. Primärproduktionen i området begränsas redan tidigare av tillgången på närsalter sommartid och en totalt sett högre produktion är då svår att erhålla utan tillförsel av näring. Ett utnyttjande av värmeenergin för en snabbare tillväxt av organismer skulle därför fodra tillskott av näringsämnen. Den högre primärproduktionen i varmvattnet får anses orsakad av dels en omvandling till närsalter av redan producerat organiskt material, dels ett något bättre utnyttjande av befintliga näringsämnen genom en minskad avätning (eng. lower grazing) från högre organismer. En schematisk framställning av produktionsförhållandena ges i fig 31.

INTRODUCTION

In the spring of 1975 it was decided that primary production measurements should be carried out at two locations near the nuclear power plant at Simpevarp, one in the hot water region at the outlet of cooling water, and the other, for comparison, in the not heated water near the intake of cooling water. The decision arouse from a concern for changes of the environment in the region of heated water outside the outlet from the power plant. Investigations were then already going on on the effects of hot water on higher trophic levels in the ecosystem, mainly fish. It was thought to be important to record any disturbance on the primary stage of the marine food chain caused by the heated water, and measurement of the primary phytoplankton production using the carbon-14 technique was meant to give this information. The hot water is occupying a very shallow coastal area where the production of benthic algae probably is of the same order of magnitude as that of the plankton, and subsequently the primary benthic production shold also have been recorded. However, an easily accomplished method for such measurements is as yet not available. The interest in the primary production forming the food base of the water should also be viewed at the background of advanced plans for utilization of the heated water for fish breeding. Experimental raising of fish in hot water ponds and net cages was already going on. The study was initiated and sponsored by the National Swedish Environment Protection Board. The author, from the Fishery Board of Sweden, Hydrographic Department in Gothenburg, was commissioned to start the measurements, to supervise the work and to evaluate the result. Measurements of nutrients and some physical parameters were carried out by other bodies engaged in the water court case regarding the power plant. (Unfortunately there was not a good coordination with these measurements, and some of the methods used can be questioned).Sampling of plankton for species determination and quantification was later taken up on advice from the author.

The investigation extended over the period May 17, 1975 to September 7, 1976 covering a total of 24 measurement occasions, which resulted in the analysis of 400 radioactive filters at Carbon 14 Centralen in Denmark, from where the above mentioned C-14 data were returned.

The problems related to thermal pollution of the marine environment became obvious first in the U.S. in connection with the extensive program of nuclear power plant constructions. Today there exists a comprehensive literature on the subject and an attempt to view it has been made resulting in the literature list in the last section of this report.

IMPACT OF HEATED WATER ON THE MARINE ENVIRONMENT

Thermal pollution is a concept created in later years when part of the heat from an increasing number of power plants had to be cooled off by water and let out inte the sea, causing a new type of environmental hazard in the area where it was let out.

Some effects were obvious immediately, such as the phenomenon that the area of warmer water attracts many species of fish. It could be observed that larger numbers of fish were passively dwelling in the streaming, warmer water at the outlet from power plants. This in turn led to a depletion of the available food, but still many species were shown to prefer the warmer water and, hence, starvation to the colder water where food was abundant. It is documented that the girth to length ratio for such fish is less in the heated water than in comparable areas without heated water.

Other effects were seen somewhat later, for example, that the parasites of fish dwelling in hot water areas developed much more rapidly than under natural conditions. It is often reported that eye parasites of fish in warm water areas make the fish blind so that it can no longer catch food.

Eventual long term effects have not yet been seen, since the giant floods of heated cooling water from nuclear power plants along the coasts has a history of only about twenty years.

To return to the more immediate and short term effects, the fate of plankton and other small life forms in the water will be given the main attention here since they can affect the primary production. Large bodies are separated from the intake water by a rough grid and the large size fish will notice the increasing stream and can escape and swim off the area. Smaller organisms like small fish, larvae, algae etc. are sucked into the inlet and to a large extent smashed and destroyed when passing the pumps. This in turn leads to a release of organic compounds of varying complexity, set free when cell walls of the organisms are broken. Microbial degration of cellular remains will rapidly bring nutrients to the warm water by a fastened remineralization process. Destruction and death of the zooplankton during the passage of the cooling system will decrease the grazing pressure on the phytoplankton in the warm water after the passage. Inactivation of the phytoplankton by mechanicaland thermal shock should be expected during the passage of cooling water. Strong turbulence will put a mechanical strain upon the organisms and the sudden temperature increase will probably at least temporarily suppress enzyme activity.

All these factors will affect the primary production of the heated water in different ways, and it is below discussed in some more detail in an attempt to postulate the main general features of the expected production changes in the warm water regime.

The destruction of young fish and larvae can reach a considerable amount. From the start of the normal-sized first power aggregate at Simpevarp, pumping a water volume of appriximately 25 m^3/s, the figure 60 kg/24 hours was given totaling appr. 44 tons in a year.

Total Baltic Sea water content of zooplankton (caught by hauls with nets of mesh size 0.15 mm) is on an average 10 g (wet weight) under one square meter (Ackefors and Hernroth, 1975). Counting over 50 m depth gives 0.2 g/m^3 as a rough value for the concentration of Baltic zooplankton biomass. Passing this through the pumps and assuming that 50 % is destroyed (values of zooplankton mortality ranging from 25 % to 100 % on passage of power plant cooling systems is reported) gives a loss of 160 tons of zooplankton each year.

In the summertime the outlet temperature sometimes exceeds 35 °C. On such occasions plankton mortality due to temperature rapidly approaches 100 % (Storr, 1974).

The destruction of zooplankton will add nutrients to the water by direct release and by subsequent microbial decomposition. Assuming that ultimately all dead organic material is mineralized before leaving the hot water area of Hannefjärden, and using the figure 5 % for the carbon content of the above estimated 160 tons wet weight and dividing it by the $1.6 \times 10^9 m^3$ (= 1.6 km^3) of water that anually passes thorugh the cooling system, the figure 5 mg C/m^3 is obtained. This means that after passage another equivalent of 5 mg C/m^3 is available to the (surviving) phytoplankton for production. Thus the nutrients available to primary producers contributed by destruction of organic material is not very important and could supply only about one tenth of a typical daily production value of 50 mg C/m^3 of the photic zone in this water area.

The effects of reduced grazing in the hot water is probably important. It is reported that the surviving zooplankton is to a large extent injured after passage through the cooling system. It can therefore be assumed that the grazing pressure on the phytoplankters in the hot water is reduced to nothing. Subsequently the primary production, with this controlling factor absent, should be allowed to increase to the limits set by availably light and nutrients in the warm water regime. In-mixing of new zooplankters could take place in the hot water basin off the outlet, but the reproduction rate of zooplankton is comparatively slow and this grazing should not be important.

Fragile phytoplankton structures such as Skeletonema-type diatoms should be expected to get damaged to some extent from the turbulent stresses in the pumps and cooling coils. The sudden rise in temperature is reported to temporarily reduce growth (Gurtz and Weiss, 1974) of phytoplankton, probably by suppression of enzyme functions. The primary production should for this reason be expected to have a delay before reaching maximum values in the outlet water. However, in-mixing of new phytoplankters into the hot outlet water and the comparatively long residence time in the hot water basin should counteract this decrease. But for certain cold-adepted species occurring in the autumn and winter the raise of appr. 10 °C in temperature should reduce growth permanently.

Thus, we might expect a primary production in the heated water that is increased with 10 % or more, as compared to the not heated water during spring, summer and autumn. During the winter we might expect a somewhat lower production due to the presence of cold-adepted species. However, since the hot water keeps the ice-cover away, more light is available to the nutrient-rich winter water and a higher production could be maintained. For benthic algae such increased winter production is observed. However, again such increased benthic plant production over longer times is prevented by the unavoidable closing down of the power plants, when the temperature suddenly approaches the normal and strikes out the remaining warm-adepted species.

On the whole no net gain can be achieved of the primary production in the heated water as compared to the not heated water. The primary production in both the heated and not heated waters is limited by light, growth factors and available nutrients. The somewhat higher primary production in the heated water is merely a rearrangement of organic material; what is broken down through the passage from already produced material is built up again.

THE NUCLEAR POWER PLANT AT SIMPEVARP

The power plant is a conventional nuclear plant with, during the period of the primary production measurements, two power units in operation, working according to the light water principle. The purpose of the plant is solely to produce electric power, the surplus heat is then cooled off and let out into the sea.

The plant is today giving an effect of 1040 Megawatt, when running at full capacity of both units.

The cooling water is taken in at the surface from a common place at the seaside, going separately through each of the cooling mantles of the reactors, and after heating it is let out through two tunnels to another place at the seaside. The distance from intake to outlet is approximately one kilometer. The inflow of cooling water is 50 m^3/s for both power units together, and the water temperature is raised on an average 10 °C from intake to outlet.

The pumps pumping cooling water are of the centrifugal type, taking in water at the center of a fanwheel, and letting it out at the periphery.

A grid is placed in front of the intake, separating large floating objects such as logs from the intake water. This grid is rinsed mechanically. Finer nets which filter away other objects are also connected to the pumps. Fish, especially flatfish, are sometimes seen in these nets; however, fish usually feel the current at the intake and swim away from the area. Jellyfish might occasionally cause a more serious problem than fish as they clog the separation nets and, when rinsed and deposited on land cause an unpleasant ammonium odour upon decay. The cooling water passes the hot reactor mantle through brass pipes of considerable length, (totally appr. 300 km). The heat is transferred through the walls of the tubes in which the water passes with a velocity of appr. 1 m/s.

THE MEASUREMENT AREA

Figure 1 is a sketch of the power plant at Simpevarp and the surronding area. The cooling water is taken in at C. The water depth there and some hundred meters outwards is only about 4 to 5 meters. The heated cooling water is let out through two tunnels into Hamnefjärden. The reason for letting out heated cooling water in a norrow semi-enclosed bay was partly to create an experimental basin for different kinds of investigations regarding the effects of the thermal pollution. Hamnefjärden is only a little more than 5 m deep at its deepest part and the mean depth is appr. 4-5 m. After passing Hamnefjärden the water flows out into the Baltic through Hamnehålet over a sill of 3 m depth.

METHODS AND TECHNIQUES

The primary production was measured with the Carbon 14 technique as developed by Steemann Nielsen (1958). Water was taken from 0, 1, 2, 3 and 4 m depth at two stations, one in the cold water at the intake of cooling water, the other in the warm water outside the outlet in Hamnefjärden (see map, fig. 1). The sampled water from each depth was put into 100 ml stoppered glass bottles, labelled with 1 ml C-14 bicarbonate solution of 4 µ Ci. The bottles were then incubated in situ at their appropriate depths (see fig.2) for half a solar day from noon to sunset.

Due to limitations of available resources one boat was used for both the cold and the warm station, which means that samples could not be put out and taken in exactly simultaneously at both stations. In order not to overestimate the warm water production, the sampling and incubation was first carried out at the cold water station whereafter the boat went up to the warm water station and repeated the procedure. The consequence of this was that the warm water was incubated with a delay of appr. half an hour compared to the cold water. At sunset the bottles were collected in the same order but the delay was then less because of the simpler handling. It should also be pointed out that it is only the time difference at the starting of the experiment that is important because ofthe high primary production in the middle of the day. At sunset when the photosynthesis is limited by the low light the difference is negligible.

Thus the samples of the cold water stations were exposed to light for appr. half an hour longer than the samples of the warm station. That means that the cold water station, under otherwise equal conditions, should be expected to show a somewhat higher primary production. This order was chosen in order not to falsely overestimate the warm water production.

As will be seen later the warm water production exceeded by far the cold water production, and by this order of incubation a suspected error of trend could be eliminated.

By coincidence the time for the cooling water to pass the power plant from intake to outlet is of the same order of magnitude, appr. half an hour. Thus the samples incubated in the cold and in the warm water can be considered as taken from virtually the same parcel of water, before and after the heating.

After incubation the samples were filtered through 0.2 µ acetate filters on which the suspended material was collected. The filters were dried and sent to Carbon-14 Centralen in Denmark and analysed for radioactivity by Geiger-Müller counting.

In connection with the incubation of water samples the temperature was registered and separate water samples were collected and brought to a local laboratory ashore where they were analysed for pH and salinity. These parameters are used for calculation of the total CO_2 content of the water, which in turn is put in to the formula to calculate the primary production.

HANDLING OF DATA

The counts obtained from the C-14 analysis and the calculated primary production were presented by C-14 Centralen in Denmark. These data represented a value for each filter, i.e. for each incubation, in the unit of milligrams of carbon produced per m^3 and day. The values are presented in figures 3 to 27.

To obtain the value for the production under one m^2 of the water surface these values were integrated vertically. Since the measurements were carried out in a shallow coastal area of fairly uniform depth, a mean water depth of 4 m for the whole area, that is for both stations, was assumed. The integration of discrete values are naturally carried out as a summation in this case, according to the formula

$$\frac{P_0 + 2P_1 + 2P_2 + 2P_3 + P_4}{2}$$

where P is the primary production value and the subscripts indicate the depths. In this way the primary production in the upper 4 meters of the water column is calculated. The photic zone of the Baltic proper is generally considered to extend to appr. 15 m depth. The photosynthesis is most effective in the uppermost part of the water column due to a rapid light extinction with depth caused by turbidity and yellow substances. However, in a free water column with a depth greater than the photic zone, there still is a considerable primary production below 4 m depth. The comparably low values of primary production found in the investigation should therefore partly be explained by the shallow water.

In order to obtain the magnitude of the annual production, the vertically integrated values are integrated with time, that is, summarized according to the formula

$$\sum_{a=0}^{N-1} \Delta t_{a-(a+1)} \times \frac{P_a + P_{a+1}}{2}, \quad (Po = 0)$$

where Pa is the primary production at one measurement occasion and Pa+1 at the following, and a-(a+1) denoting the interval between them, Δt is the number of days of this interval, and N is the total number of measurements during the year considered.

RESULTS

The measurement of primary production at the two stations resulted in the calculation of the annual values and the values for the whole measurement period from May 17, 1975 to September 7, 1976. A graph of these values is shown in fig. 28

	Cold Water	Warm Water	Rate $\frac{Warm}{Cold}$
Annual primary production May 17, 1975 - May 3, 1976	21.0	30.1	1.43
Primary production for the period May 17, 1975 - Sept. 7, 1976	43.5	53.5	1.23

The units are g Carbon/m^2

The temperature was recorded in connection with the measurement of primary production. The graph of the temperature values is shown in fig. 29. At some occasions there is almost no difference in temperature between "cold" and "warm" water, for example on June 1, 1976. At these occasions the power producing reactors were closed down for maintenance and repair. At one occasion, on Aug. 20, 1975 there was a situation of recirculation, where the heated water after leaving Hamnehålet followed close to the coast and went again to the intake. The weather condition was a strong easterly wind towards land, with a south-ward current parallel to the coast.

DISCUSSION OF RESULTS

The immediately apparent result of the investigation is that the primary production of the heated water is higher than of the cold water at the intake. Only during a short period in the late autumn is the cold water primary production higher. During this period the level of primary production is on the whole fairly low. Over the entire period of the primary production measurements, from May 17, 1975 to September 7, 1976 the warm water primary production was 23 % higher than the cold water production. This is a rather striking difference, the causes of which are not immediately clear, and caution in the interpretation is necessary. The higher primary production in the warm water could at first be considered as a yield or a benefit from the higher temperature in the warm water regime. In that case the higher primary production would be a potential resource to be utilized in some way. However, the difference is largest in spring and summer, the period when primary production on the whole reaches the highest values in these latitudes. In Baltic surface waters, which are used for cooling, the nutrients phosphate and nitrate are often (both) depleted in spring and summer, thus limiting the primary production. Now, if nutrient depleted surface water is heated ten degrees by passing a power plant, how could it produce more if no nutrients are added? The cause of the primary production increase must consequently be found in some other process, increased metabolic rates of the plant plankton by the higher temperature can not alone account for the primary production increase.

The lack of reliable nutrient analyses must again be regretted, the complementary information about the high warm water production is hidden in nutrient values. However, based on quantitative considerations the high warm-water production will be discussed a little further.

Hamnefjärden, the bay outside the power plant where the warm water remains for a while before leaving through Hamnehålet out into the Baltic, is appr. 4 m deep with a surface area of appr. 0.1 $(km)^2$. This gives a volume of 4×10^5 m^3. Using the value 50 m^3/s as a value for the flow of heated cooling water through the bay, a residence time of only 3 hours appr. is obtained.

Such a short residence time of the water indicates that there is probably a similar type of plankton flora at the intake and in the warm water basin, the water does not remain long enough to allow the development of a separate phytoplankton flora in the warm water. However, the flow pattern at the outlet is not known in detail, and there might well be a "flood" of warm water from the outlet tunnel to the escape at Hamnehålet, whereas "pockets" of water in Hamnefjärden have a much longer residence time and thus can develop separate plant plankton populations.

The pumps which circulate the water through the cooling systems are, as mentioned before, of a centrifugal type and are considered to be "mild" to the creatures in the water. However, investigations in the United States indicate that the strong turbulence of the water causes injuries to the zooplankton as well as to fish eggs, fish larvae and small fish, whereas the phytoplankton seem to pass the system fairly unaffected. Loss figures of 30 - 100 % for the zoo biota is reported. A brief look in the microscope at the warm water from Simpevarp indicates a similar situation; some damage to the zooplankton and unaffected phytoplankton.

From the start of the first power unit at Simpevarp in 1974, it was reported in the press that appr. 60 kg per day of small fish and larvae were destroyed when passing the pumps. Doubling this figure, for the two aggregates operating today we get a daily loss of 120 kg of organic material. (Considering these being secondary producers with a 10 % efficency factor between the trophic levels, the figure corresponds to a loss of 1.2 tons per day of primary produced material.) According to a common consideration (20 % dry weight of which 40 % is carbon) and a carbon : nitrogen : phosphorus ratio of 41 : 7 : 1, by weight, this material would yield appr, 1.4 kg nitrogen and 200 g phosphorus per day. Assuming that the dead organic material sinks to the bottom of Hamnefjärden, where it is subject to bacterial decomposition, this calculated amount is eventually given back to the warm water. However, these figures are very low and the fertilization caused by this supply should be of minor importance. It is likely that the true amount of destroyed material is much higher, and that the figure (60 kg) given was underestimated.

However, there is most likely a separation so that sedimentation of detrius takes place in "pockets" and consequently the regeneration of nutrients in the warm water basin will fertilize only parts of the passing water; these parts may gain a higher primary production. Further, the given figure is probably far too low and refers only to the quantity of small fish which can be seen to be destroyed and so quantitatively estimated, whereas all other destroyed organisms that pass the cooling systems are not included. A measure of the organic material achieved by total nitrogen or total phosphorus determination of the ingoing water would presumably give a better estimate of the total amounts of nutrients available on the warm water side after a delay of bacterial degradation of the detrital material.

Another possible cause for the higher primary production in the warm water is the lack of control by grazing organisms. With the assuption that the phytoplankton pass fairly unaffected from the cold to the warm water while the zooplankton are partly killed and injured and uncapable of feeding, it follows that the normal grazing pressure on the phytoplankton is decreased. The multiplication rate of cells and thus the total uptake of carbonate into the tissue is then larger, if nutrients are available, than if normal zooplankton grazing is controlling the growth.

COMPLEMENTARY MEASUREMENTS

In order to further elucidate the causes of the higher primary production in the warm water , the Institute for Marine Microbiology at the University of Gothenburg measured a large number of parameters in the warm and cold water of Simpevarp on two occasions in 1977. The results are presented in a report (in print, see ref.) to the Swedish National Environment Protection Board. On these occasions, March 15-18 and June 17-19 careful nutrient analyses were carried out. Alkalinity was determined by a pH-titration method developed by the Department of Analytical Chemistry at the University of Gothenburg. Determination of heterotrophic activity, electron transport activity and nitrogen fixation were carried out, as well as dissolved oxygen content and biological oxygen demand (BS_5) plus salinity and pH, in water and in sediment. Counts of bacteria were carried out and a rough determination of phytoplankton species and numbers was made.

The results confirm in the main the conclusions regarding the nutritive picture of the cold and warm water basins, discussed in the preceding section.

CONCLUSIONS

The results are mainly that an increased primary production of 23 % is recorded in the warm water regime as a total during the measurement period. However, there is also a trend of maginification of the extremes, so that during the period of high production in summer and autumn, the production is still higher in the warm water, whereas during the winter with a low natural production the production in the warm water is still lower.

The high warm water production should not be considered as a gain of material, but rather as a reorganization of previously produced material. The surface waters of the Baltic are depleted of critical nutrients in the summer, thereby limiting primary production. It should therefore be difficult to increase considerably the primary production unless nutrients are added. To benefit from the higher temperature in the form of an increased organic production we must thus add nutrients. (As on land, the production in a hothouse on a meagre soil can not be increased considerably without the addition of fertilizer.)

The higher production in the warm water is probably an effect partly of a high supply of nutrients from the breakdown of previously produced material and partly of a more effective utilization of the available nutrients due to a lower grazing pressure on the phytoplankton. There is also a probability of an accumulative effect as regards the regeneration of nutrients so that a higher microbial activity in the summer period converts an increased amount of organic material, accumlated by sedimentation, into nutrients available to the primary producers.

A summarizing schematic illustration of the productive situation is given in Fig. 31.

This gives a distorted picture of the plankton-nekton community in the warm water. The normal pyramidal productive decline up through higher trophic levels is disturbed. Moreover, the migration of fish following the temperature gradient into the warm water regime creates a nutritional demand at the top of the pyramide which can not be met by the disturbed lower level production.

It seems obvious that if the limited ecosystem of the warm water regime is allowed to develop on its own, the supplied energy is dissipated via mainly unprofitable pathways. In order to take advantage of the general higher rate of production in warm waters, the specific conditions should be known and controlled. A better knowledge of carbon pathways and nutrients cycles in a thermally disturbed area, and active measurements to direct and control growth of selected species should enable us to benefit from the warm waters.

CLOSING REMARKS

It is regrettable that the coordination of the work of different institutions investigating the Simpevarp warm water area has not always been satisfactory. The precision of parallel nutrient analysis of water samples has sometimes been too low to adequately support the primary production measurements.

For follow-up and future work a closer cooperation and better exchange of information should be of value for the institutions involved.

As a pilot study the work has, however, provided useful basic information. It is essential to record the production changes of the lowest trophic level in order to foresee the nutritional consequenses.

The work also implies that it should be possible to take advantage of the warm water discharges. The waste of energy that the cooling water discharges constitutes today can be converted to a gain of useful raw materials if new ideas are applied. Cultivation of fast growing species like blue-green algae, which under natural conditions often live in warm waters, could bind the energy to organic material for further use as food or even for methane conversion and later restoring of the energy by burning. Continued research will provide the knowledge needed to change what is today an ecological hazard into a utilizable resource.

ACKNOWLEDGEMENTS

The difficult work of carrying out primary production measurements at Simpevarp in all weathers could not have been done without the skilful help of B.S. Håkan Stenbäck, and I want to address my thanks to him for our good cooperation within the project.

Dr Erik Neuman, who is responsible for the joint research at Simpevarp, provided data and other useful information.

Financial means were supplied by the National Swedish Environment Protection Board.

Mrs Anita Taglind performed the drawings of figures 2 to 31.

Professor Kaare Gundersen and our group at the Institute for Marine Microbiology, University of Gothenburg, have by the complementary measurements provided new information for a better knowledge of the microbial processes in the warm water of Simpevarp.

LEGENDS TO FIGURES

For all figures where a thick and a thin line is applied
the thick line ▬▬▬▬ is used for conditions in the WARM water
the thin line ──── is used for conditions in the COLD water

Figure No

1. Map over the power station area at Simpevarp and its surroundings. The heated cooling water is discharged into Hamnefjärden, and the warm water measurement station is marked by W. The cold water station near the intake of cooling water is marked by C.

2. Sketch of the arrangement for C-14 in situ incubations. (Similar for both stations.)

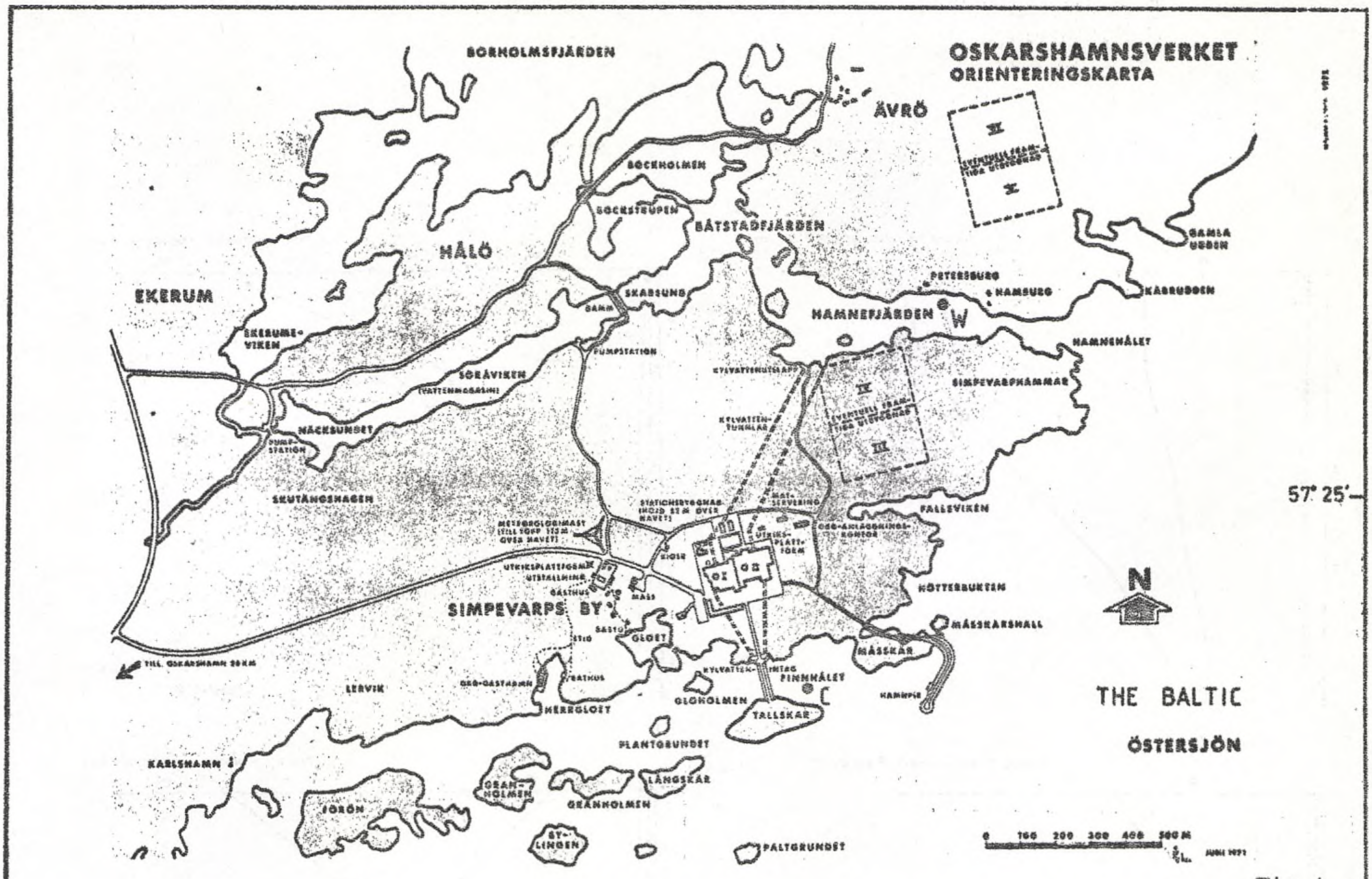
3. - 27. Vertical profiles of all C-14 measurements from May 17, 1975 to Sept. 7, 1976.

28. Variation of the vertically integrated primary production values with time during the measurement period.

29. Temperature variations measured at the same occasions as primary production incubations.

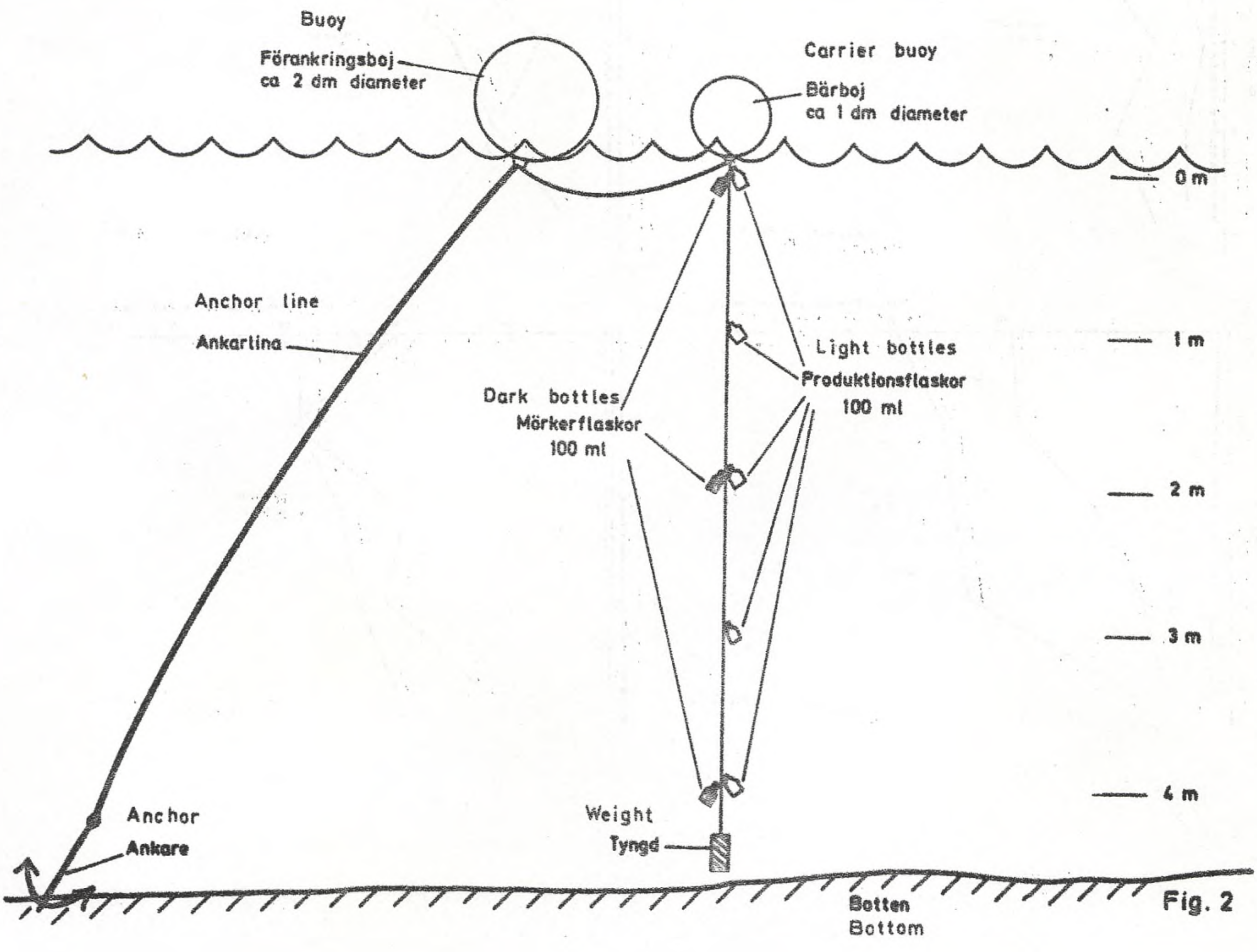
30. Variations of Secchi depth in the measurement period.

31. Sketch of the principal causes for the high primary production in the heated cooling water.



OSKARSHAMNSVERKET
ORIENTERINGSKARTA
BORHOLMSFJÄRDEN
ÄVRÖ
HÅLÖ
EKERUM
BÅTSTADFJÄRDEN
HAMNEFJÄRDEN
W
SIMPEVARPS BY
C
57° 25'
N
THE BALTIC
ÖSTERSJÖN
FÖRÖN

Fig. 1



Buoy
Förankringsboj
ca 2 dm diameter
Carrier buoy
Bärboj
ca 1 dm diameter
0 m
Anchor line
Ankarlina
1 m
Light bottles
Produktionsflaskor
100 ml
Dark bottles
Mörkerflaskor
100 ml
2 m
3 m
4 m
Anchor
Ankare
Weight
Tyngd
Botten
Bottom

Fig. 2

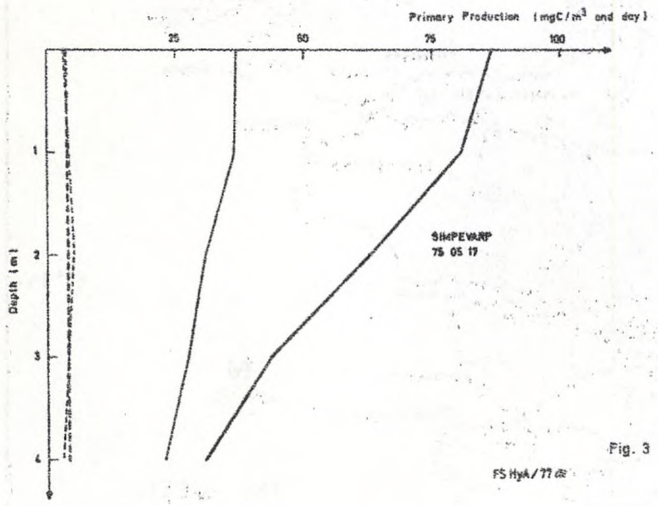


Fig. 3

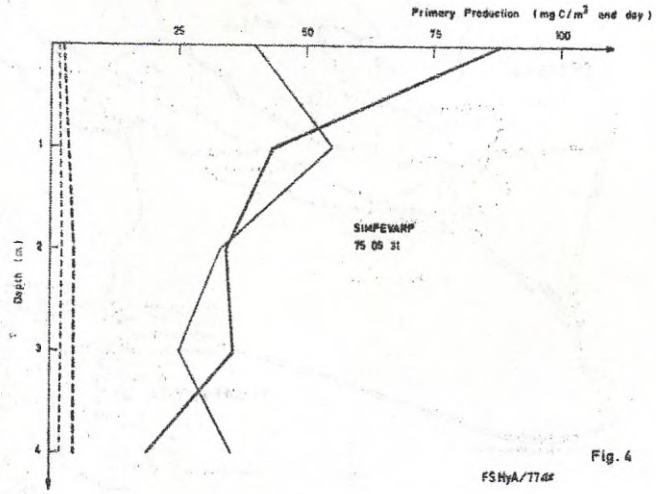


Fig. 4

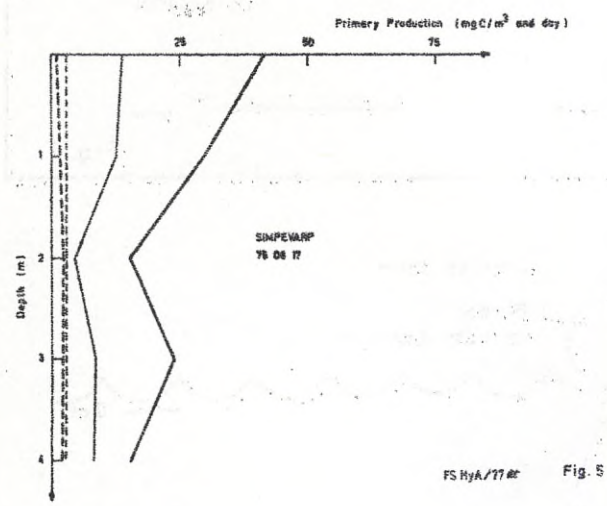


Fig. 5

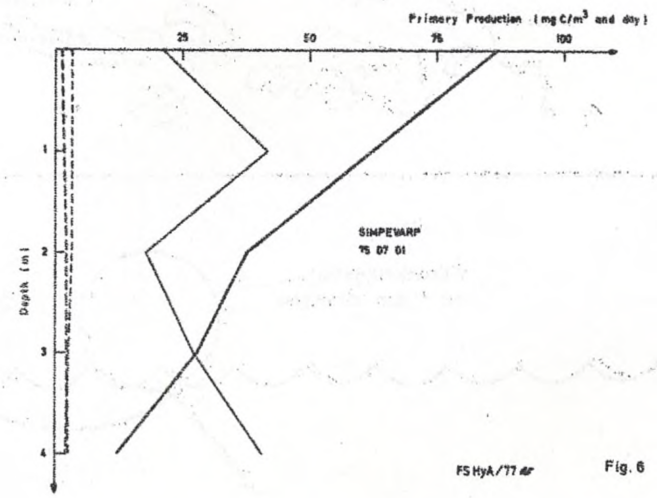


Fig. 6

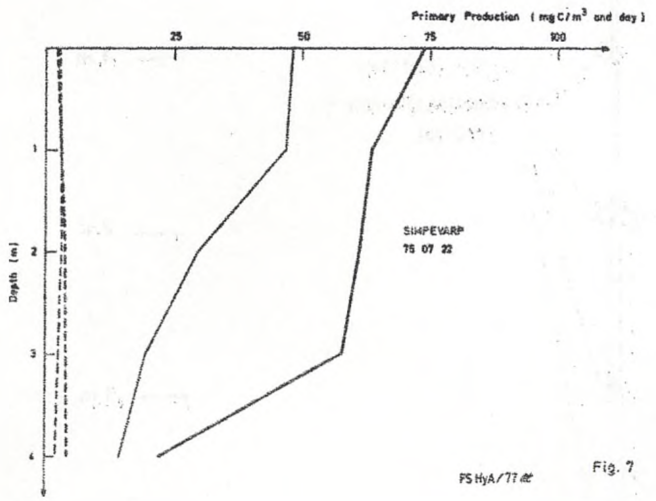


Fig. 7

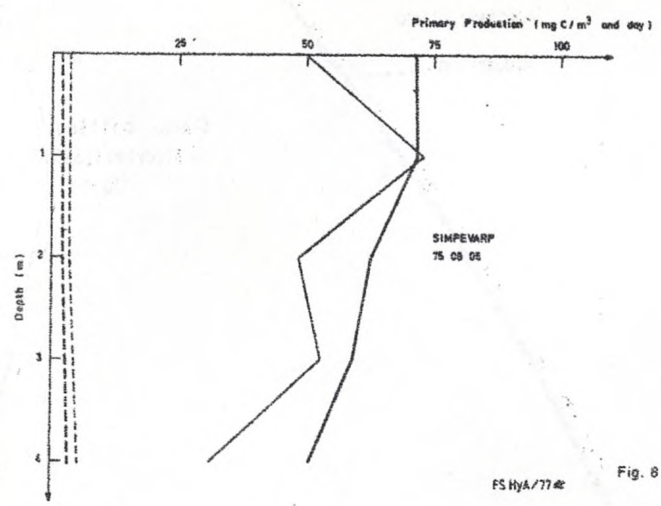


Fig. 8

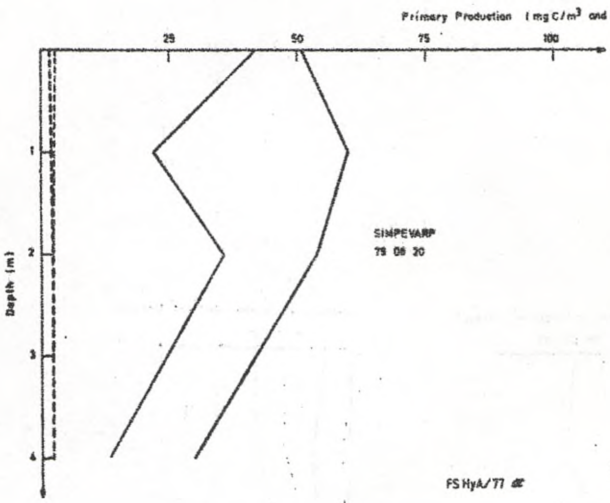


Fig. 9

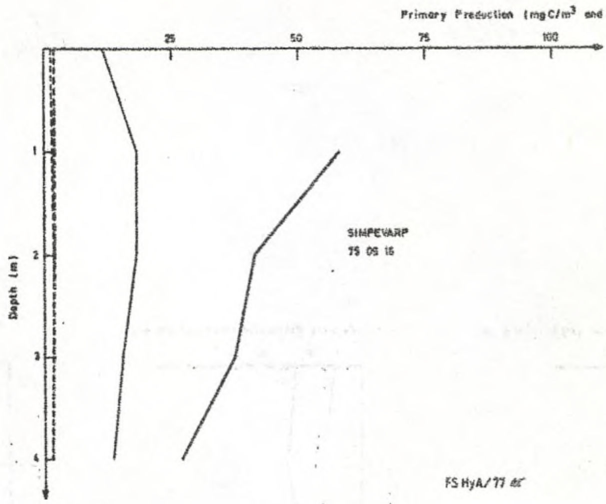


Fig. 10

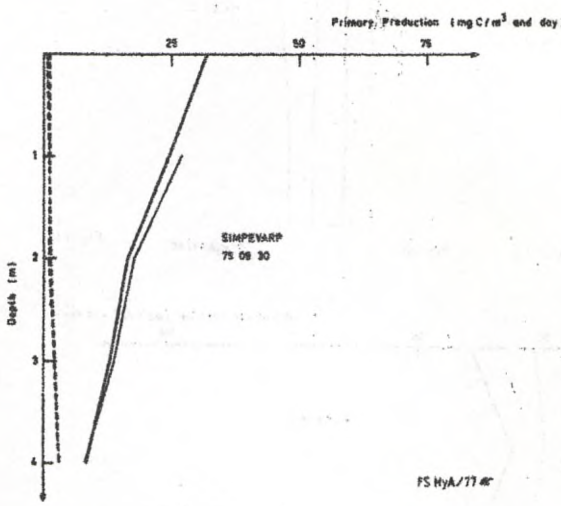


Fig. 11

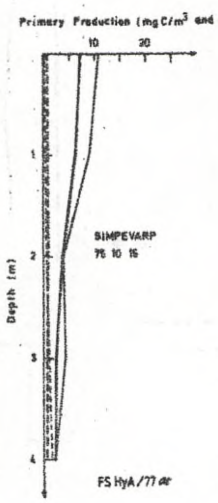


Fig. 12

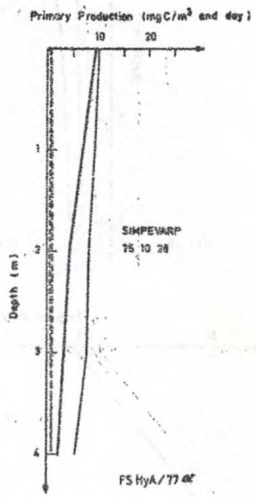


Fig. 13

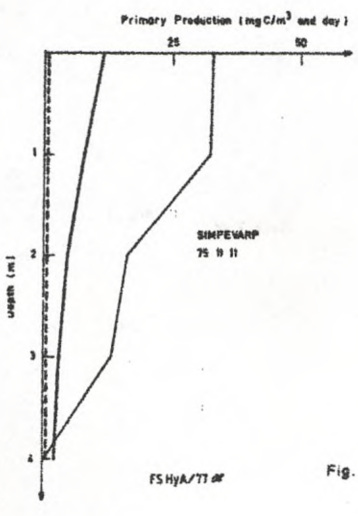


Fig. 14

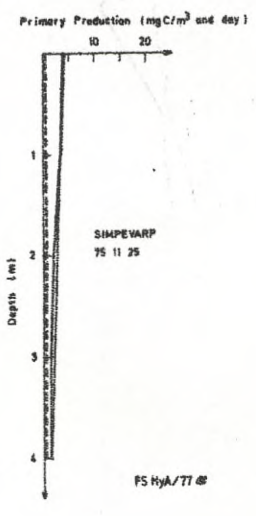


Fig. 15

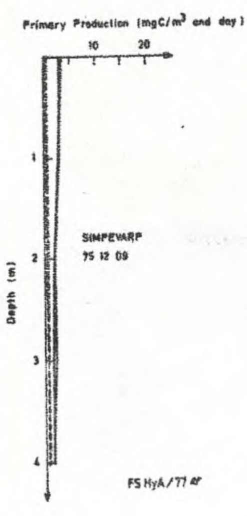


Fig. 16

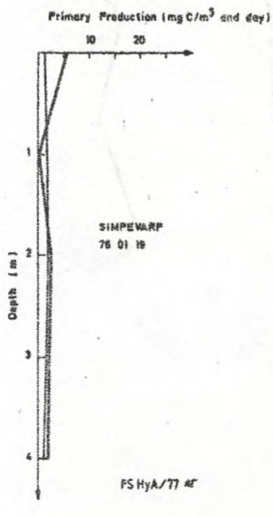


Fig. 17

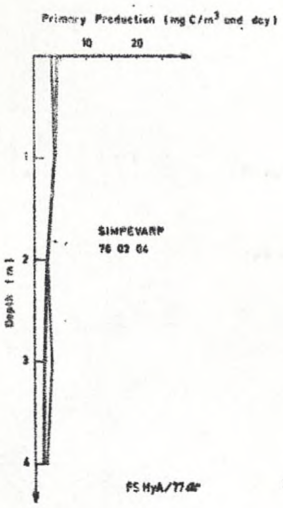


Fig. 18

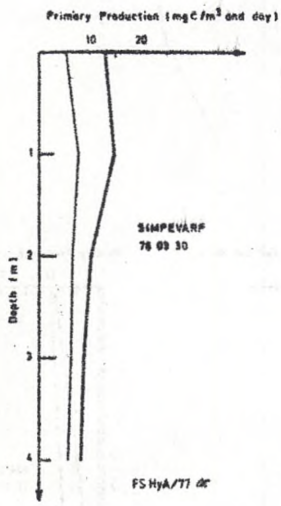


Fig. 19

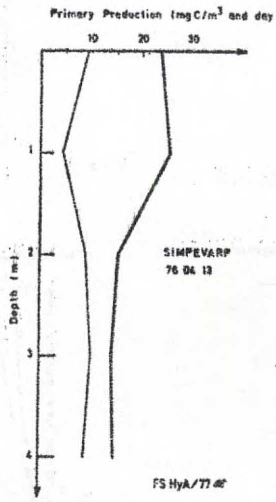


Fig. 20

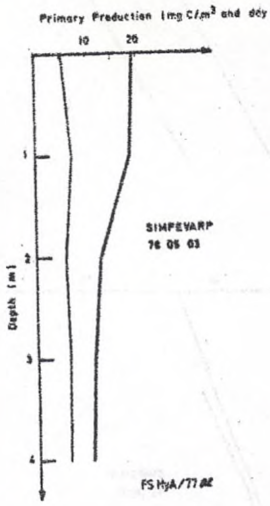


Fig. 21

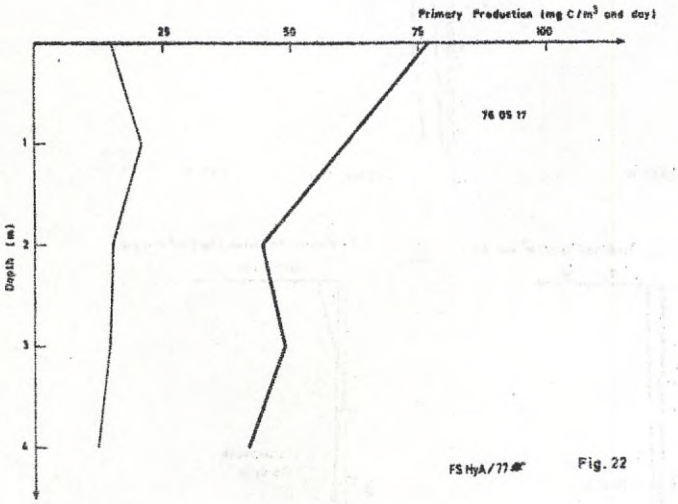


Fig. 22

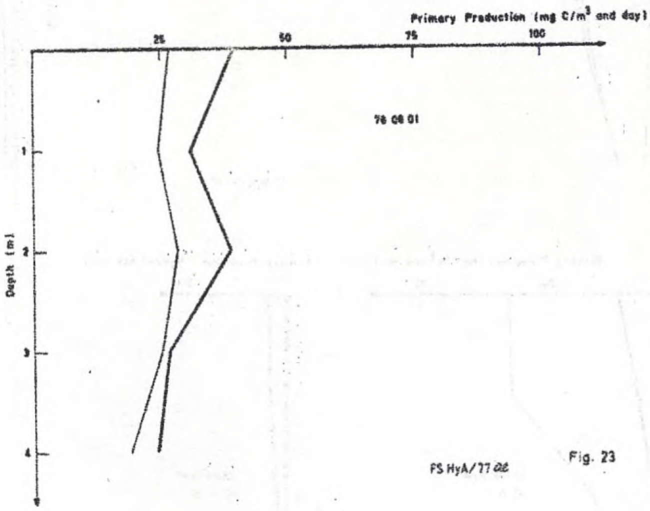


Fig. 23

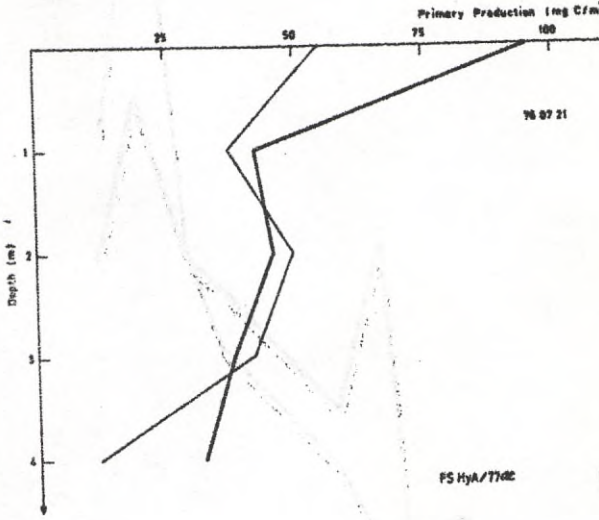


Fig. 24

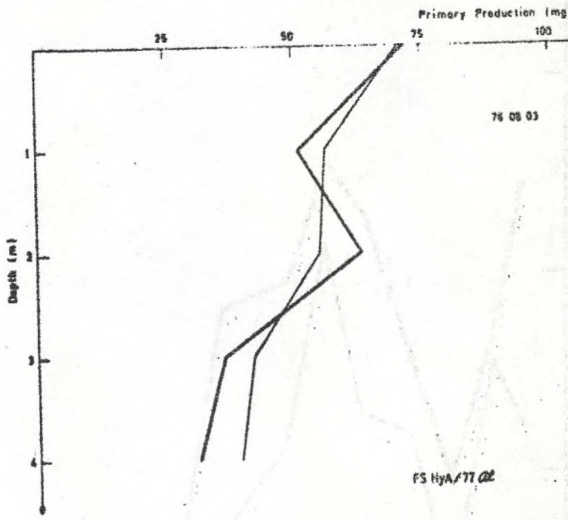
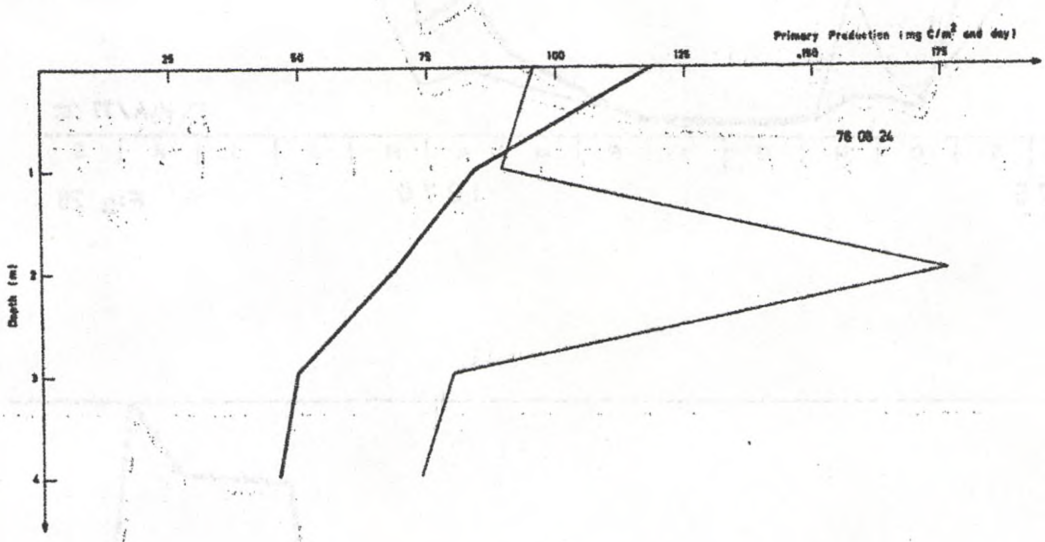


Fig. 25



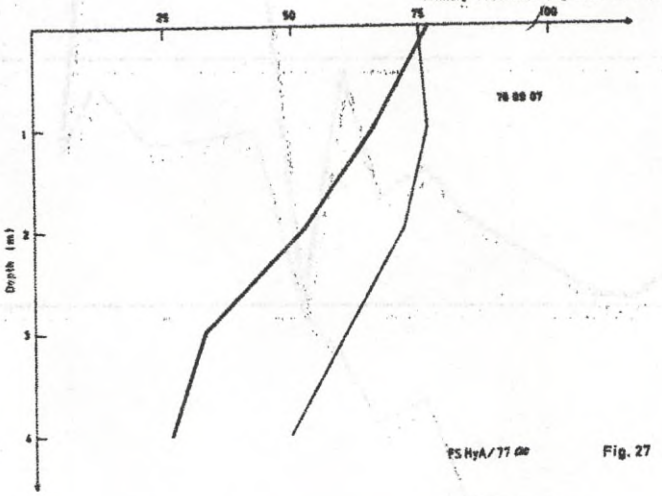
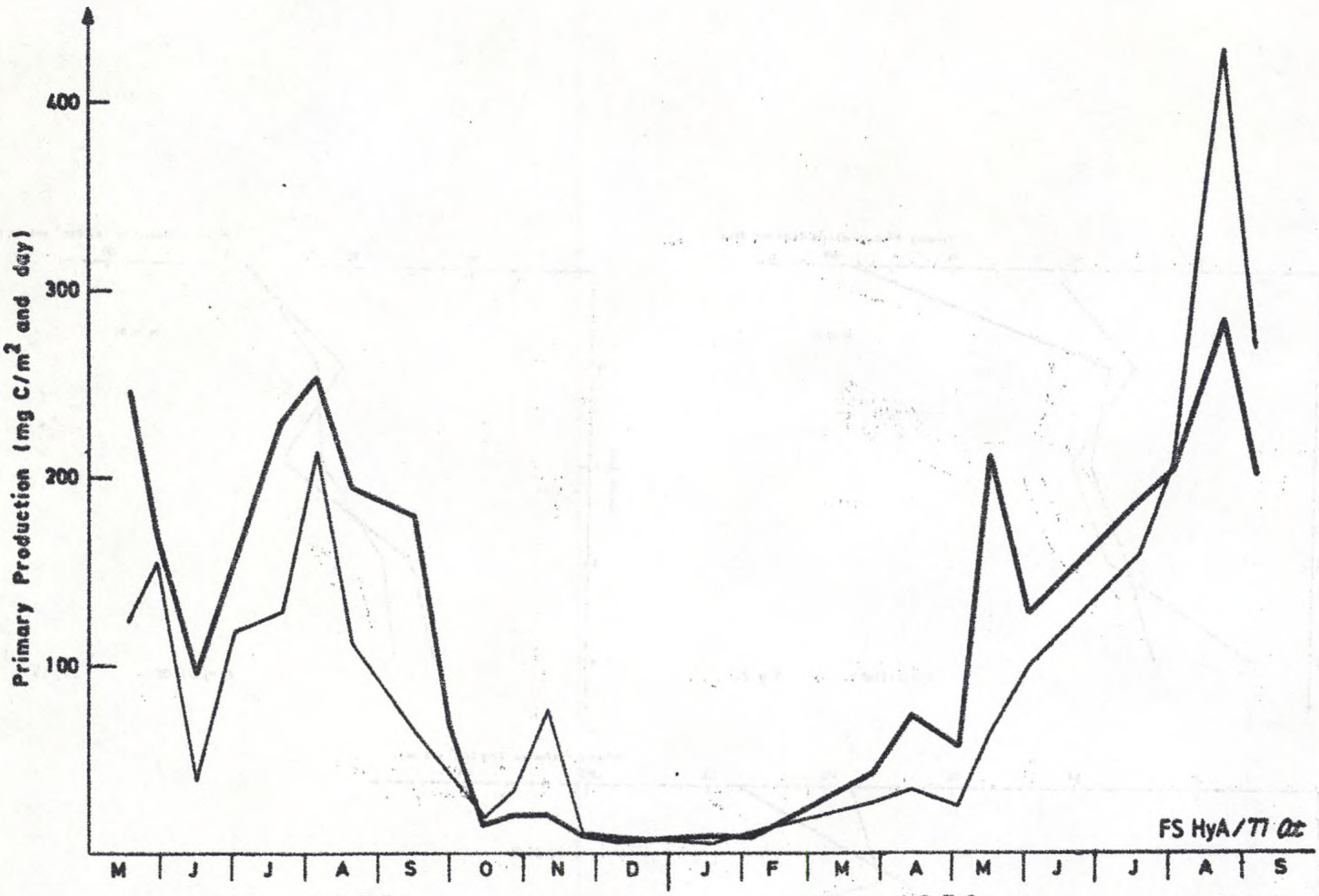
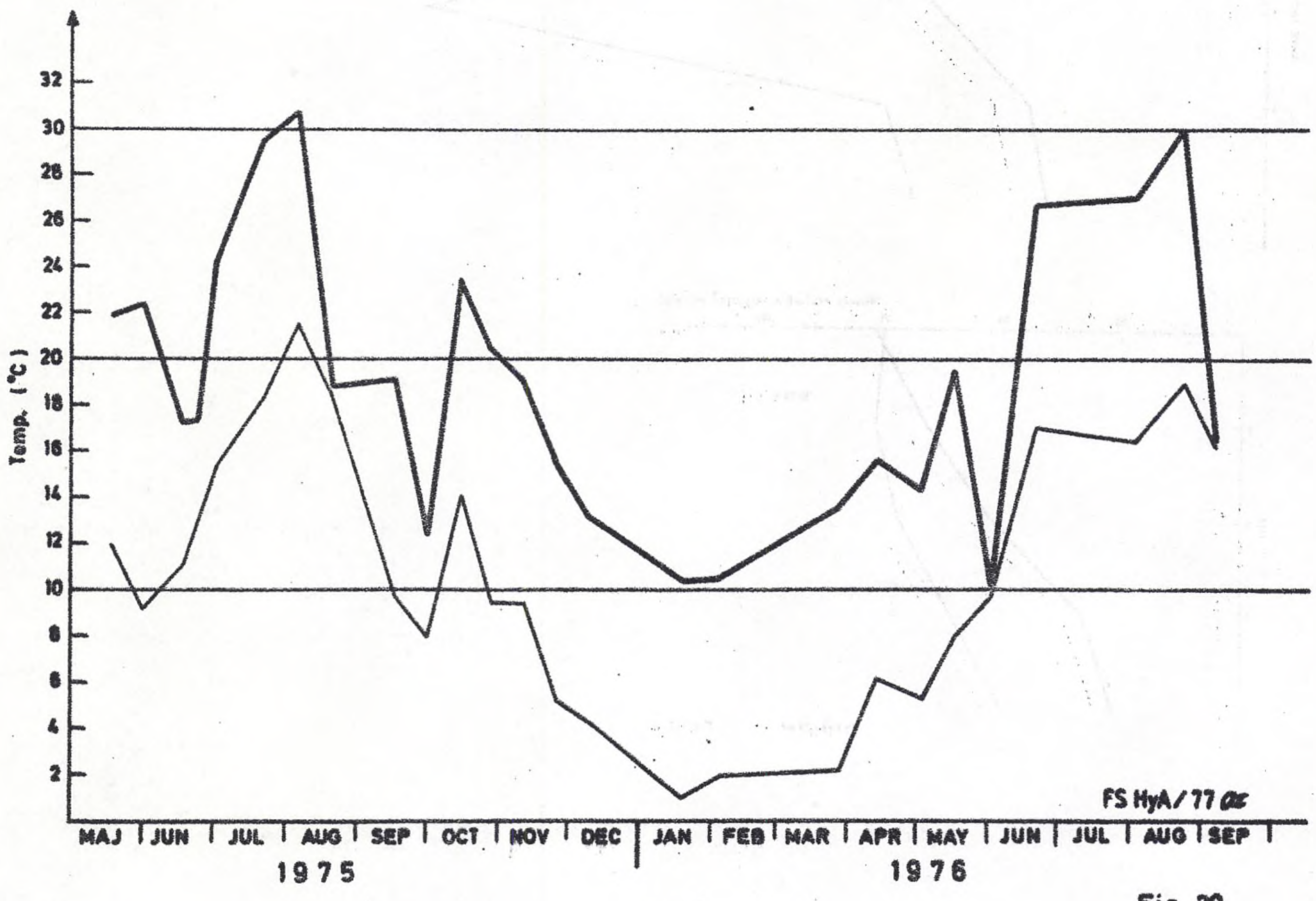


Fig. 27



Primary Production (mg C/m² and day)
400
300
200
100
FS HyA/77
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
1975
1976

Fig. 28



Temp. (°C)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
FS HyA/77
MAJ
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
1975
1976

Fig. 29

BREDGRUND N 57° 24.'04 E 16° 48.'02

SECCHI DEPTH PARAMETER

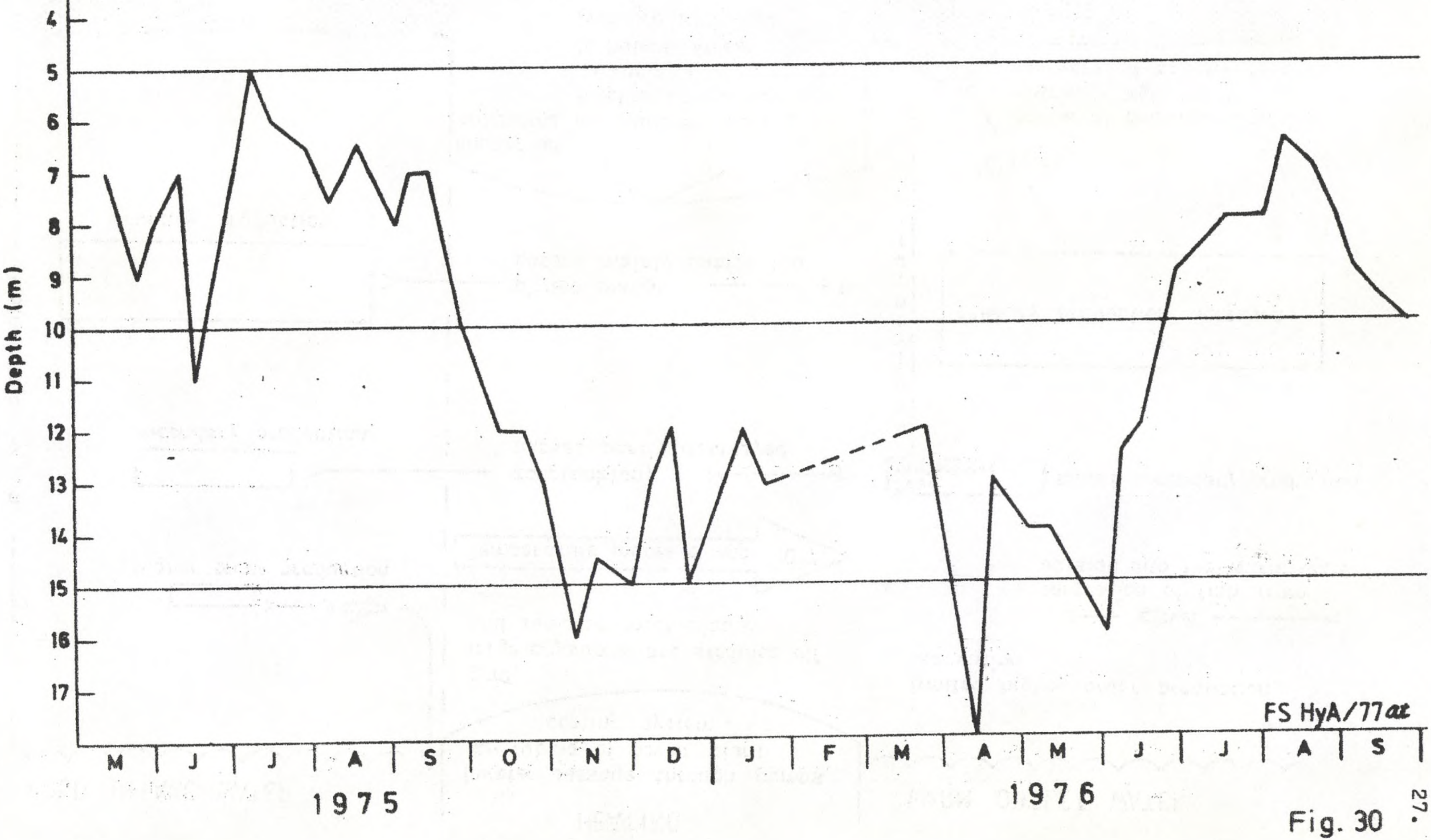
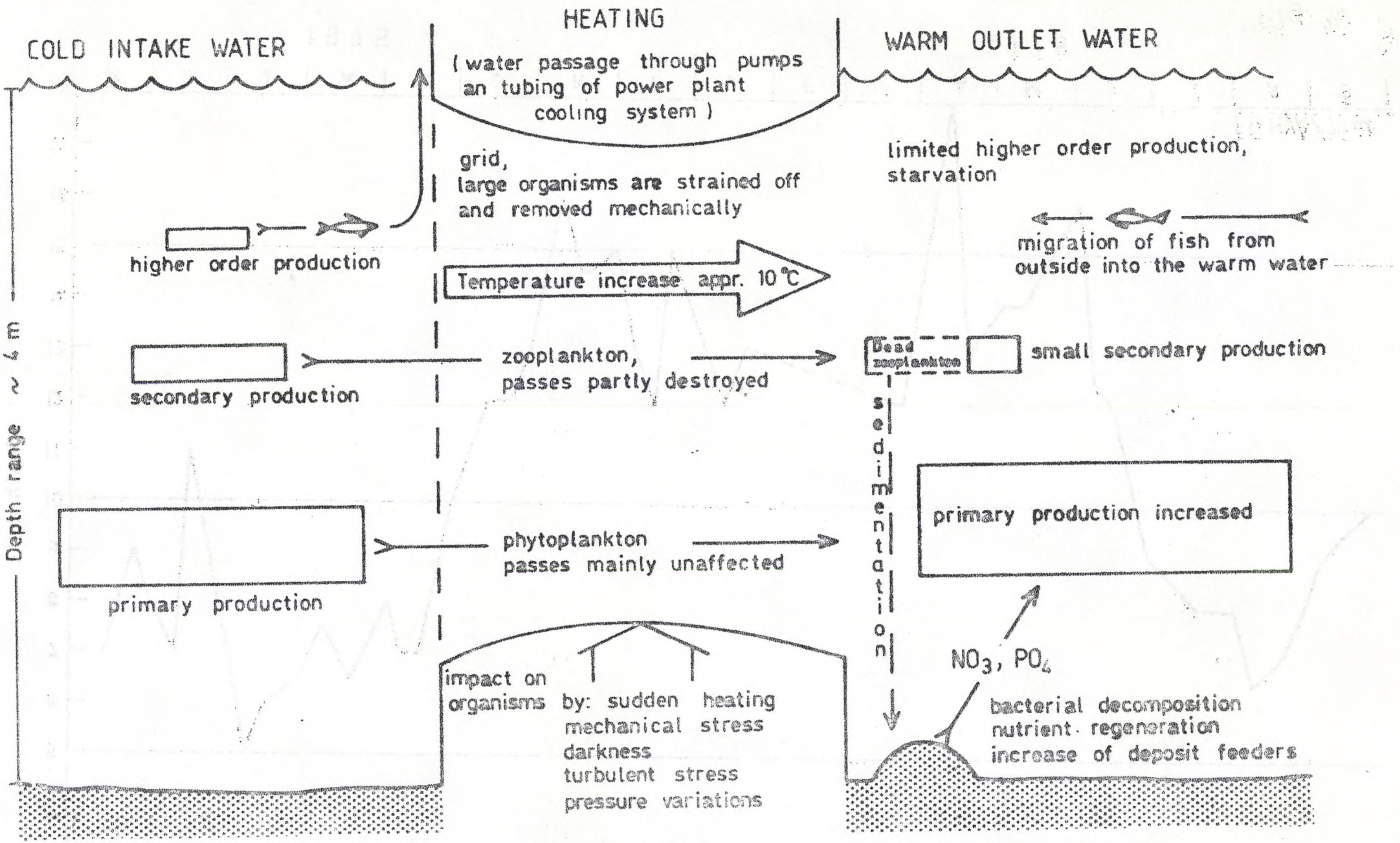


Fig. 30



Schematic qualitative description of planktonic production relations before and after passage of cooling system at Simpevarp

Fig. 31

FS HyA/77

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