Chapter VI

I. Aspects of dynamic biology in the Southern Bight of the North Sea and the Sluice Dock at Ostend

by

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General introduction

As an ecosystem is a dynamic entity, it is impossible to understand its functioning by a structural description of static parameters such as concentrations, biomasses, etc. It is necessary to estimate the *activities* of the different organisms (primary and secondary production, respiration rates, heterotrophic activity, etc.). Only the quantitative and qualitative description of interactions and transfers, temporally and spatially integrated, gives us a dynamic picture of the working of the ecosystem.

In our opinion, only this fundamental knowledge of the interactions in the ecosystem will allow us to understand pollution problems, such as eutrophication, or heavy metals contamination. This knowledge will also be very useful for applied biology, as in fisheries or marine organisms farming.

The following report is a first step in this direction of dynamic description of the biology of the marine ecosystem, in the Sluice dock at Ostend and the Southern Bight of the North Sea.

1.- Primary production

1.1.- Methods

1.1.1.- Primary production (photosynthesis measurements)

The $^{14}CO_2$ technique [Steemann Nielsen (1952)] has been used for photosynthesis measurements in the pelagic environment. *In vitro* incubations (potential production) have been performed at sea on each cruise and all sampling stations. Several *in situ* and *semi situ* incubations (integrated production) have also been performed [Mommaerts (1973a,b)]. Results are given separately for nannoplankton and netplankton after fractional filtration on 45 µm or 25 µm meshes [Mommaerts (1973a, b,f)].

Similarly, *in vitro* and *in situ* incubations were performed weekly in the Sluice Dock at Ostend [Podamo Jo (1973a), (1974)].

A prototype for the automatization of sampling and *in vitro* incubation has been built and used in the Sluice Dock. This device allows the collection of records for 24 h periods (experiments actually performed) or longer times (several days) [Podamo Jo (1973b), Cromboom and Mommaerts (1973)].

The phytobenthos production in the Sluice Dock has also been investigated. Some *in situ* oxygen production determinations (Winkler method) have been made. Clear and dark plexiglass incubation chambers were designed for such experiments [Podamo Jo (1973a)].

1.1.2.- Photosynthetically available radiation (P.A.R.)

Use was made of global solar radiation data known for the area from the continuous records made at De Haan, near Ostend, and calculated in Joules/cm^2/30 min at the Royal Meteorological Institute. We have measured the absorption of available radiation in the water column (range 400 - 700 mμ) . This was done at sea and in the Sluice Dock with an immersible photometer fitted with green, red and blue filters (Chance Pilkington O Gr 1, BG 7, RG 630). Calculations of energy fluxes are made as suggested in Vollenweider (1969).

1.1.3.- Phytoplankton standing crop

Chlorophyll and phaeophytin a have been determined weekly in the Sluice Dock at Ostend as described in Strickland and Parsons (1968). In the North Sea, this work is done and discussed by Steyaert and Lancelot-Van Beveren (1973).

The Utermöhl technique [Utermöhl (1936)] has been used for the nannoplankton numerations in the Sluice Dock [Podamo Jo (1974)].

The improving of autoradiographic procedures for phytoplankton numeration is going on [Mommaerts (1972d), Cromboom et Mommaerts (1974)].

1.1.4.- Precision of the measurements

a) $^{14}CO_2$ incubations

At the 30 mg C/m^3/h level, the standard deviation represents 8 % of the average [Mommaerts (1973d)]. At the 2 mg C/m^3/h level, it amounts to 23 % [Mommaerts (1973e)]. In both cases this was determined experimentally by incubating 10 subsamples under the usual working conditions.

b) Pigments

The precision of the measurements has been estimated in the same way for the Sluice Dock at Ostend : 10 subsamples : standard deviation 2 % of the average, at the 10 mg chlor a/m^3 level.

1.2.- Results

1.2.1.- Spatial and temporal variations of phytoplankton

a) North Sea

A synthetic approach to the spatial distribution patterns of phytoplankton in the area studied is attempted with the potential production results collected from 1971 to 1973 [Mommaerts (1972a), (1972b), (1972c), (1973c)].

From the average depth profile (fig. 6.1) it appears that the water is thoroughly mixed in the water column (the mouth of the estuaries excepted) [Mommaerts (1973b)].

An average horizontal distribution profile (from coast to open sea) has also been computed for each cruise. The existence of an important nannoplanktonic fraction (escaping meshes of 45 µm and even 25 µm) has been emphasized [Mommaerts (1973a), (1973f)]. It seems to be chiefly composed of flagellates as shown in Mommaerts (1973g) and also Steyaert et Van Beveren (1972). When nannoplankton and netplankton are considered separately, typical patterns are demonstrated for each period of the year (figs. 6.2 and 6.3) : winter, spring bloom, summer, automnal bloom. All these profiles can in turn be synthetized in one figure (fig. 6.4). One sees that the high standing crop fringe extends to 50 km off the coast.

From 30 km , the nannoplanktonic potential production becomes proportionally more important than that of netplankton. It is possible that this pattern is related to the nutrients profile [Elskens (1972)] in connection with the lower specific half-saturation constants for limiting nutrient uptake that are exhibited by nannoplanktonic phytoplankton [Parsons and Takahashi (1973)].

Our records, however limited in number, show that the amplitude of seasonal variations of netplanktonic production can be important in the coastal area in contrast with those of nannoplanktonic production. However, in the open sea both categories exhibit variations of very low amplitude. Such patterns have led to the concept of zones [Elskens (1972)] *i.e.* a coastal fringe (zone 1), relatively important for the area

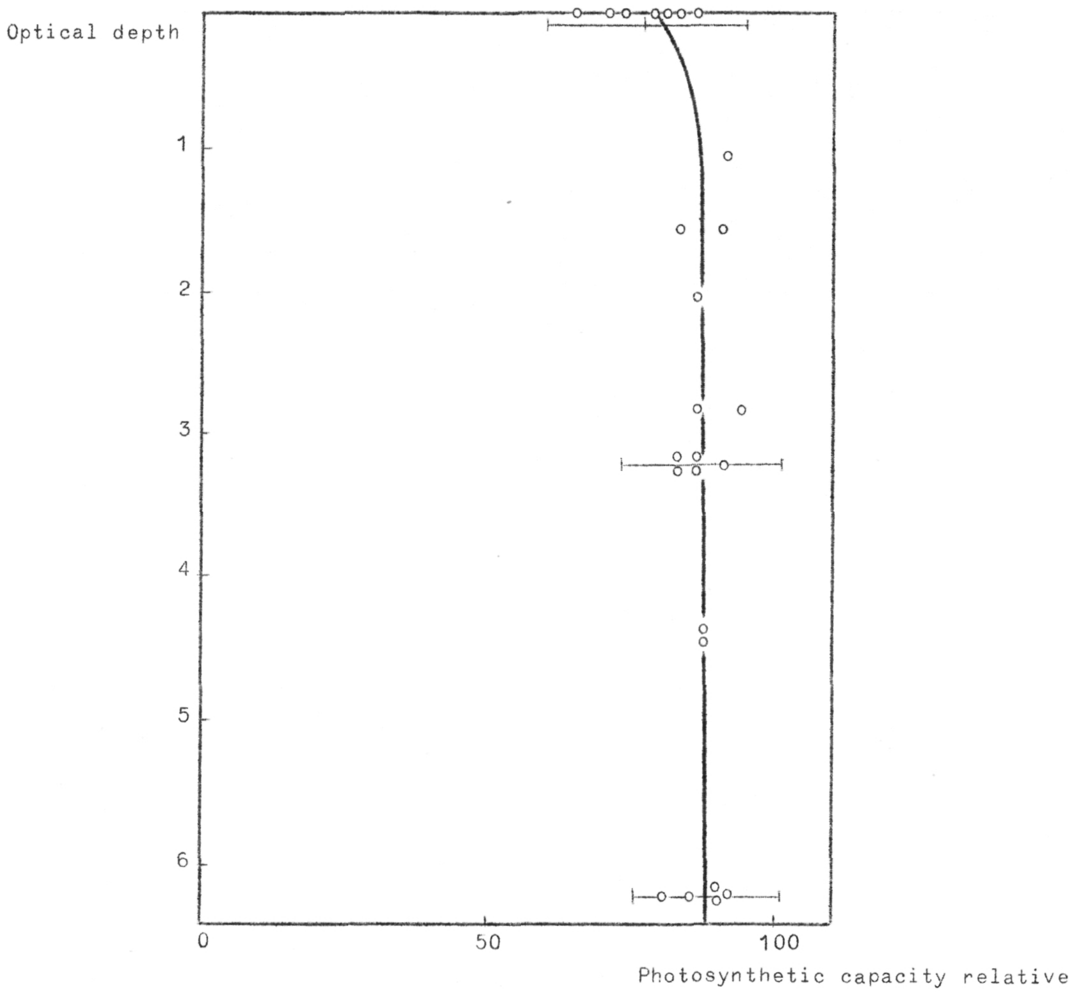
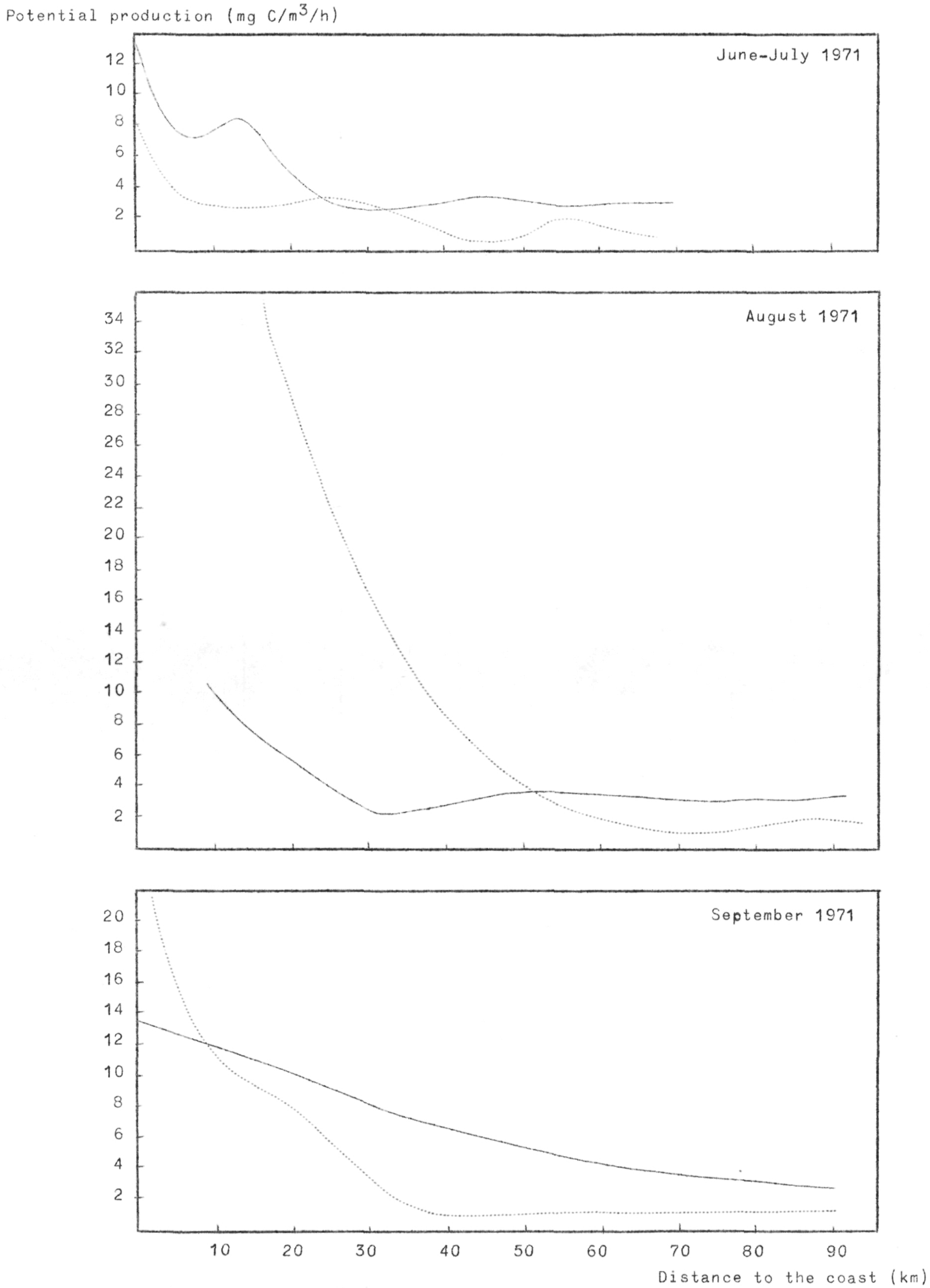


fig. 6.1.
Average depth profile of potential production. Each potential production result has been expressed as a percentage of the maximum figure recorded in the water column; then the figures are averaged for every cruise and relative irradiance level. The optical depth scale is such that each unit causes a halving of irradiance.

studied, and the beginning of a vast area (zone 2) more exactly representative of the Southern Bight of the North Sea. One has also considered a division in zone 1 (fig. 6.38 and table 8.1), as figures differ frequently in the northern (1N) and in the southern parts (1S). Seasonal variations recorded in the North Sea (fig. 6.5) conform to patterns known from the literature for temperate coastal seas [*e.g.* in Raymont (1963)]. In the course of a week however, the potential production variations seem to be negligible. The study of the nycthemeral cycle of production might help in the understanding of this slow variation pattern. Such cycles



Potential production (mg C/m3/h)
June-July 1971
12
10
8
6
4
2
August 1971
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
September 1971
20
18
16
14
12
10
8
6
4
2
10
20
30
40
50
60
70
80
90
Distance to the coast (km)

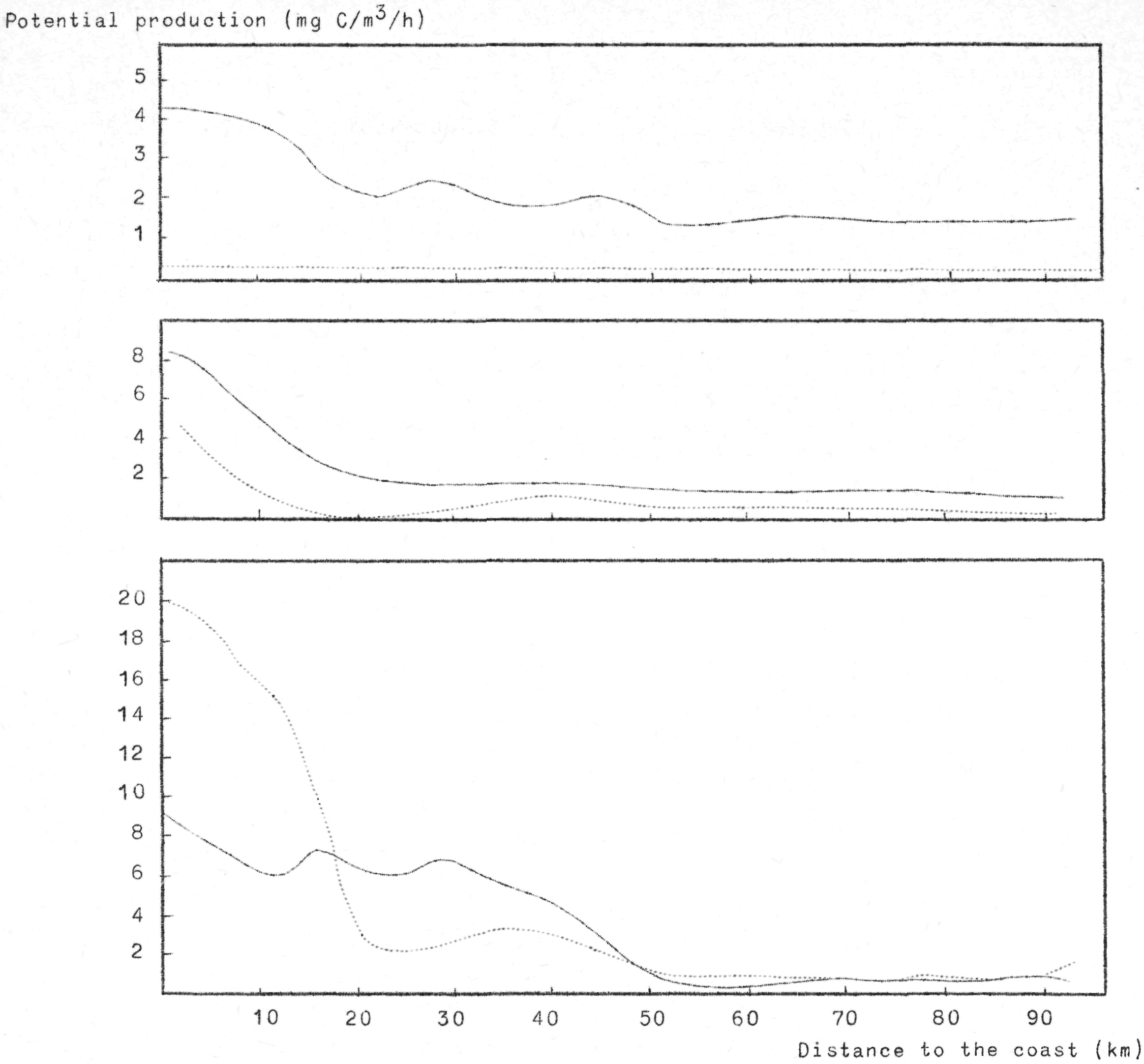


fig. 6.2. and 6.3.
Average horizontal distribution patterns of potential production at different times of the year. (Stippled line : netplankton; solid line : nannoplankton.)

have been studied at sea with variable results [Mommaerts (1973g)]. Indeed, water motions interfere on such experiments. However, experiments made in the Sluice Dock either with automatization device [Cromboom et Mommaerts (1973)] or in the usual way (see below) give consistent results.

b) Sluice Dock

The water is fairly homogeneously distributed in the Sluice Dock. Phytoplankton stratification is negligible in most cases. Where the horizontal distribution pattern is concerned, a narrow littoral fringe shows

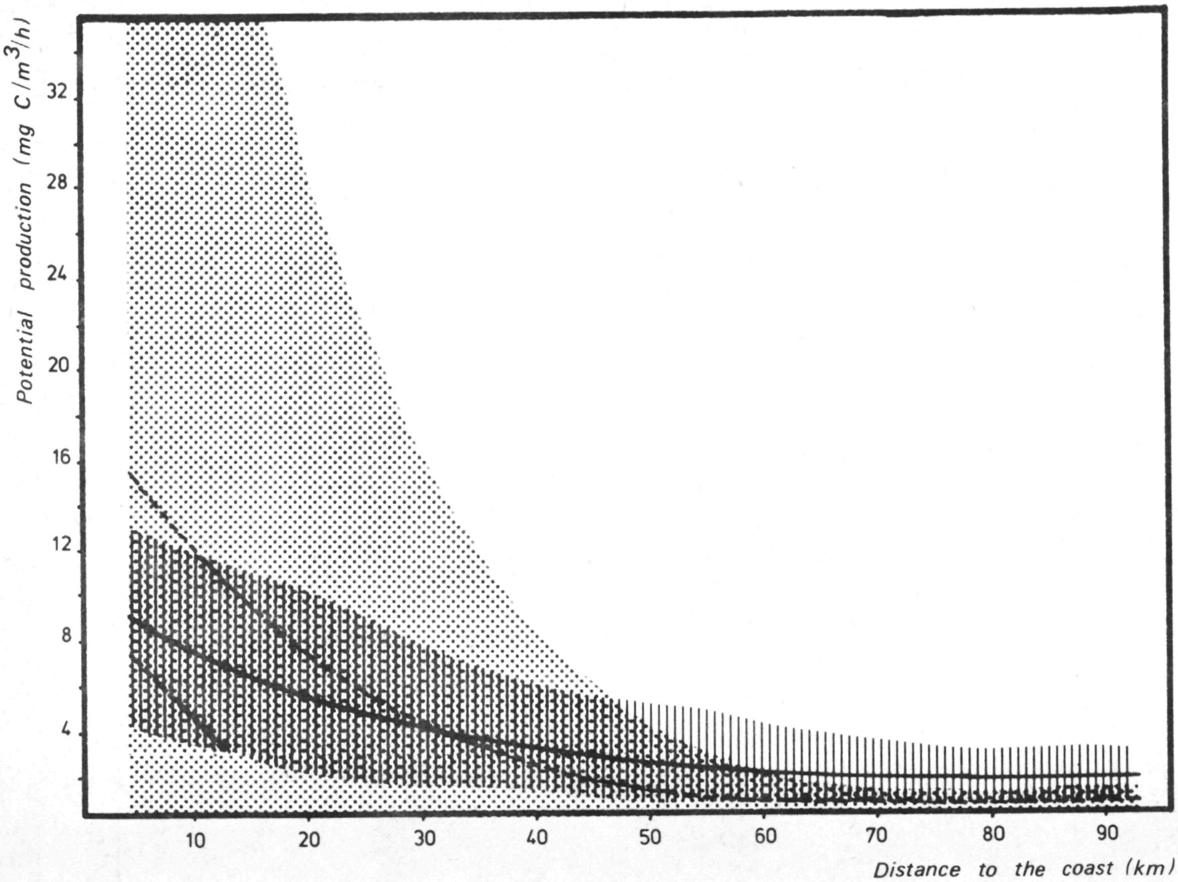


fig. 6.4.
Average horizontal distribution pattern of potential production, averaged for the year (stippled line : netplankton; solid line : nannoplankton). The dotted area shows the range of variations for netplankton. The hatched area shows the range of nannoplankton variations.

higher production figures. However, results collected from a single central sampling station are very representative for most of the area.

An important phytobenthic community of macrophytic seaweeds can develop in the Sluice Dock as relatively high irradiance levels (commonly 25 % of surface irradiance) are recorded on the bottom. The seaweeds grow mainly at the periphery. Biomasses are very important. As much as 2 to 3 kg wet weight/m^2 have been recorded in July. At this time of the year the total Sluice Dock phytobenthic production amounts to about one third of that of the phytoplankton [Podamo Jo (1973a)].

Seasonal variations recorded in the Sluice Dock [Podamo Jo (1974)] are very different from those observed in the North Sea. In this

Table 6.1

Period	Zone	Production/ m²/d	Total biomass/ m²	Implied biomass/ m²	Available radiation/ m²/d	Efficiency/kcal	
						(1)	(2)
January 71	1S	960	13500	2250	52000	0.82	0.13
June-July 71	1S	6420	37530	5000	440000	0.29	0.03
	2	7220	37170	15930	440000	0.10	0.04
August 71	1N	18420	46620	15150	349000	0.35	0.11
	2	9530	28660	18830	349000	0.14	0.09
September 71	1S	7000	53520	10700	289000	0.22	0.04
	1N	15000	107190	32150	289000	0.16	0.04
	2	7320	28350	15390	289000	0.16	0.08
January 72	1S	520	9040	1500	52000	0.66	0.11
	1N	1550	4500	3370	52000	0.88	0.66
	2	1290	9450	3510	52000	0.70	0.26
April 72	1S	3150	24570	6550	302000	0.15	0.04
	1N	3440	19440	5340	302000	0.20	0.05
	2	3320	11180	6070	302000	0.18	0.09
June-July 72	1S	7160	13770	10100	440000	0.16	0.11
	1N	7300	9450	9450	440000	0.17	0.17
	2	5670	13230	13230	440000	0.10	0.09
September 72	1S	3800	20110	6030	289000	0.21	0.06
	1N	5750	48150	14440	289000	0.13	0.04
	2	5080	10710	5200	289000	0.34	0.16
October 72	1S	4880	17680	6480	176000	0.42	0.15
	2	4390	4450	4390	176000	0.56	0.55
January 73	1S	1180	4110	1370	52000	1.65	0.55
	2	1200	3920	1570	52000	1.47	0.58
April 73	1S	4950	81670	13610	302000	0.10	0.01
	1N	6260	49220	17220	302000	0.12	0.04
	2	2470	15570	4000	302000	0.20	0.05
June 73	1S	3400	13420	2230	435000	0.35	0.05
	1N	13250	30140	24110	435000	0.12	0.10
	2	1090	5350	3520	435000	0.07	0.04

All parameters in gcal.

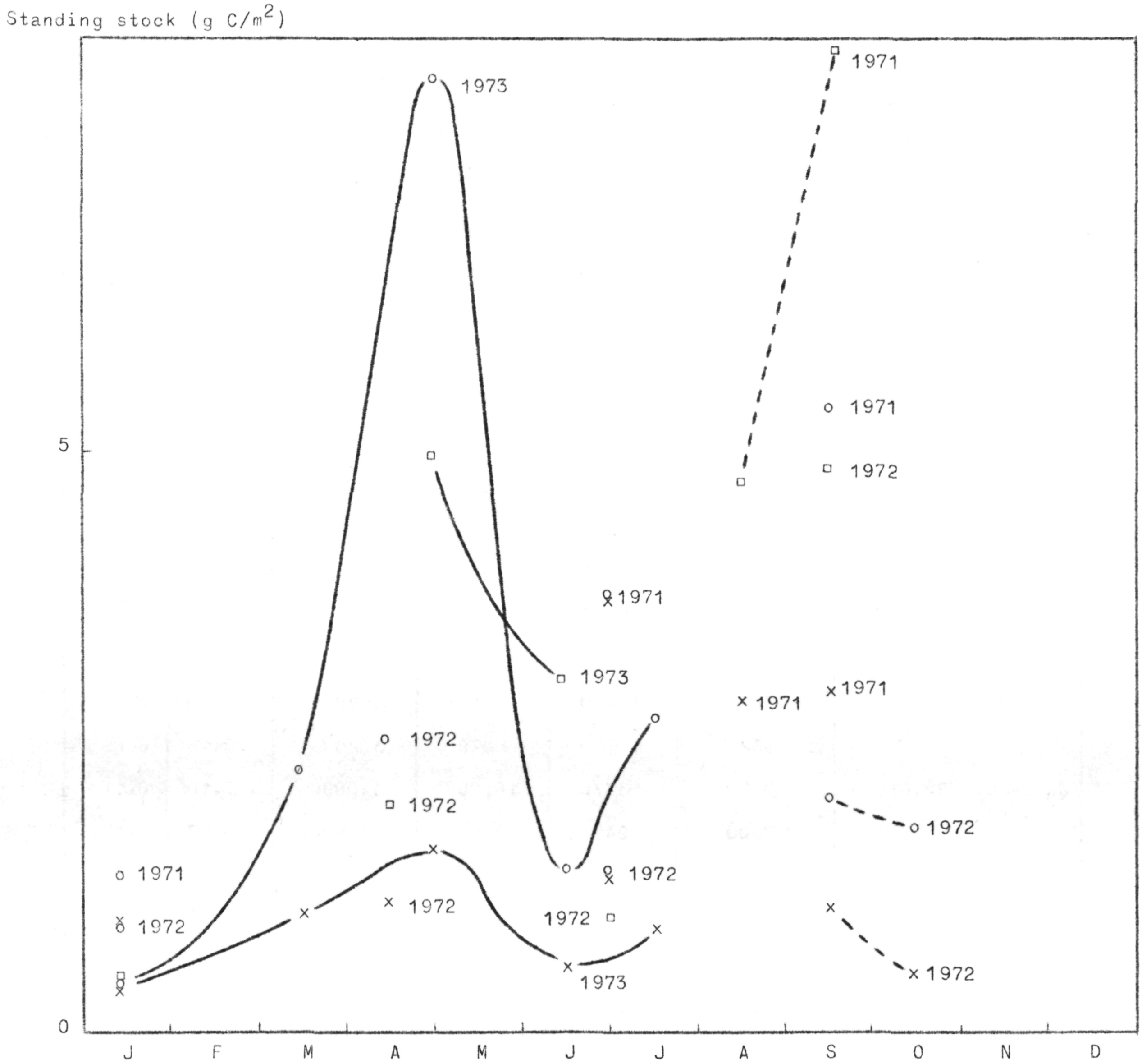


fig. 6.5.

Annual variation of phytoplankton standing stock in the Southern Bight of the North Sea known from the different cruises. A sufficient frequency of samplings allows the 1973 results to be linked (circles : zone 1S ; crosses : zone 2 ; squares : zone 1N).

particular environment, low production levels are observed until the end of May. Grazing is the main limiting factor in May. From June to the end of August, production is very important (fig. 6.6). This is only possible with a very efficient recycling of the nutrients.

Nycthemeral cycles of production observed at various times of the year show typical features. One of those cycles has been particularly

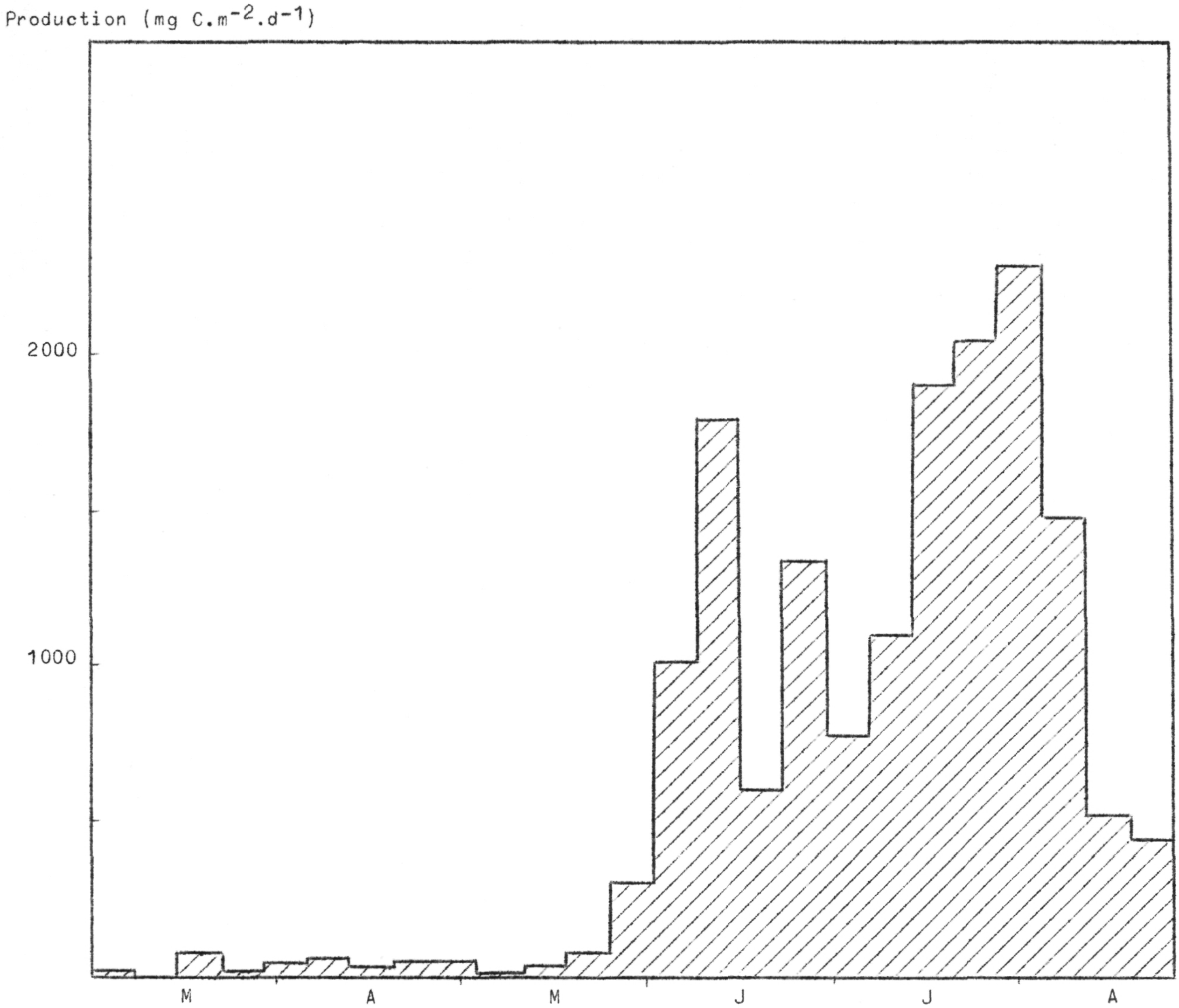


fig. 6.6.
Annual variation of phytoplankton production in the Sluice Dock at Ostend, in 1972.

studied in a slow variation period (May) [Mommaerts (1973g)]. Fig. 6.7 shows the evolution of potential production, chlorophyll a and phaeophytin a on 28.5.1973.

As a result of primary production, the phytoplanktonic biomass increases in the day time (as shown in the simultaneous fluctuations of chlorophyll a and potential production) until a peak is reached at the end of the afternoon. Phaeophytin a peaks seem to correspond to decay periods (especially at night). Figure 6.8 shows the production-mortality balance computed for 30 min intervals. The mortality factor operates

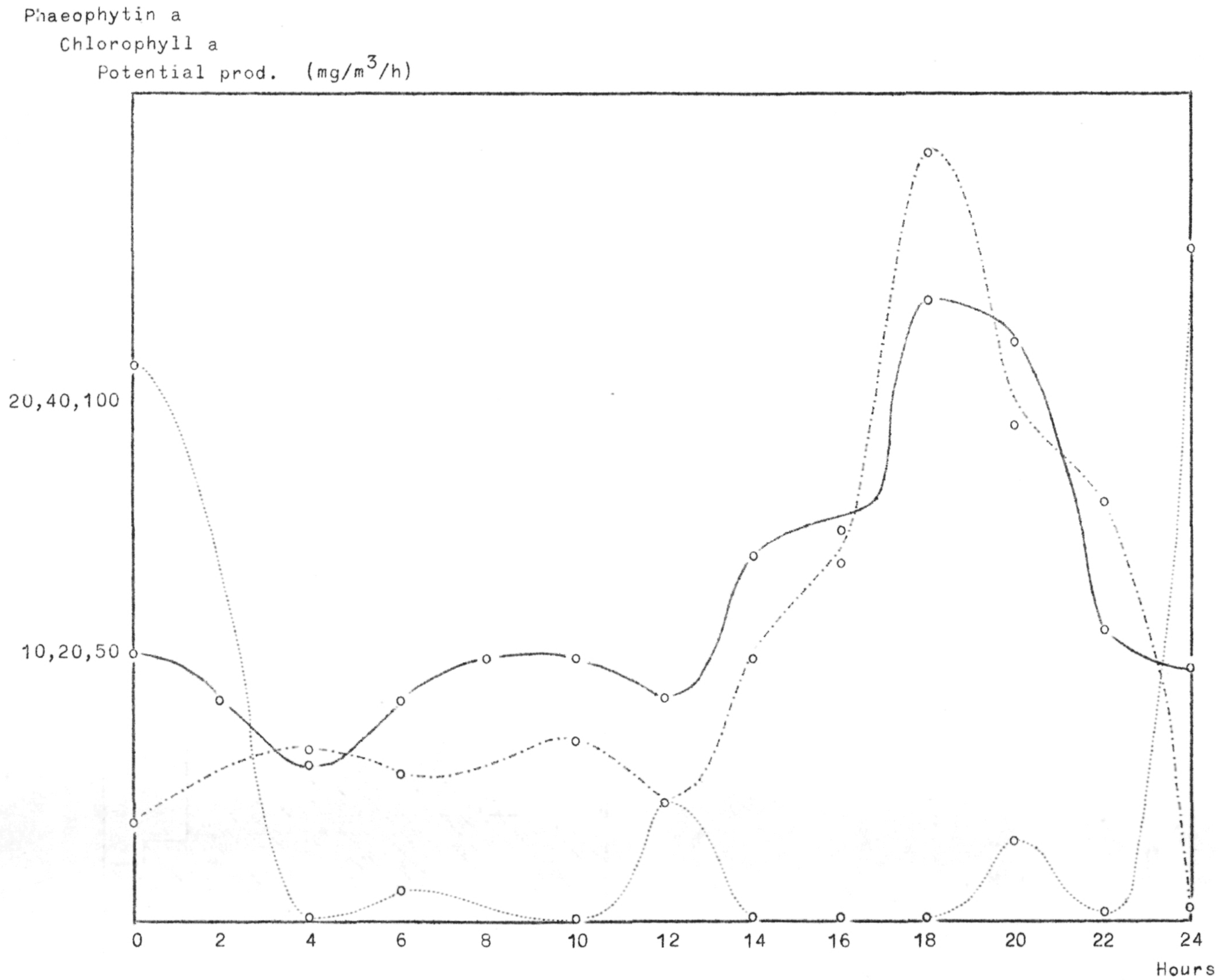


fig. 6.7.
Nycthemeral variation of potential production (solid line), chlorophyll a (dots and dashes) and phaeophytin a (dotted line) in the Sluice Dock at Ostend on 29th May 1973.

at day but is most important at night. Correspondingly, biomass increases are limited and ultimately annulled. The relative importance of grazing in the mortality measured on this particular day could not be determined. We think that such a cycle could explain the slow variation pattern demonstrated in May and perhaps also those observed at sea.

1.2.2.- Productivity

The ratio $\frac{\text{potential production}}{\text{biomass}}$ (productivity) reflects the physiological condition of the phytoplankton community at the sampling station as well as its specific composition.

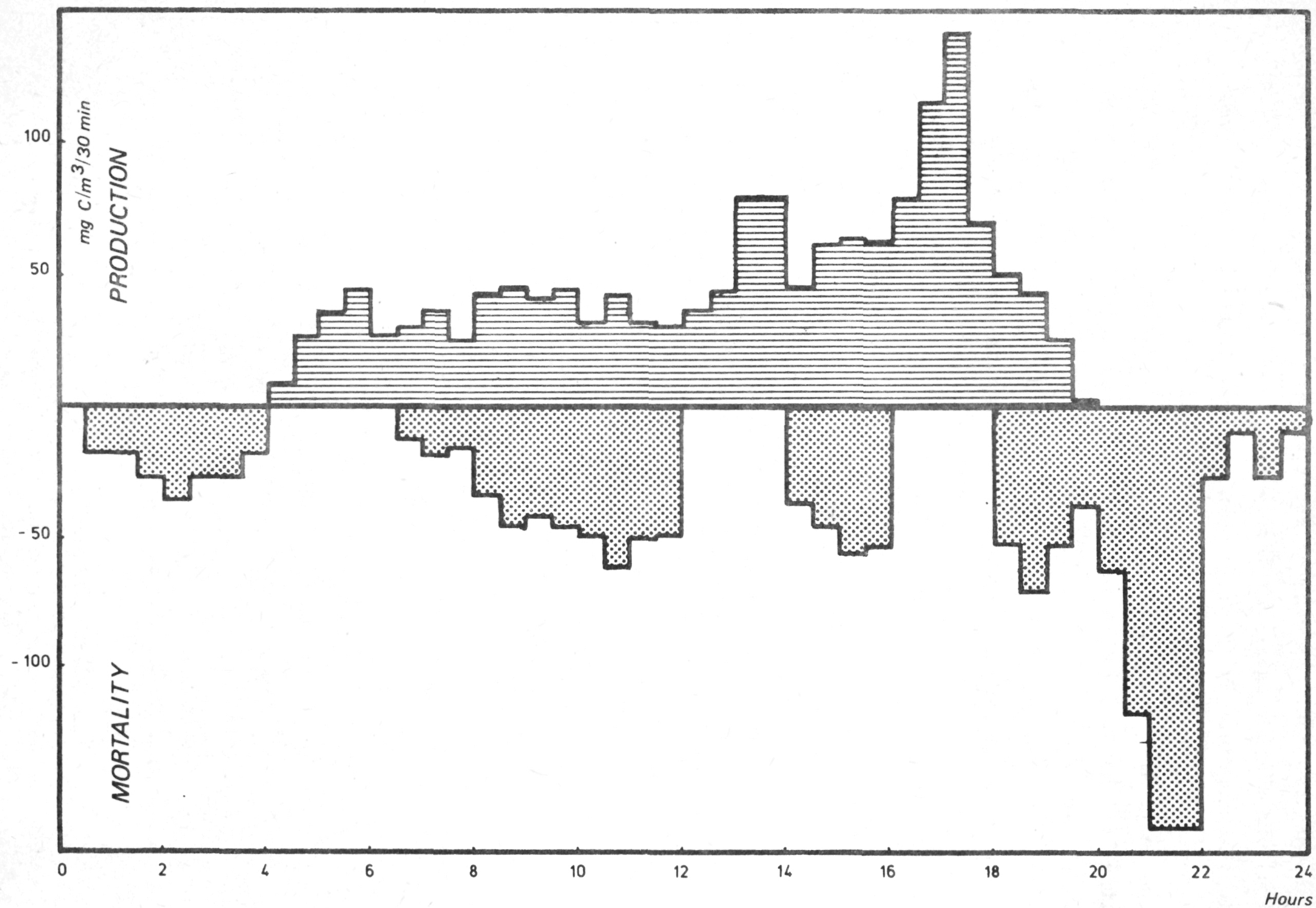


fig. 6.8.

Production-mortality balance computed for the 29th May 1973 cycle. The actual production increment for each 30 min block is the sum of mortality (-) and production (+) figures.

In the first case it can reflect the effect of environmental modifications. Population ageing or internal rhythms are corollary effects. Examples are provided by the lower winter figures (temperature effect), the abnormal figures recorded at sampling stations 6 and 7, July 1971 (environmental disturbance) [Mommaerts (1973b)]. An example of seasonal transition is observed in the Sluice Dock at Ostend when productivity is in full augmentation however nothing of this appears from production measurements [Podamo Jo (1974)]. Indeed, at this time of the year (May), the phytoplanktonic biomass remains low as zooplankton is actively grazing on it.

Nycthemeral variations of productivity reflect also physiological modifications. Such variations have been demonstrated in the North Sea [Mommaerts (1973g)]. One has recorded a peak of maximal endogenous activity at the time of optimal daylight intensity (noon in the winter and later in the afternoon at the end of spring) (fig. 6.9).

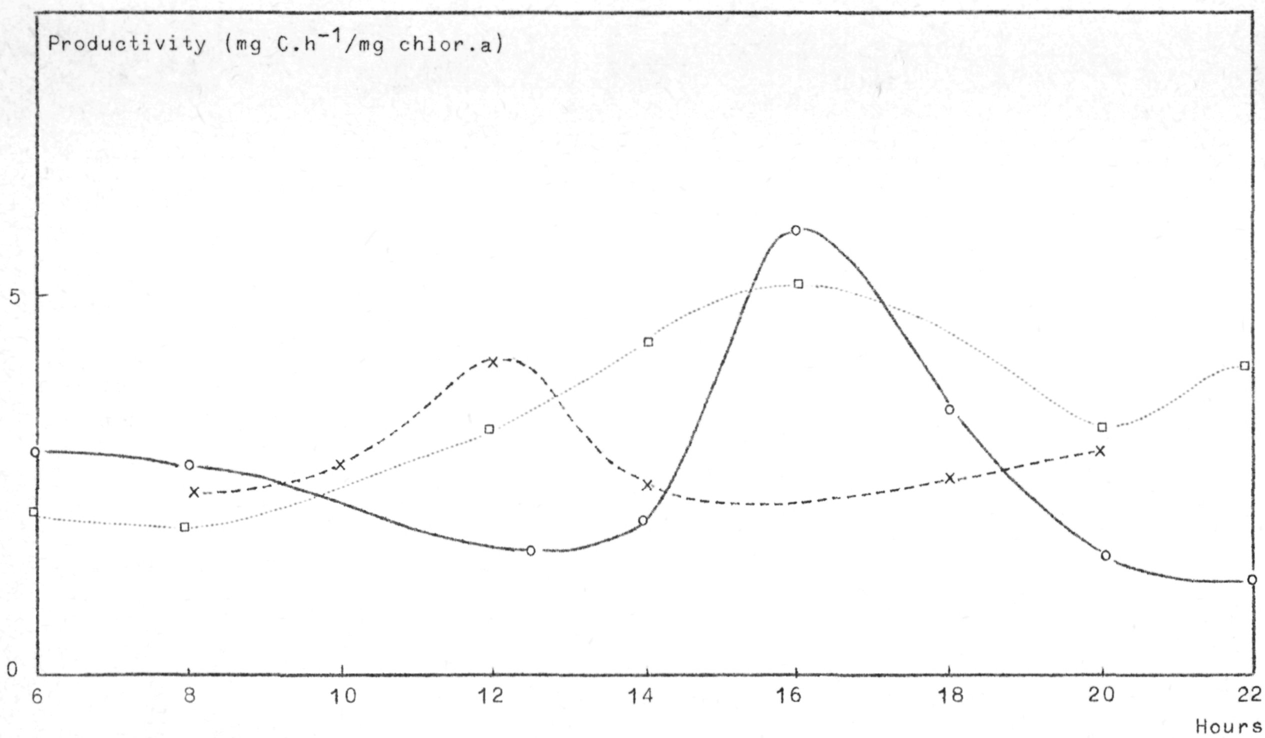


fig. 6.9.

Nycthemeral variation of productivity (P/B ratio) in the Southern Bight, at sampling station 16, 8th May 1973 (solid line); sampling station 1, 24th January 1973 (stippled line) and sampling station 6, 7th June 1973 (dotted line).

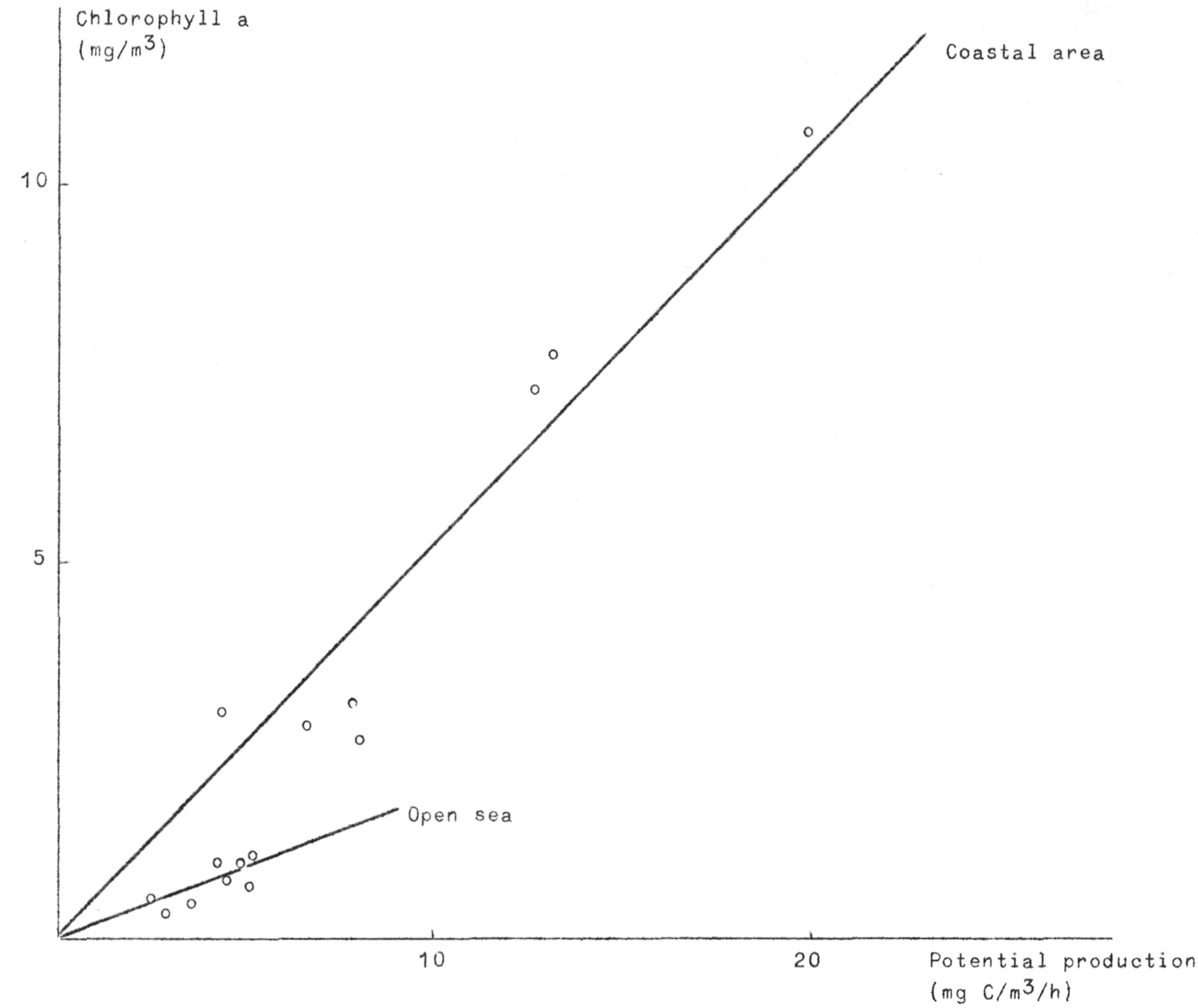


fig. 6.10.
Potential production - chlorophyll a relationship in the Southern Bight of the North Sea, in September 1972.

Where the specific composition is concerned, an example is found in the differences recorded between open sea and coastal water productivity figures [Mommaerts (1973g)]. Productivity is higher in the open sea, where nannoplankton is dominant. On the contrary, figures recorded for coastal waters where netplankton is dominant are lower (fig. 6.10).

1.2.3.- <u>Light-temperature adaptation properties</u>

With production measurements made simultaneously *in situ* and *in vitro*, one has computed photosynthesis-light diagrams for many sampling stations and cruises (fig. 6.11) [Mommaerts (1973g)]. From each diagram

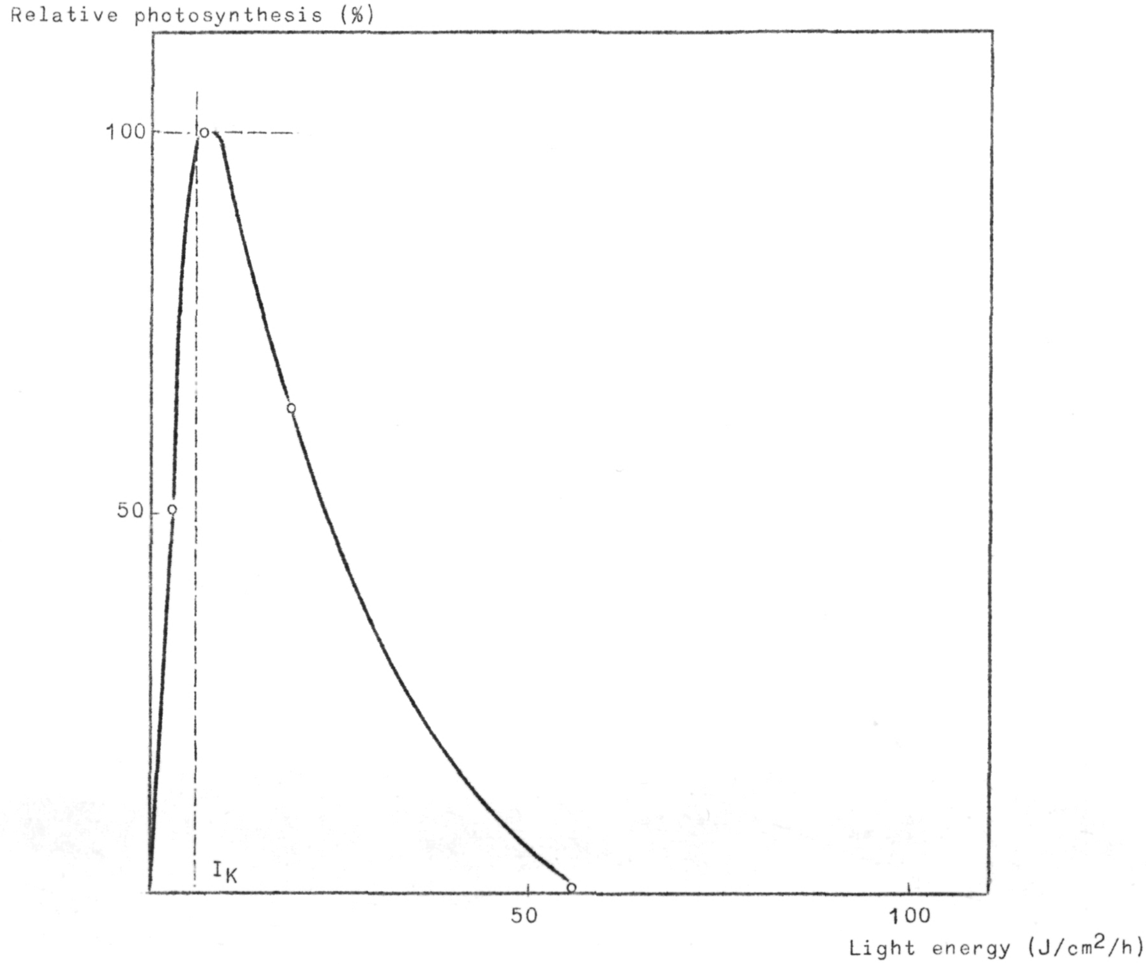


fig. 6.11.
Photosynthesis-light diagram for phytoplankton collected at sampling station 61, 17th April 1972, in the Southern Bight of the North Sea.

one can calculate a light intensity I_K (defined as the intensity at which the onset of photosynthesis saturation is recorded) which measures the light-adaptation property of the phytoplankton community at sampling time. A small I_K corresponds to a better efficiency of light energy utilization. In the North Sea, figures ranging between 2 and 34 $J/cm^2/h$ (P.A.R.) have been recorded. In the Sluice Dock (fig. 6.12) at Ostend however, I_K figures are always higher (about 50 $J/cm^2/h$) . Another difference is the strong photoinhibition pattern that is exhibited immediately after saturation (no real plateau) for North Sea phytoplankton while the Sluice Dock phytoplankton shows almost no photoinhibition in the range of light intensities recorded (up to 200 $J/cm^2/h$) . These

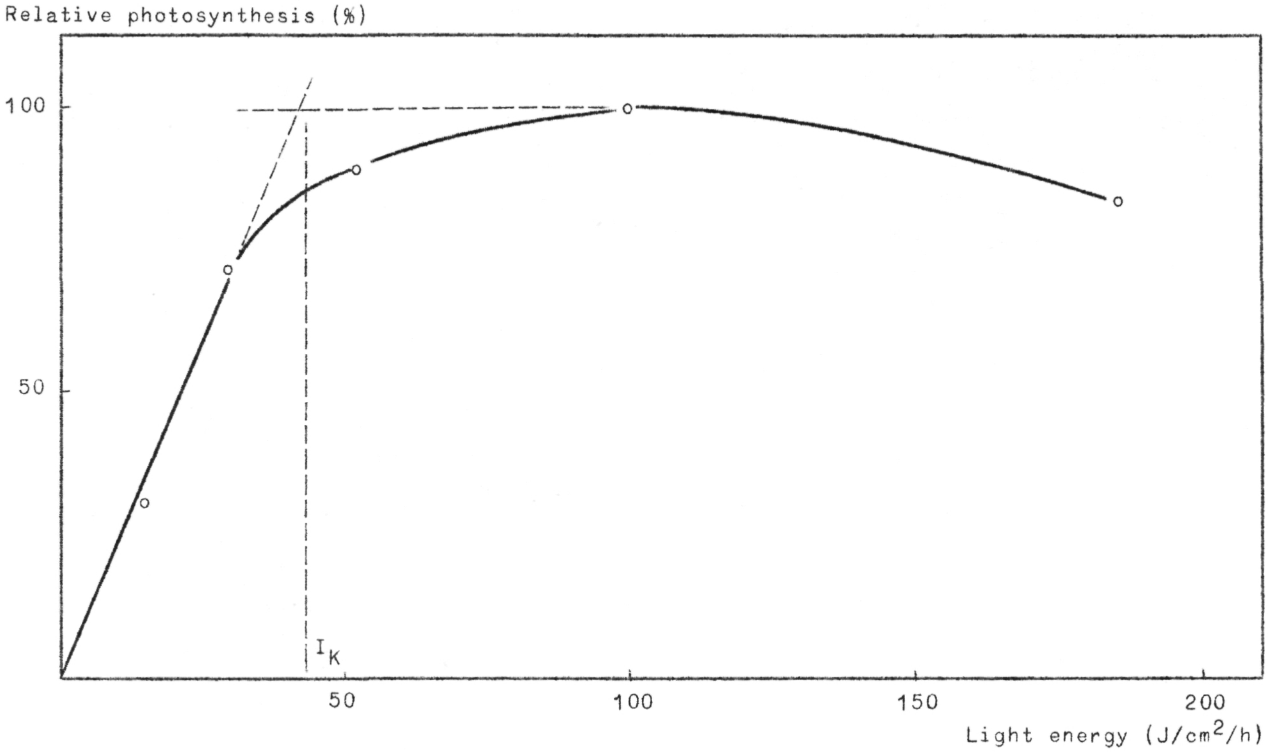


fig. 6.12.
Photosynthesis-light diagram for phytoplankton collected on 2d May 1973 in the Sluice Dock at Ostend.

differences probably reflect the adaptation of the North Sea phytoplankton to the lower average illumination conditions that prevail in this environment.

I_K is also temperature-sensitive. Lower winter figures have an ecological importance as saturation of photosynthesis is reached at deeper levels. Hence, the effect of poor illumination conditions is partially compensated by an improved utilization of light energy in the water column.

Finally, diurnal variations of I_K have been observed in the Sluice Dock and are at study.

1.2.4.- Integrated production

The spatial distribution of phytoplankton in the North Sea being known, and having determined :

1) the variation mechanisms of productivity [Production = f (Biomass) with light energy kept constant].

2) the variation mechanisms of light adaptation [Production = f (Light energy) with biomass kept constant],

one can feed these parameters in an integrated production model. The absorption coefficient of the water for photosynthetically available radiation η and the incident radiation I_0 are also used in such a model [*e.g.* Vollenweider (1965), Mommaerts (1973g)].

Hence, spatial distribution of potential production (as well as pigments) does not strictly reflect that of real *in situ* primary production. It was demonstrated that the low transparency of coastal waters limits the primary production in such a way that only a fraction (upper layer) of the phytoplanktonic biomass is implied in photosynthesis. This has a considerable levelling effect on differences between zones (fig. 6.13).

But this also means a difference in yields [Mommaerts (1973g)]. Expressed as efficiency percentage of energy transfer per Kcal of total biomass under a m^2, one finds on an average 0.11 % in zone 1-South, 0.15 % in zone 1-N and 0.18 % in zone 2. Hence the flux of organic matter through the phytoplankton is about 1.5 times greater in the open sea than that measured in the coastal fringe (Table 6.1).

1.3.- Conclusion

The Southern Bight of the North Sea and the Sluice Dock at Ostend have been surveyed intensively so that we have a fairly good picture of spatial and temporal variations of phytoplankton activity, by now. A further insight on production mechanisms was given by the study of productivity ($\frac{P}{B}$ ratio) and light adaptation variations. Still there is much left to do in this respect especially in connection with the nutrients availability. In the same connection, the study of specific nutrient uptake abilities could help in the understanding of the succession or the spatial distribution of phytoplanktonic populations. The differences observed between netplankton and nannoplankton are probably relevant to this problem.

The study of the effect of zooplankton grazing on phytoplankton production is also scheduled. Studies on phytoplankton mortality have already been started in 24 h observation cycles. On the other hand

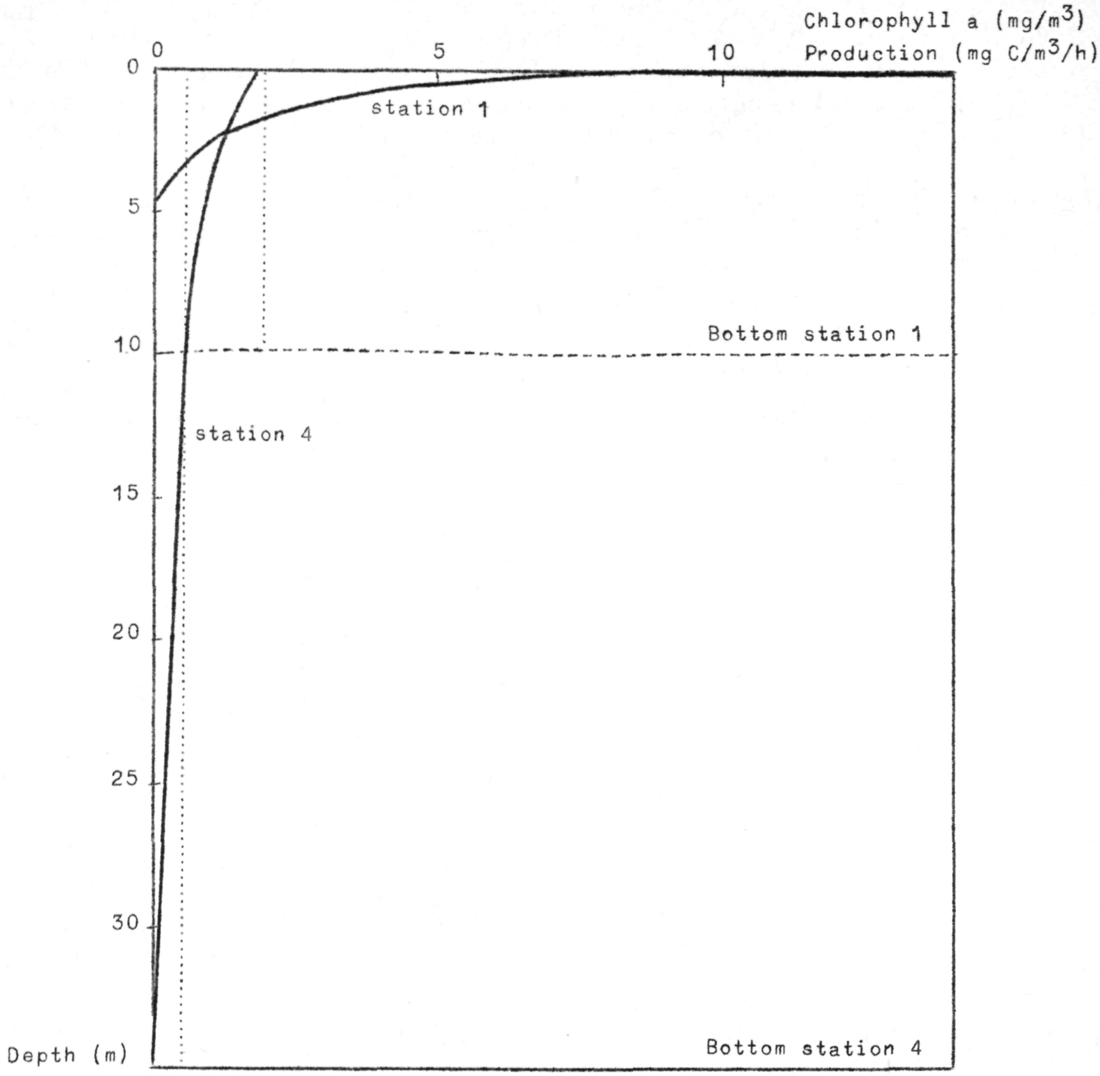


fig. 6.13.
Production (solid line) and chlorophyll a (dotted line) vertical profiles at sampling stations 1, 11th October 1972, and 4, 12th October 1972, in the Southern Bight of the North Sea.

some *in situ* experiments (unpublished) have shown an enhancement of primary production when the phytoplankton was exposed to the influence of zooplankton. Grazing effect and enhancement set an interesting interaction problem.

The problem of production modelling remains. First attempts concern only static solutions. One hopes to feed more interaction parameters and variation laws in successively improved models.

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2.- Zooplankton

2.1.- Introduction

The quantitative and qualitative evolution of zooplankton has been studied for several years at the Sluice Dock at Ostend [Leloup and Polk (1967), Daro and Soroa (1970), Daro (in preparation)], in 1970, 1971 and 1972 in the North Sea in a zone of 20 km^2 near the shore (zone 1S) by monthly sampling and in the Southern Bight of the North Sea (Mathematical model of the North Sea network) during the cruises in 1971, 1972 and 1973.

The description of the spatial and temporal distribution of the zooplankton different species in the North Sea [Polk (1971), Bossicart, Hecq, Heyden, Houvenaghel and Polk (1972)] is followed by a description of their metabolic activity and their role in the ecosystem.

An approach for the calculation of the secondary production is proposed.

2.2.- Methods

2.2.1.- In the Sluice Dock at Ostend

Weekly sampling by filtering 50 ℓ water through a 48 μ mesh net gives us the year cycli on a quantitative and qualitative basis. A composed net was designed to study the nycthemeral vertical migrations [Daro (1974)] and observations by a binocular was done on living material in the field laboratory to study the ethology and autoecology of the dominant species [Daro (1973)].

2.2.2.- Lombardzijde

Monthly quantitative sampling was obtained by filtering 50 ℓ water in a plankton net of 48 μ meshes; 9 points were sampled in a 20 km^2 zone.

2.2.3.- Southern Bight of the North Sea

Sampling of zooplankton was done during the cruises at each point of the network as in §2.2.2 (Qualitative sampling was done with a

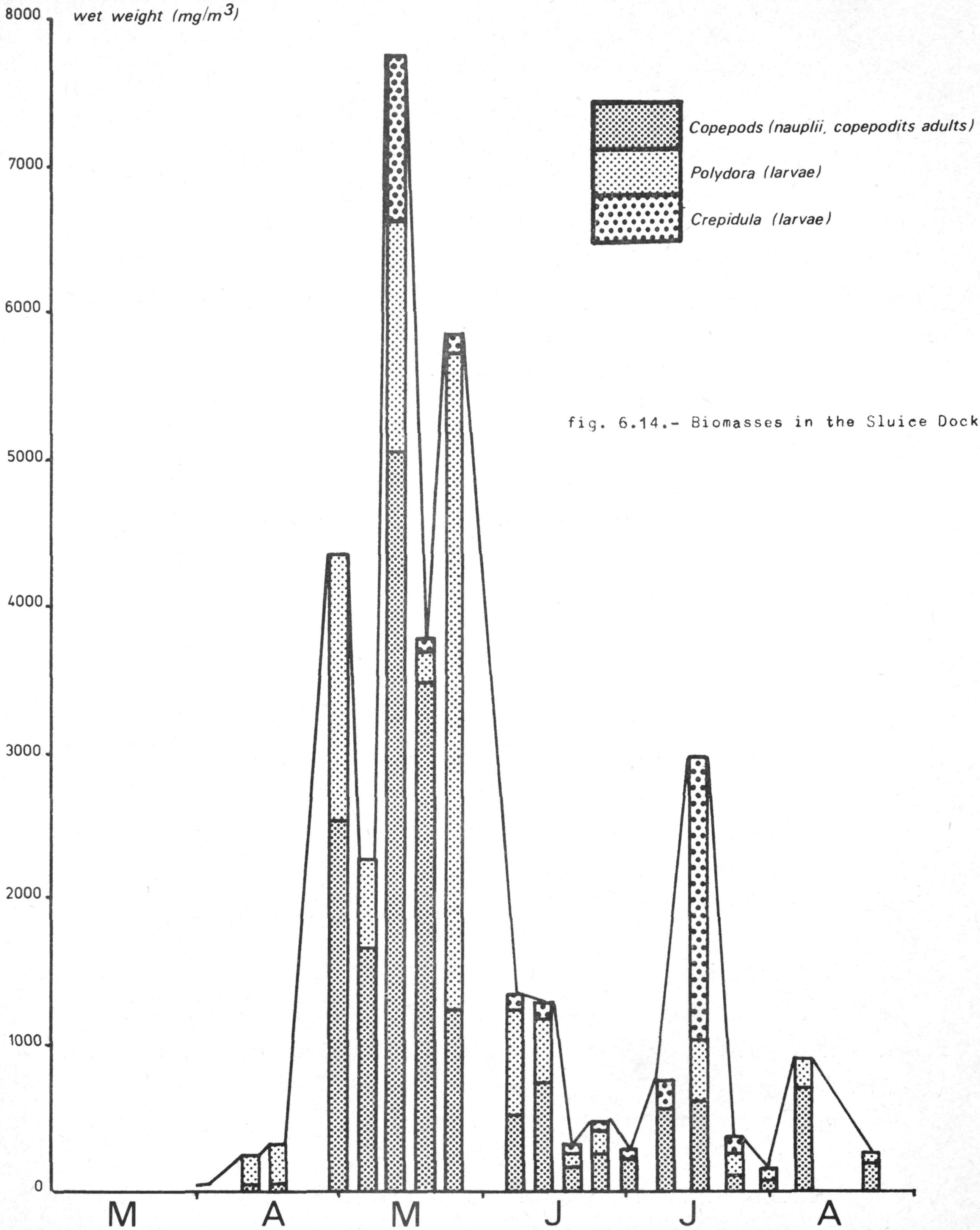


fig. 6.14.- Biomasses in the Sluice Dock.

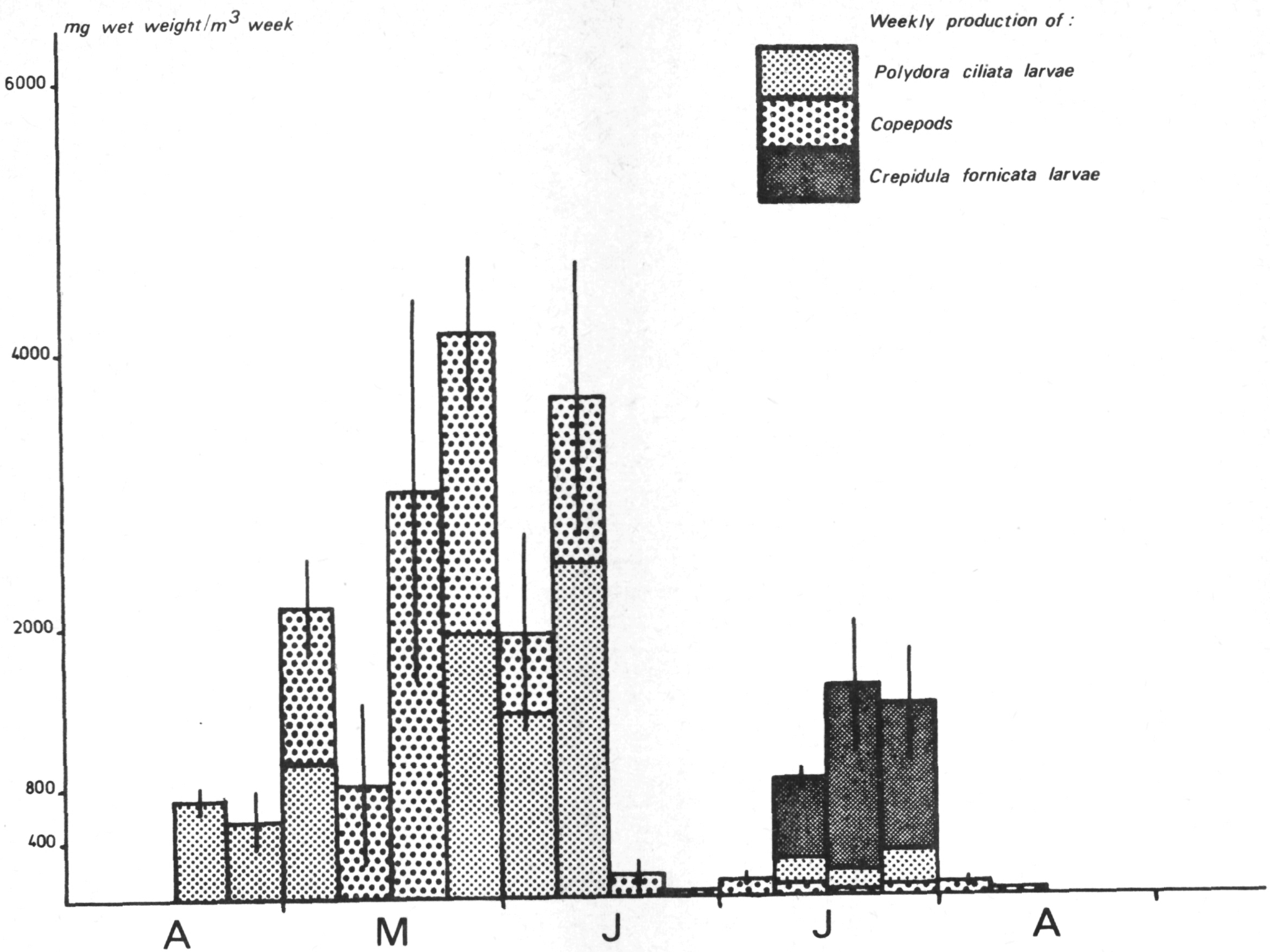


fig. 6.15.- Secondary production in the Sluice Dock.

zooplankton net of 200 µ meshes by hauls of ± 15 min). Respiration rates were carried out on the ship by incubation of zooplankton in dark bottles Winkler of 300 mℓ , at the temperature of the sea water during 9 h time. Oxygen was determined by the Winkler method (see Hecq).

2.3.- Results

2.3.1.- Sluice Dock

a) Distribution

The horizontal distribution in the Sluice Dock is homogeneous; vertical nycthemeral migrations were studied. Specific migrations patterns are established for the dominant species and their age classes [Daro (1973), Daro (1974)].

b) Secondary production

The evolution of the biomass during the year shows the dominancy of 4 species all herbivorous (fig. 6.14). To calculate the secondary production, we used the method of Winberg [Winberg (1970)]. Full details are found in Podamo Jo (1974).

The weekly production of each species is calculated for a 6 month period (fig. 6.15).

2.3.2.- North Sea

a) Distribution

The vertical distribution is homogeneous [Bossicart (1973)]. The horizontal distribution, correlated with hydrodynamics of the North Sea and under the influence of the estuaries [Polk (1972), Bossicart and Daro (1973)] permits us, using the dominant group of Copepoda (biomasses in wet weight) to distinguish three zones (see paragraph 1, Primary production) (figs. 6.16, 6.17, 6.18 and Table 6.2).

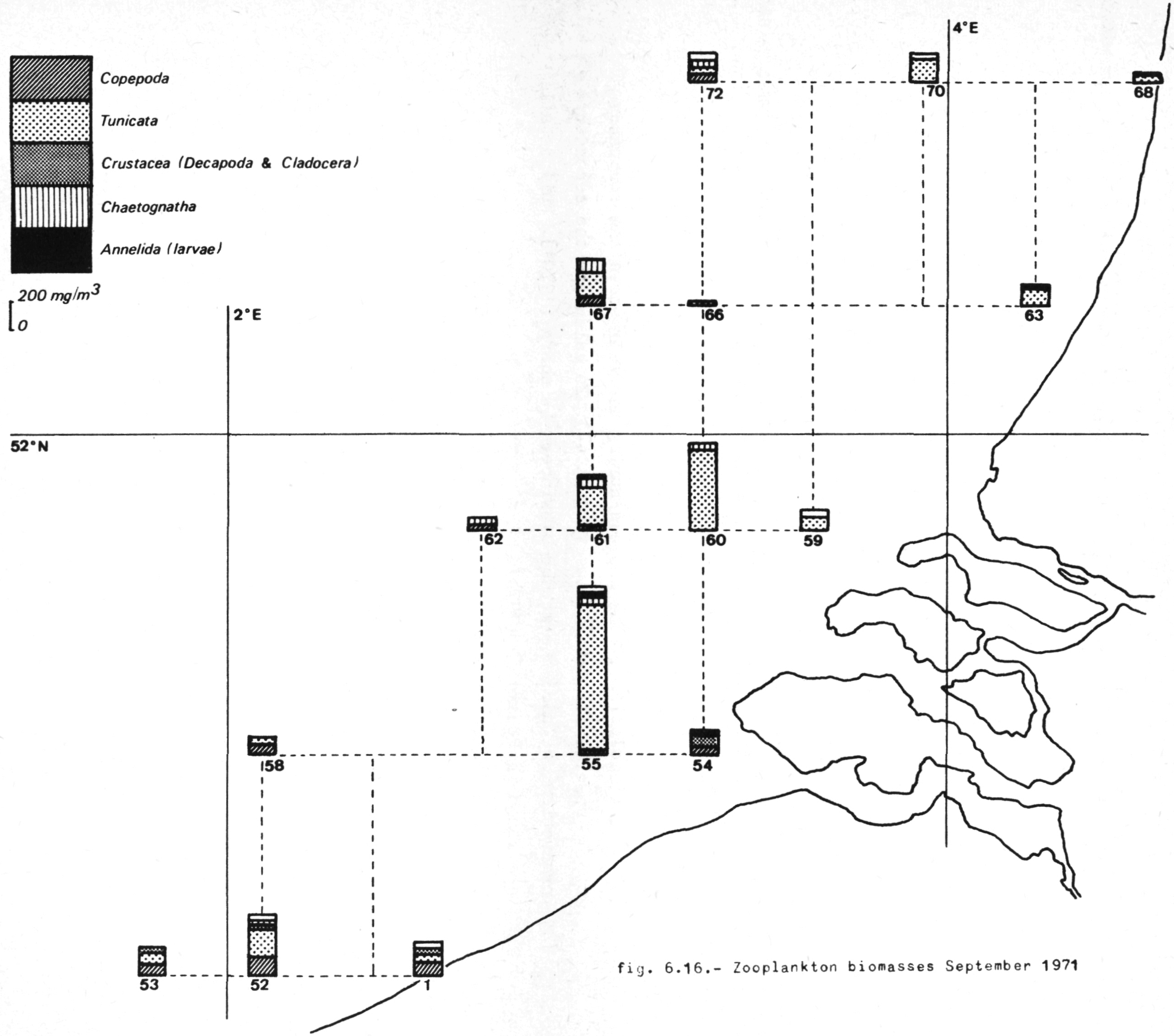


fig. 6.16.- Zooplankton biomasses September 1971

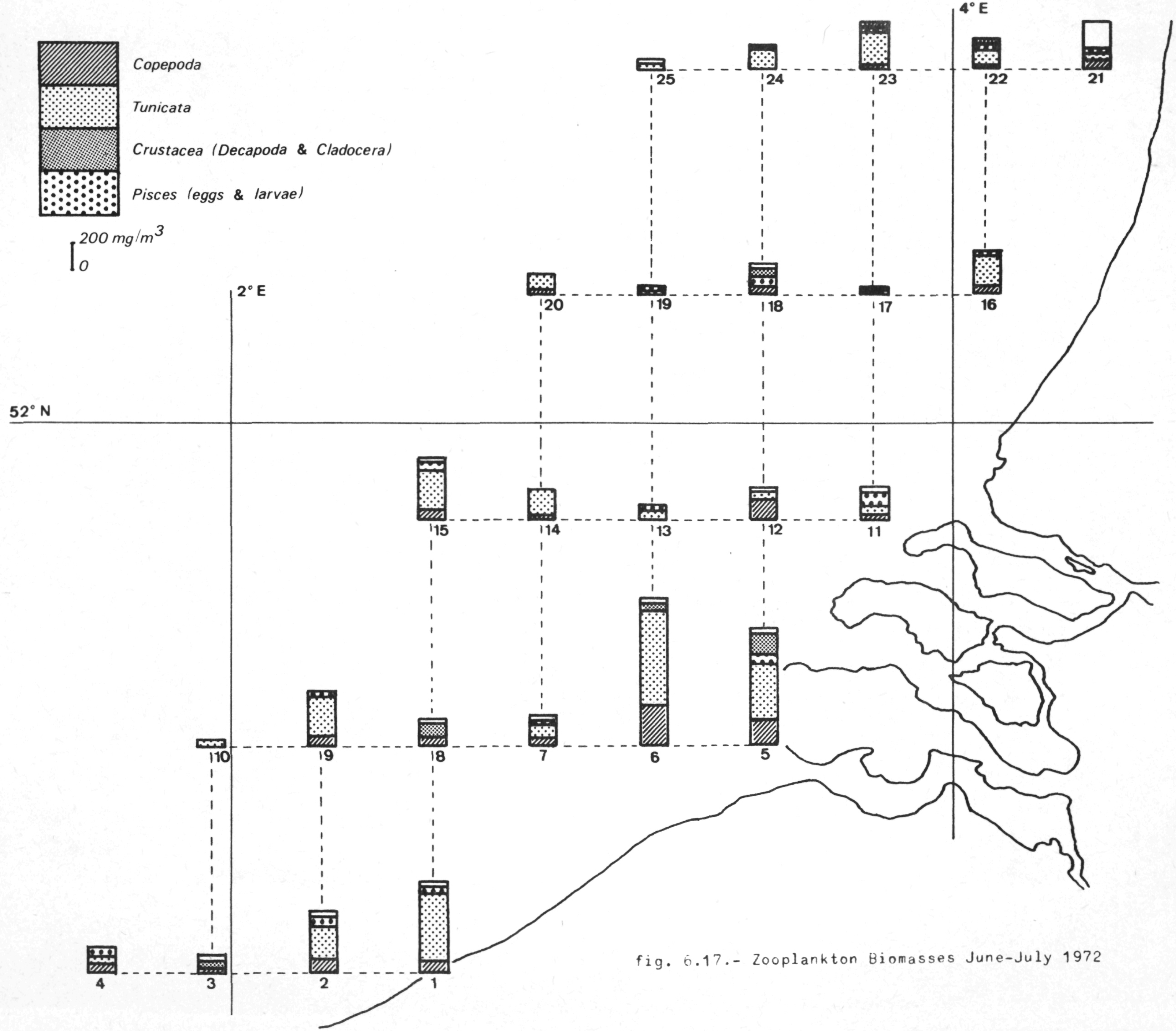


fig. 6.17.- Zooplankton Biomasses June-July 1972

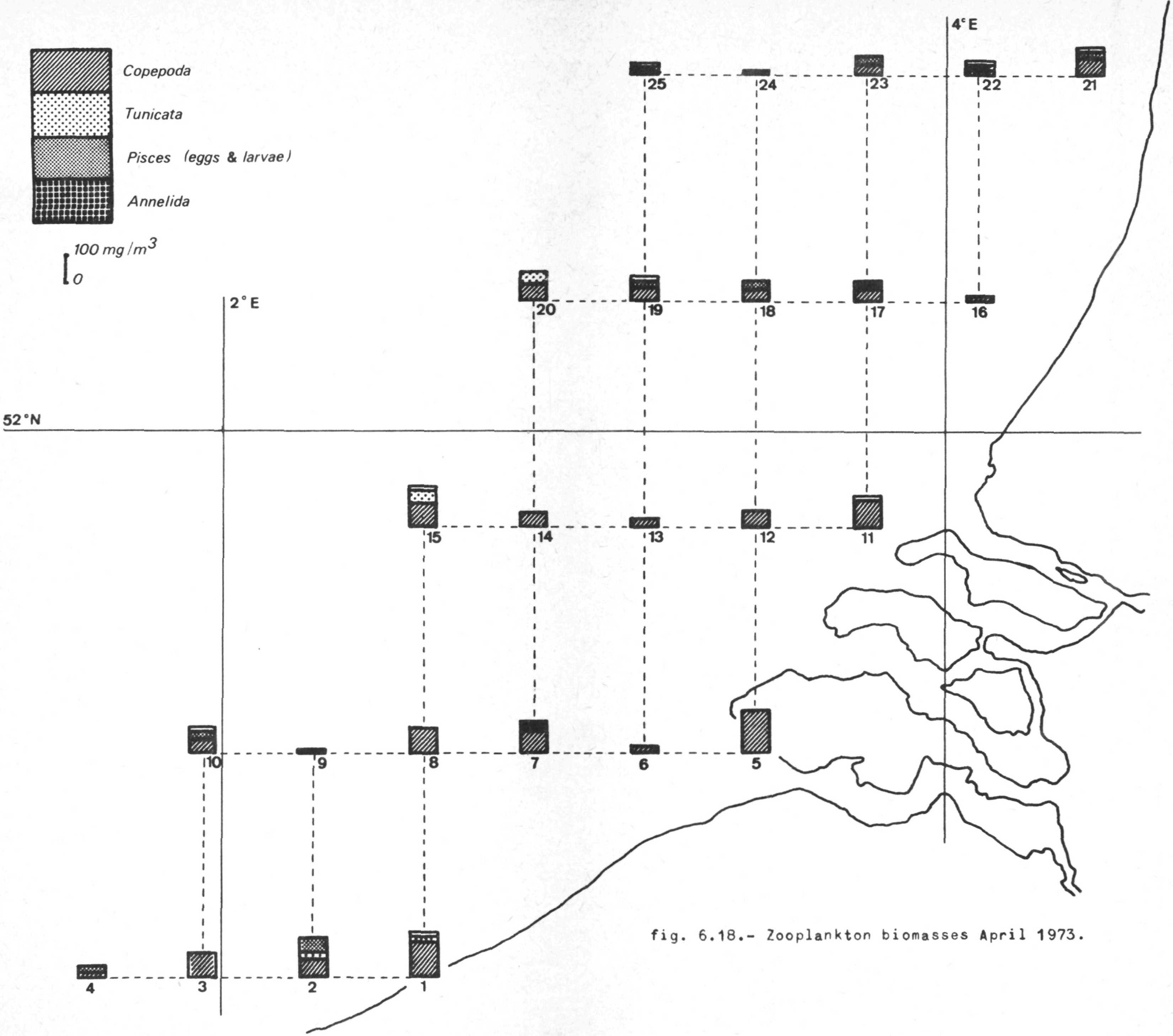


fig. 6.18.- Zooplankton biomasses April 1973.

Table 6.2

Mean values of biomasses of Copepodes per zone / per cruise (net weight/m^3)

Cruise	Zone 1 South	Zone 1 North	Zone 2
April-May 1973	84	31	27
September 1971	75	4	42
September 1972	205	41	80

b) Dominancy

Three groups are dominant : the herbivorous group of Copepods and Tunicates (*Oikopleura*), the carnivorous Chaetogathes [Bossicart and Daro (1973), see figs. 16, 17, 18]. The activities and food ingestion, linked with the biomasses of these groups are retained to calculate the transfers of matter.

c) Food chains

1° Lombardzijde

As the sampling was at regular monthly intervals at Lombardzijde (§ 2.2.2), we used these data to calculate the food chain.

The mean value of the 9 points was used. Using the biomasses (figs. 6.19, 6.20) and the daily food rations [Petipa (1970)] the grazing or predation are calculated (Tables 6.3, 6.4, 6.5 and fig. 6.21).

Table 6.3

Predation of Chaetognatha in 1971 expressed in mg/m^3/month (wet weight)

Month	Predation
June	51
July	331
August	612
September	637
October	153
November	25
Total	1809

Table 6.4

Grazing of Copepods in 1971 expressed in mg/m^3/month (wet weight)

Month	Nauplii	Copepodites	Adults	Total
January	102.3	111.6	65.1	279
February	102.3	111.6	65.1	279
March	174.3	231	101.2	506.5
April	553	385	63	1001
May	503.5	849.4	194.1	1547
June	999.8	1633.6	591.5	3225
July	802.2	1578.5	1657.6	4038.3
August	685	1719.3	1504	3908.3
September	356.5	1417	476.8	2250.3
October	882	1617	850.5	3359.5
November	651	859	945	2454
December	198	216	315	729
Total	5010	10729	6828.9	23576.9

Table 6.5

Grazing of Oikopleura in 1971 expressed in mg/m^3/month (wet weight)

Month	Grazing
January	78
February	78
March	9.9
April	39
May	156
June	487
July	702
August	877
September	1251
October	731
November	263
December	39
Total	4710.9

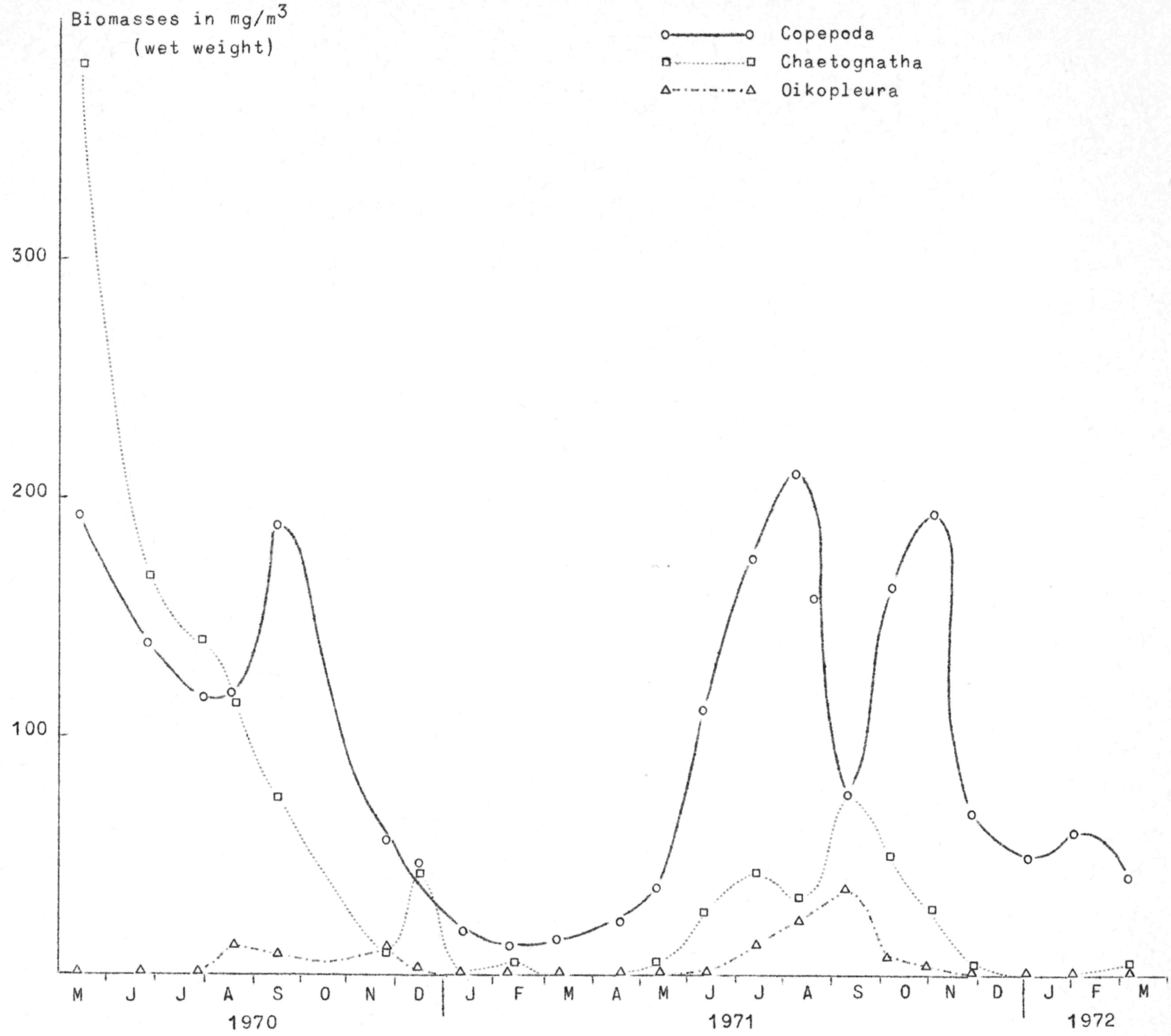
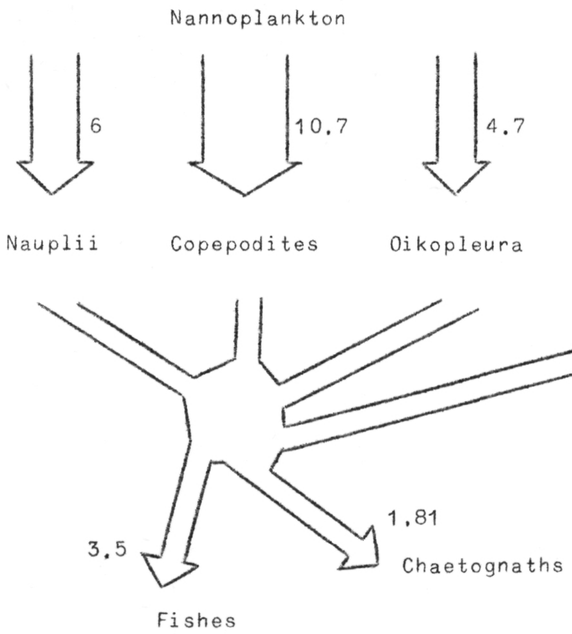


fig. 6.19.- Lombardzijde biomasses Copepoda - Tunicata.

Complete food chain

The results of Gulland (1970) permit us to estimate the predation of fishes on herbivores : the fishes use 12.5 % of the total food intake of the herbivores on an annual basis. Total annula is 28,288 mg/m^3 of which predation is 3,536 mg/m^3 by fishes.

The food chain expressed as g wet weight/m^3/year is :



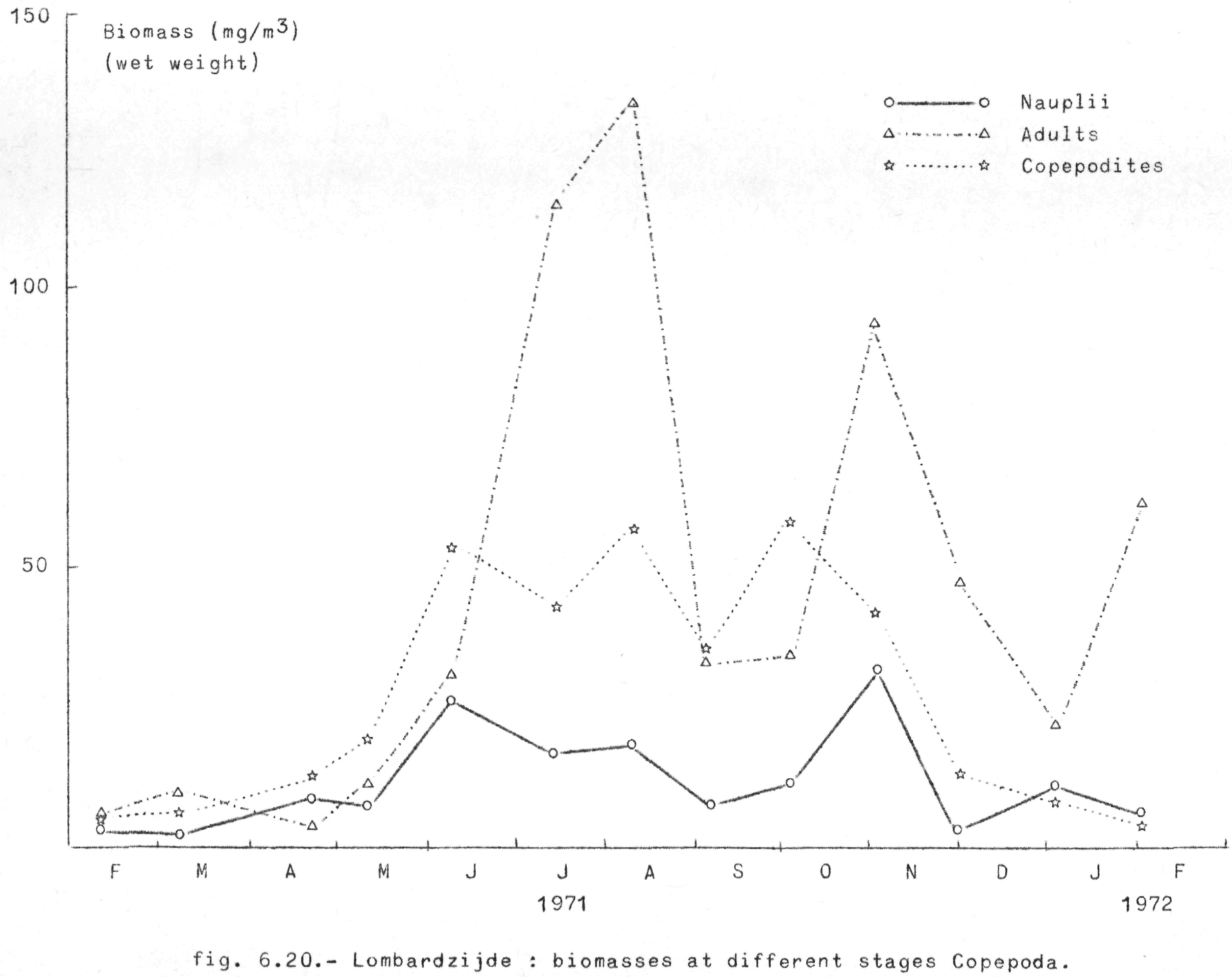


fig. 6.20.- Lombardzijde : biomasses at different stages Copepoda.

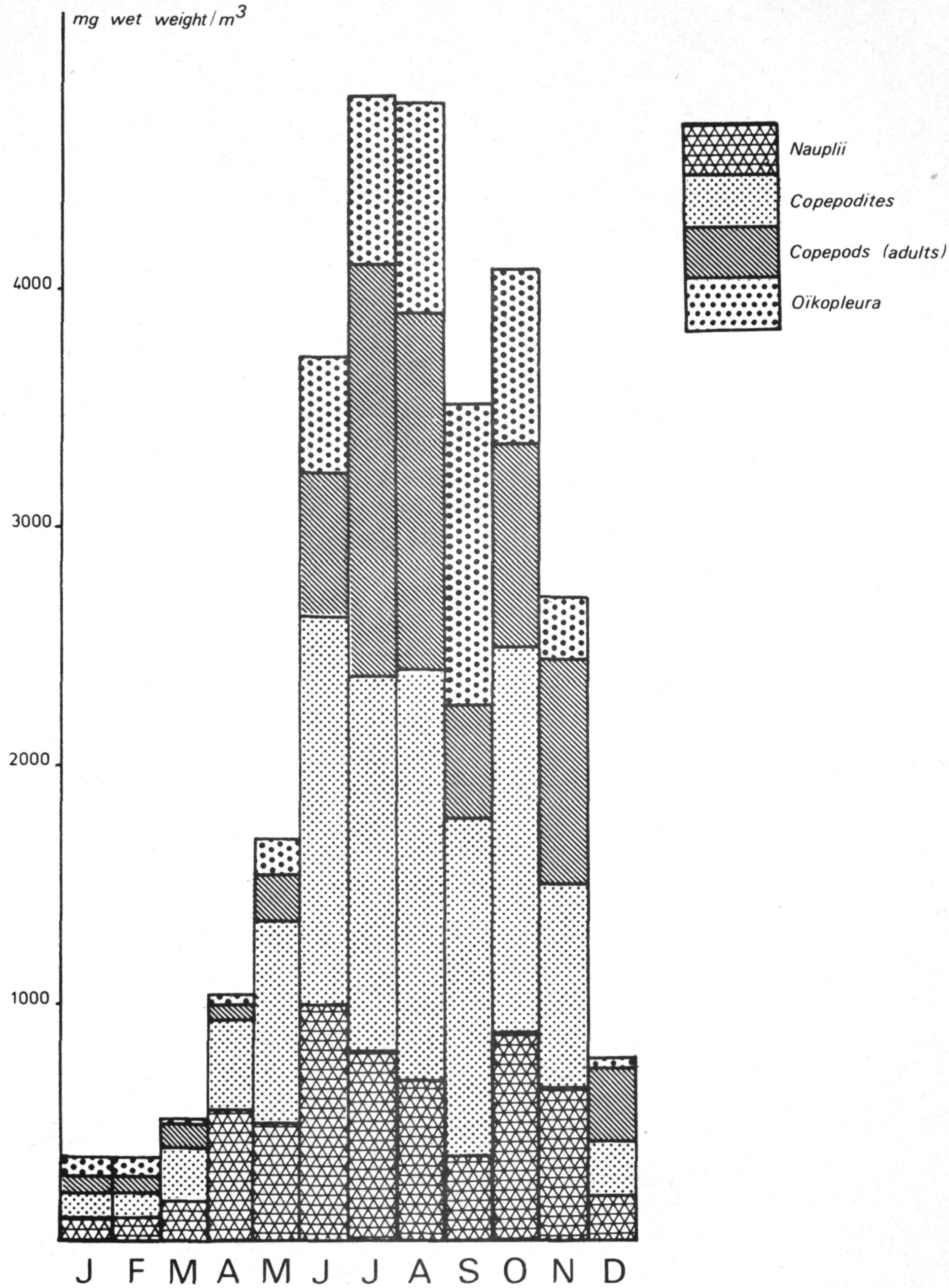


fig. 6.21.- Grazing Copepoda and Oikopleura, Lombardzijde 1971.

2° Grazing in the North Sea

To evaluate the biomasses of the three dominant groups, the mean values of biomasses have been calculated for each zone and cruise (see Table 6.6) and the evolution of the biomasses evaluated (see figs. 6.22, 6.23, 6.24).

Table 6.6

Mean values of biomasses of Copepods, Oikopleura and Chaetognatha expressed in mg/m^3 (wet weight)

Month	Zone 1 South			Zone 1 North			Zone 2		
	Cop.	Oik.	Chaet.	Cop.	Oik.	Chaet.	Cop.	Oik.	Chaet.
July 1971	231	104	0	-	-	-	86	0	0
August 1971	-	-	-	29	225	45	109	62	60
September 1971	75	334	16	4	334	16	42	95	39
January 1972	36	0	0	41	0	0	40	0	0
April 1972	87	185	0	30	2	0	106	174	0
June-July 1972	140	384	0	45	82	0	37	105	0
September 1972	205	50	13	41	224	34	80	28	12
October 1972	182	27	3	-	-	-	82	9	1
April-May 1973	84	9	0	31	3	0	27	10	0

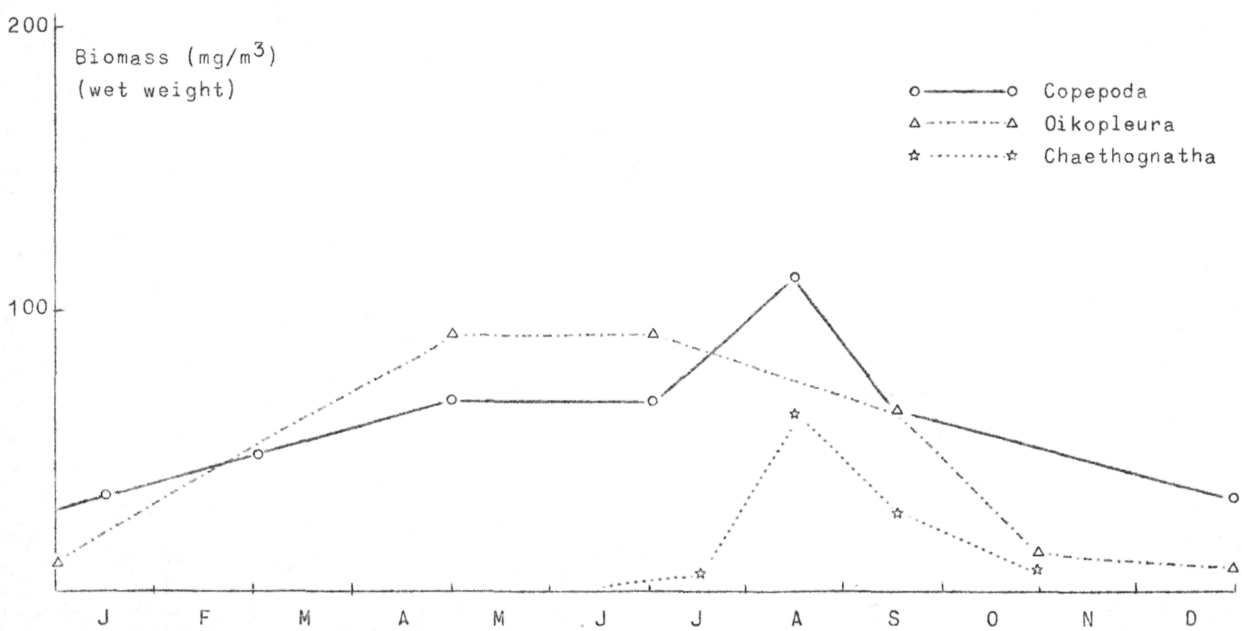


fig. 6.22.- Biomasses zone 2.

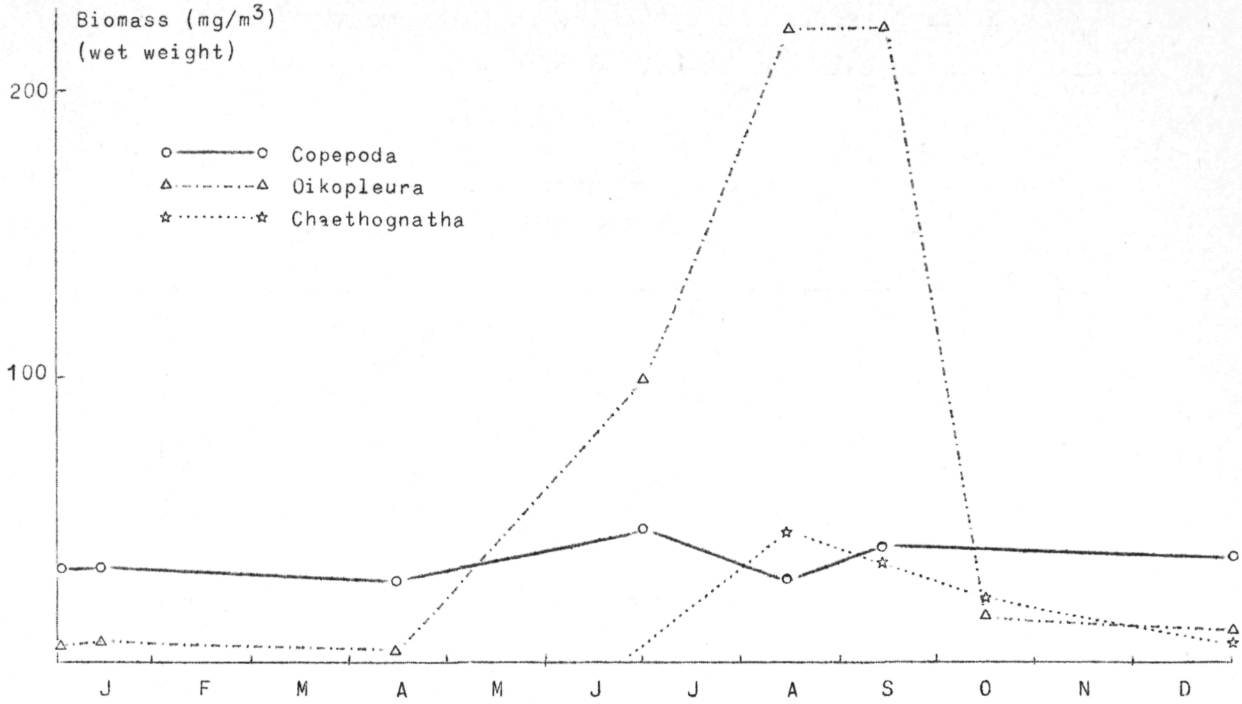


fig. 6.23.- Biomasses zone 1 North.

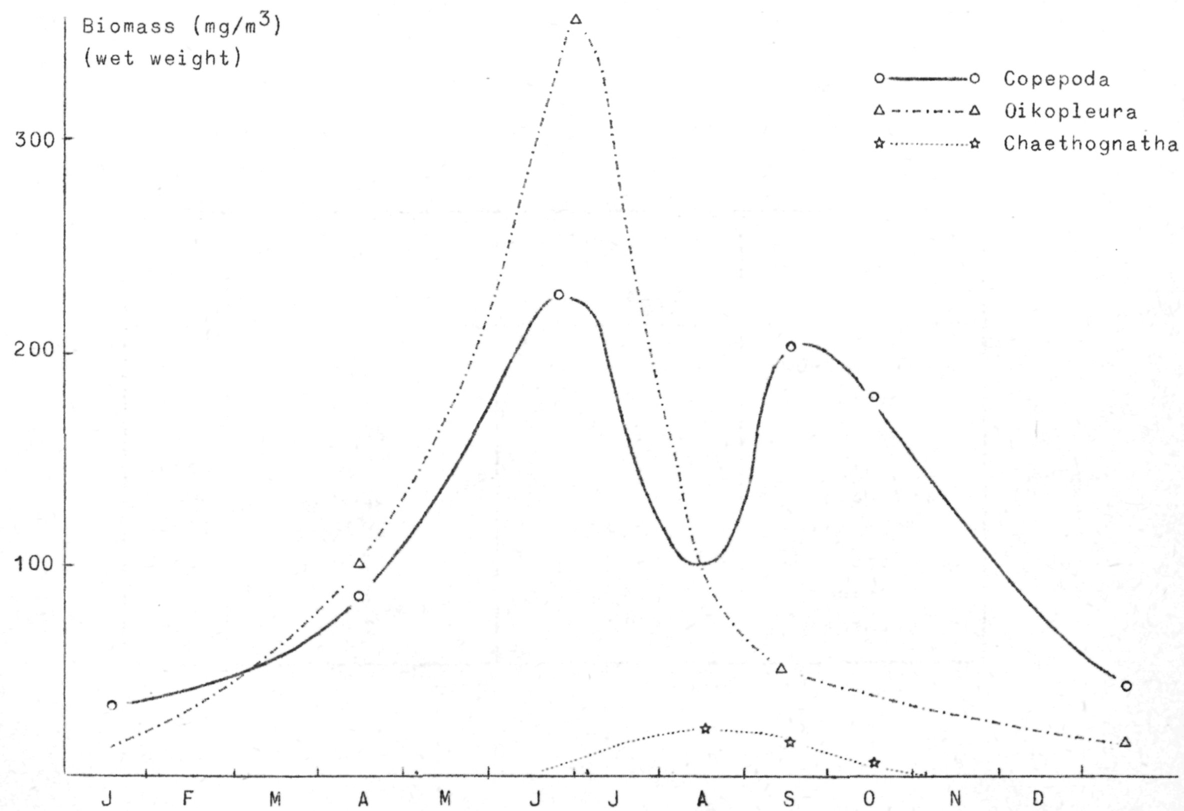


fig. 6.24.- Biomasses zone 1 South.

The grazing values are estimated in the same way as presented in 1° and are represented in Tables 6.7, 6.8, 6.9.

Table 6.7

Zone 1 South

Month	Grazing Copepoda (all stages) mg/m^3/month	Grazing Oikopleura mg/m^3/month	Total
January-February	1530	975	2505
March	1800	1267	3067
April	2700	2086	4786
May	4350	3510	7850
June	6150	5557	11707
July	3765	4192	7957
August	3375	2194	5569
September	5475	1072	6547
October	5250	682	5932
November	2625	487	3112
December	1200	390	1590

Table 6.8

Zone 1 North

Month	Grazing Copepoda (all stages) mg/m^3/month	Grazing Oikopleura mg/m^3/month	Total
January-February	1267	195	1462
March-April	1920	195	2115
May-June	2250	2047	4297
July	1200	2730	3930
August	960	5250	6210
September	1140	3802	4942
October	1170	1170	2340
November	1170	195	1365
December	540	156	696

Table 6.9

Zone 2

Month	Grazing Copepoda (all stages) $mg/m^3/month$	Grazing Oikopleura $mg/m^3/month$	Total
January-February	1584	1170	2754
March-April	3450	2730	6180
May-June	5400	2535	7935
July	2400	1657	4057
August	3000	1462	4462
September	1949	1101	3050
October	1800	536	2336
November	1275	195	1470
December	570	175	745

On an annual basis we can express the grazing in the three zones

- Zone 1 South 60,632 mg/m^3 (wet weight) or expressed in m^2 (as the zooplankton is homogeneously distributed over the depth). Mean depth in zone 1 South is 15 m ; grazing is 909,480 $mg/m^2/year$, or in carbon 36,379 mg $C/m^2/year$.
- Zone 1 North, Total grazing is 27,357 $mg/m^3/year$ with a mean depth of 20 m , 547,140 $mg/m^2/year$, or in carbon 21,885 mg $C/m^2/year$.
- Zone 2, total yearly grazing is 32,989 mg/m^3 , with a depth of 35 m , 1,154,615 mg/m^2 , or in carbon 46,185 $mg/m^2/year$.

We calculated the ratio of grazing to primary production (Table 6.10).

As the biomasses of zooplankton are not significantly changing, during a week [Bossicart (1973)], these values are significant for the time of a week.

Maximal grazing takes place in zone 1S; minimal in zone 1N. Comparing the grazing with the primary production, only once (April 1972) the grazing is 100 % of the production. The same phenomenon is stated in the Sluice Dock : only one month the grazing is equal to, or a little more than the primary production (see fig. 6.25).

Most of the time in both cases (North Sea and Sluice Dock) grazing is a little part of primary production. This should mean that only exceptionally the phytoplankton growth is hindered by grazing.

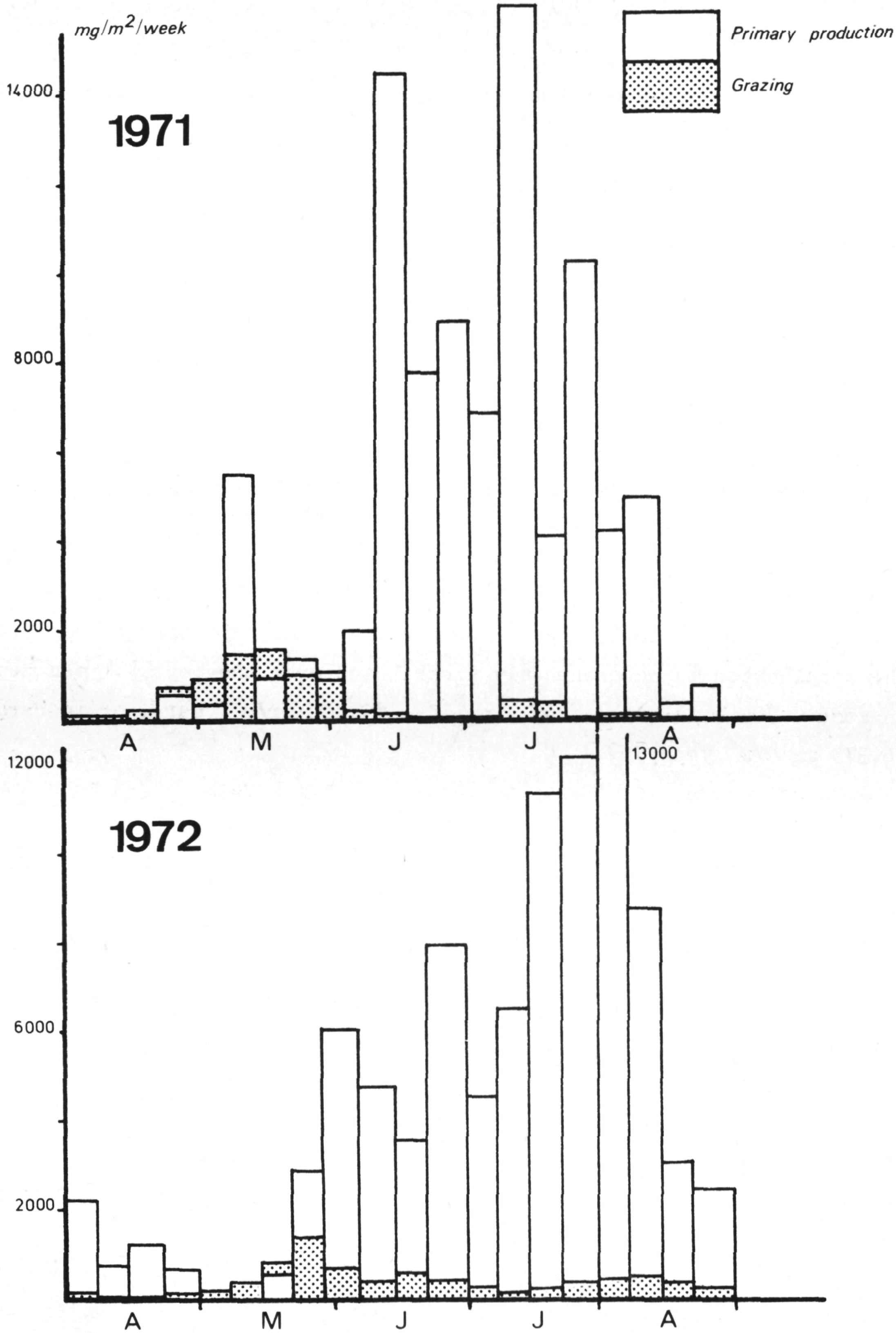


fig. 6.25.- Comparison grazing/primary production at the Sluice Dock.

Table 6.10

Cruise	Grazing expressed in mg C/m^2/day			Grazing expressed % of primary production		
	Zone 1S	Zone 1N	Zone 2	Zone 1S	Zone 1N	Zone 2
June-July 1971	205	-	221	39.7	-	26.5
August 1971	-	135.4	127.4	-	8.7	14.7
September 1971	157.8	95.4	116	5.3	7.8	17.6
January 1972	8	24.3	25	5.4	15.2	19.2
April 1972	222.5	24	312	105.5	6.7	77.7
June-July 1972	182	80	132.5	42	9.3	21.2
September 1972	241	139.8	147.3	74	22.7	54.3
October 1972	152.6	-	88.7	38.5	-	36.5
April 1973	48.5	33.7	38.1	18.6	8	25.4

3° The respiration of zooplankton

The respiration is a good indication of activity of zooplankton. The obtained results are to be taken with caution as the results of these experiments indicate not only the respiration of concentrated zooplankton but include phytoplankton and zooplankton respiration.

The results of the cruise in April 1973 [Hecq (1973)] show a difference in respiration between zone 1N-1S and zone 2.

In the samples where Copepods are dominant, we can express the results in carbon respired/animal/day.

Zone 1 N-S : 1.29 ± 0.59 µg C/animal/day

Zone 2 N : 19.71 ± 8.71 µg C/animal/day

S : 3.19 ± 0.38 µg C/animal/day

The results of respiration were compared with the results of calculated grazing.

After Petipa (1970) the respiration is 80 % of the assimilation for the herbivorous Copepods.

The regression line shows a good correlation (0.91 with confidence < 0.001) between our results of respiration and our estimations of grazing; with an excess of 40 % for the values of respiration : the values of the respiration are 120 % of the values of the grazing.

The measurement of the respiration rates, worked out in the future can be an indicator of the physiological condition of the population and his activity.

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3.- Bacteriology : Heterotrophic Bacteria

3.1.- Methods : counting techniques

The *Institut d'Hygiène et d'Epidémiologie* (Barbette *et al.*) used the pour plate method. Colonies were counted after a maximum incubation period of seven days.

The *Laboratorium voor Ekologie en Systematiek, Vrije Universiteit Brussel* (Joiris *et al.*) used the spread plate method. Counting happened after an incubation period of twelve days at 18 °C .

The latter method gives systematically higher results : shorter incubation time or/and use of too hot smelted agar could give less colonies.

As the reproductibility of the second method is good [Podamo Jo (1972)], standardization is proposed : Marine Agar 2216 (Difco), spread-plate method and incubation at 18 °C for twelve days.

3.2.- Results

3.2.1.- Year cycle of the bacterial concentration

The cycle of the planktonic marine heterotrophic bacteria is known in the Sluice Dock at Ostend [Podamo Jo (1972), Joiris (1973a)]. After closing the sluices, the bacteria disappear (t_{50} = 4 to 5 days) ,

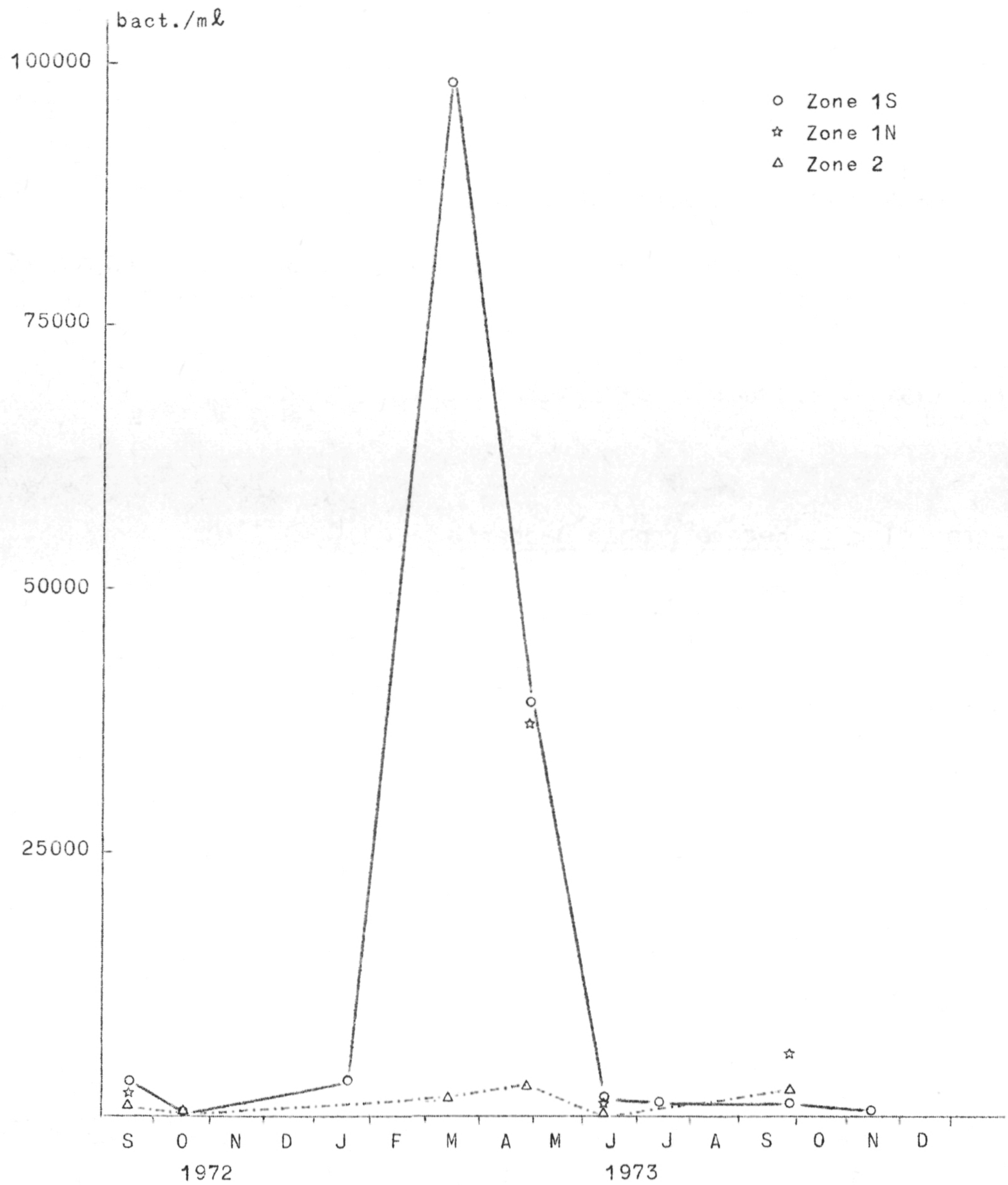

fig. 6.26.
Seasonal variation of the marine heterotrophic bacteria in the Southern Bight of the North Sea (Average number of bacteria/mℓ of water). From Joiris (1974).

probably by consuming the organic matter they are depending on. In the next phase their numbers follow the different peaks of phytoplankton : they depend probably on the dead phytoplankton cells, perhaps the main source of organic matter in seawater.

In the Southern Bight of the North Sea, a summer peak, especially in the coastal zone, is found (fig. 6.26). This peak corresponds also to the spring bloom of phytoplankton (see also §1, Primary production). As in the Sluice Dock, dead phytoplankton is thus probably the most important source of organic matter to be utilized by the heterotrophic bacteria. Indeed, the spring bloom of phytoplankton is responsible for a peak of organic material in sea at the Dutch coast [Duursma (1962), (1963)] and in the Channel [Banoub and Williams (1973)].

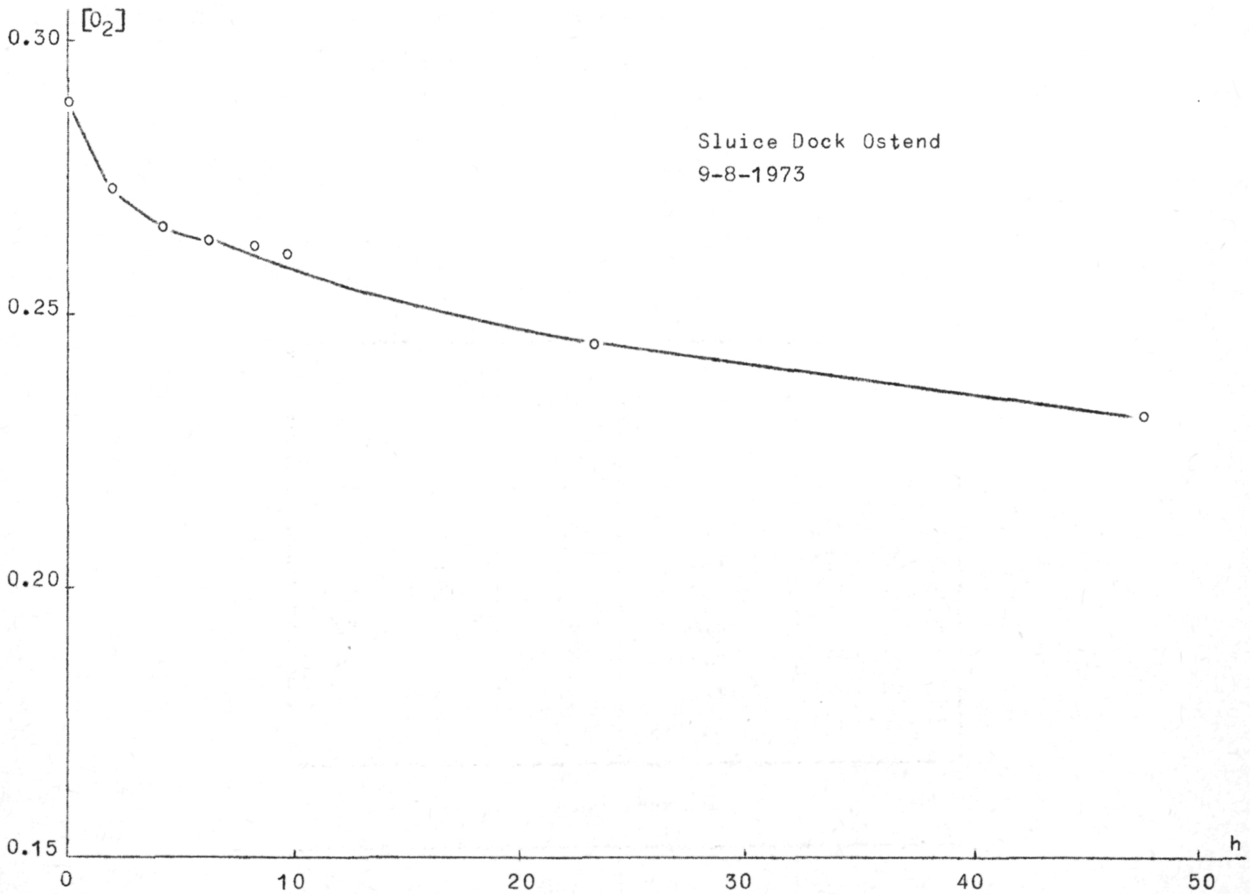

fig. 6.27.
Oxygen consumption in fresh sea water. Incubation : 18 °C , darkness. Oxygen concentration in mM. From Joiris (1973).

Our hypothesis on the relation bacteria-organic matter (spring peak of the phytoplankton) seems to be confirmed by these data [see discussion in Joiris (1974)].

3.2.2.- Relation between bacterial concentration and activity

As the knowledge of activity is more important than that of biomass (see General Introduction), we tried to develop a method of determination of aerobic heterotrophic activity by measuring the initial rate of oxygen consumption in fresh sea water (Winkler method). As seen in figure 7.27, the oxygen consumption rate is decreasing rapidly : the fast evolution of the water and of the bacterial population in time makes it necessary to use only the initial consumption rate as an index of activity. No immediate correlation exists between bacterial concentration and activity : the biomass of bacterial populations cannot be used as an index for their activity (Table 6.11) [Joiris (1973b,c)].

Table 6.11

Measure of activity (oxygen consumption rate), heterotrophic bacteria and organic matter

Sluice Dock Ostend

Date	Initial O_2 consumption rate ($\mu M\ O_2/h$)	BOD_5 ($\mu M\ O_2$)	Heterotrophic bacteria (b/mℓ)
09-08-1973	8.3	107	2.37×10^5
20-08-1973	1.2	83	0.34×10^5
29-08-1973	1.8	119	0.85×10^5
21-10-1973	2.0	74	3.56×10^5
13-11-1973	2.6	160	1.5×10^5
22-11-1973	1.5	63	2.44×10^5
12-12-1973	8.3	44	-

North Sea

25-09-1973	2.2	138	2.04×10^3
02-10-1973	2.5	131	-
28-11-1973	15.5	> 300	600

The same conclusions are apparent for the nitrifying bacteria in the Scheldt Estuary (see also the Estuary report) : a decrease in the numbers of nitrifying bacteria is observed from the Rupel on downstream, probably due to dilution and mortality in sea water (as they are mostly of terrigenous origin).

But nitrification occurs only several kilometers downstream Antwerp, where numbers of bacteria are strongly reduced. No correlation is thus found between activity and numbers of the responsible organism, because the latter can be present in high concentration in an environment where they are completely inactive [Billen (1973)].

4.- Bacteriology : Bacterial activity in bottom sediments

4.1.- Global heterotrophic activity

For evaluating the global heterotrophic activity in bottom sediments, two types of methods could be used : on the one hand, a direct *in situ* or near *in situ* measure of bacterial activity. Dark $H^{14}CO_3^-$ incorporation [Romanenko (1964)] can be used, but caution is to be made because of the possible interference with chemoautotrophic metabolisms and the possible variations of the ratio CO_2 incorporated — total C metabolized (Overbeck). Another technique often used is to measure O_2 uptake by a sediment core [Hargrave (1973)]; this technique unfortunately neglects the maybe important anaerobic heterotrophic activity.

On the other hand, if stationary conditions are assumed, heterotrophic activity can be evaluated by differentiating an experimental organic matter-depth curve. This method also needs an evaluation of sedimentation rate.

These two methods ($H^{14}CO_3^-$ incorporation and differentiating of organic N profil) have been used in the Sluice Dock at Ostend [Podamo Jo (1974)], and the obtained results are of the same order of magnitude (96 to 560 g C/m^2 year and 135 g C/m^2 year respectively).

No such measure has been done in the North Sea. However a gross estimation of the order of magnitude of bottom respiration can be deducted from the work of Hargrave (1973) who studied correlations between sediment oxygen uptake, primary production and depth for various aquatic ecosystems. According to this model, bottom respiration respectively in the three zones of the network, would correspond approximately to 25 % of the primary production in zone 1N, 40 % in zone 1S and 35 % in zone 2.

4.2.- Microbial activity involved in the recycling of nitrogen

Profiles of the concentration of ammonium, nitrates and nitrites in the intersticial water of sediments have been measured in the Sluice Dock at Ostend [Podamo JO (1974)]. These data allow us to evaluate the rate of diffusion of nutrients from the bottom, by measuring the concentration gradient at the water-sediments interface. For ammonium, this transfer is approximately constant during the whole season, because of the huge reserve of organic nitrogen and ammonium in the sediments.

In contrast, for nitrates, the transfer rate varies with the concentration in the water. Moreover, the sediments behave as nitrate consumers in the sludgy zone (where only denitrification occurs) and sometimes as consumer, sometimes as producer according to the concentration in the water in the sandy zone (where both nitrification and denitrification occur).

Table 6.12

	Sludgy zone	Sandy zone	Reference
Ammonification	8.4 g N/m^2. 6 months	-	Podamo (1974)
Nitrification	0	0.3 to 0.7 g N/m^2.6 months (only above 5 to 1 cm depth)	Billen et Vanderborght (1974)
Denitrification	0.3 to 0.9 g N/m^2.6 months	0.3 g N/m^2. 6 months (only under 5 to 1 cm depth)	idem

The mathematical analysis of these profiles by means of a small stationary model has allowed us to relate them with the intensity of bacterial activity in the sediments [Podamo Jo (1974c), Billen and Vanderborght (1974)].

Table 6.12 gives the figures which have been found for the order of magnitude of bacterial activity.

5.- Bacteriology : Pollution indicators and antibacterial properties of sea water

5.1.- Methods

See Technical Reports : Barbette *et al.*(1971-1973), Joiris (1972), (1973).

5.2.- Results

5.2.1.- *In situ* observations

The coliform bacteria [for *E. coli*, faecal *Streptococcus*, see Barbette *et al.* (1971-1973)] have maximal concentrations near the coast (zone 1N and 1S), low concentrations offshore (zone 2) (fig. 6.28).

The year cycle shows seasonal variations with maximal numbers in winter, minimal during summer. The input rates have maximal quantities in summer, minimal in winter (*Rapport Inventaire Pollution*). This indicates that fecal bacteria have a greater survival time in winter than in summer.

5.2.2.- *In vitro* study [Joiris (1973d)]

The antibacterial properties of sea water are studied by inoculating *Escherichia coli* from a culture in sea water. The evolution is studied by counting the colonies twice a day (Petri-dishes, spread-plate method on MacConkey Agar and, except when stated, the experiments are done in the dark at 18 °).

a) Figure 6.29 shows a typical kinetic of disappearance of *E. coli*, with three successive phases : the latency phase, the phase of exponential decrease and eventually a phase of survival of a small percentage of the

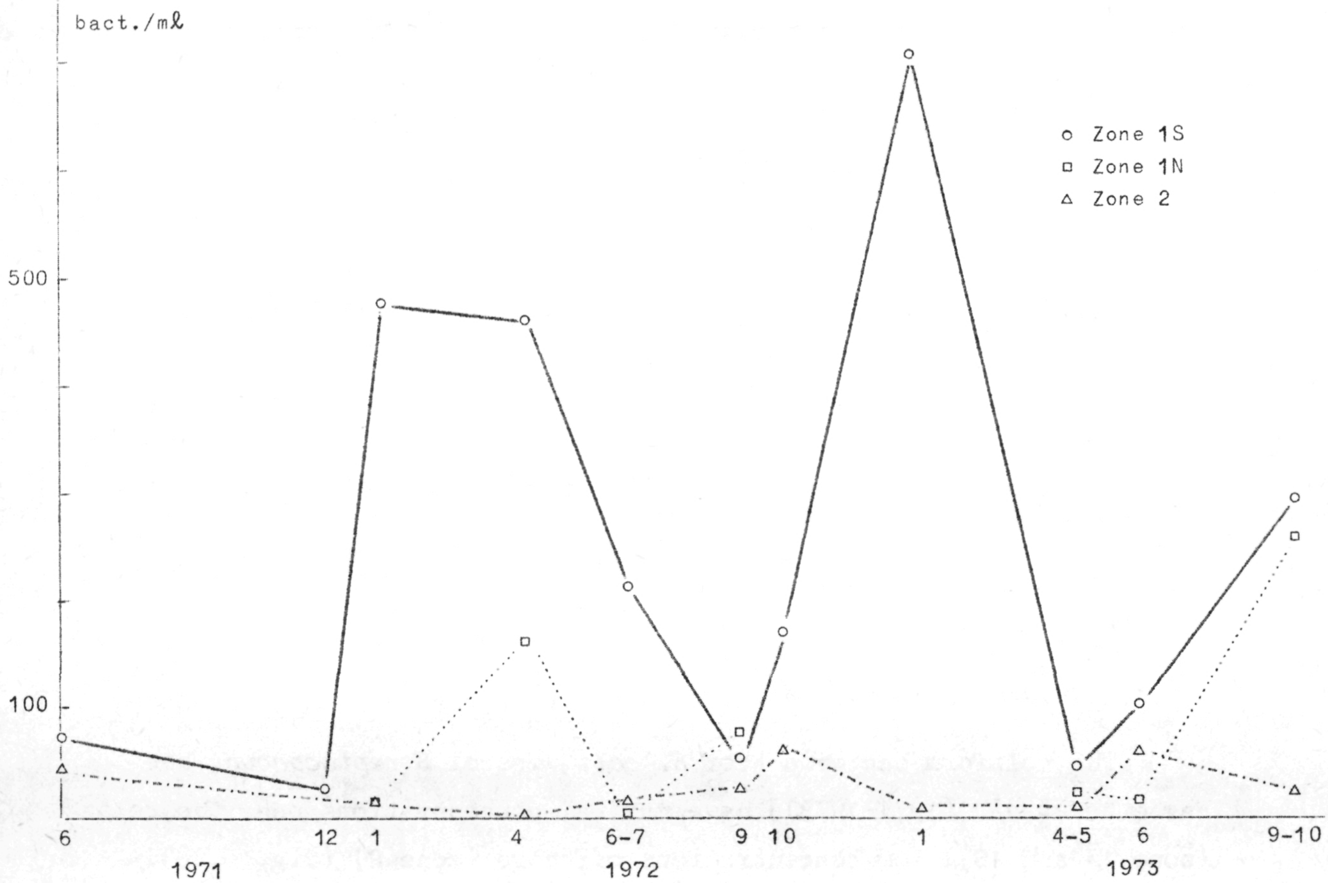

fig. 6.28.
Seasonal variation of the coliform bacteria in the Southern Bight of the North Sea. From the countings of Barbette et al. (1971-1973).

initial inoculum : it is necessary to measure each phase. Counting only the colonies after 2 or 3 days does not give the necessary information.

Control experiment shows that sea water sterilized by autoclave or by filtration on millipore filter (0.45 μ) loses its antibacterial properties and *E. coli* survives for several weeks (fig. 6.30).

b) The results obtained with sterilized sea water are sometimes light-dependent : sterilized sea water has sometimes no antibacterial activity when exposed to constant light intensities, but in other periods, it has.

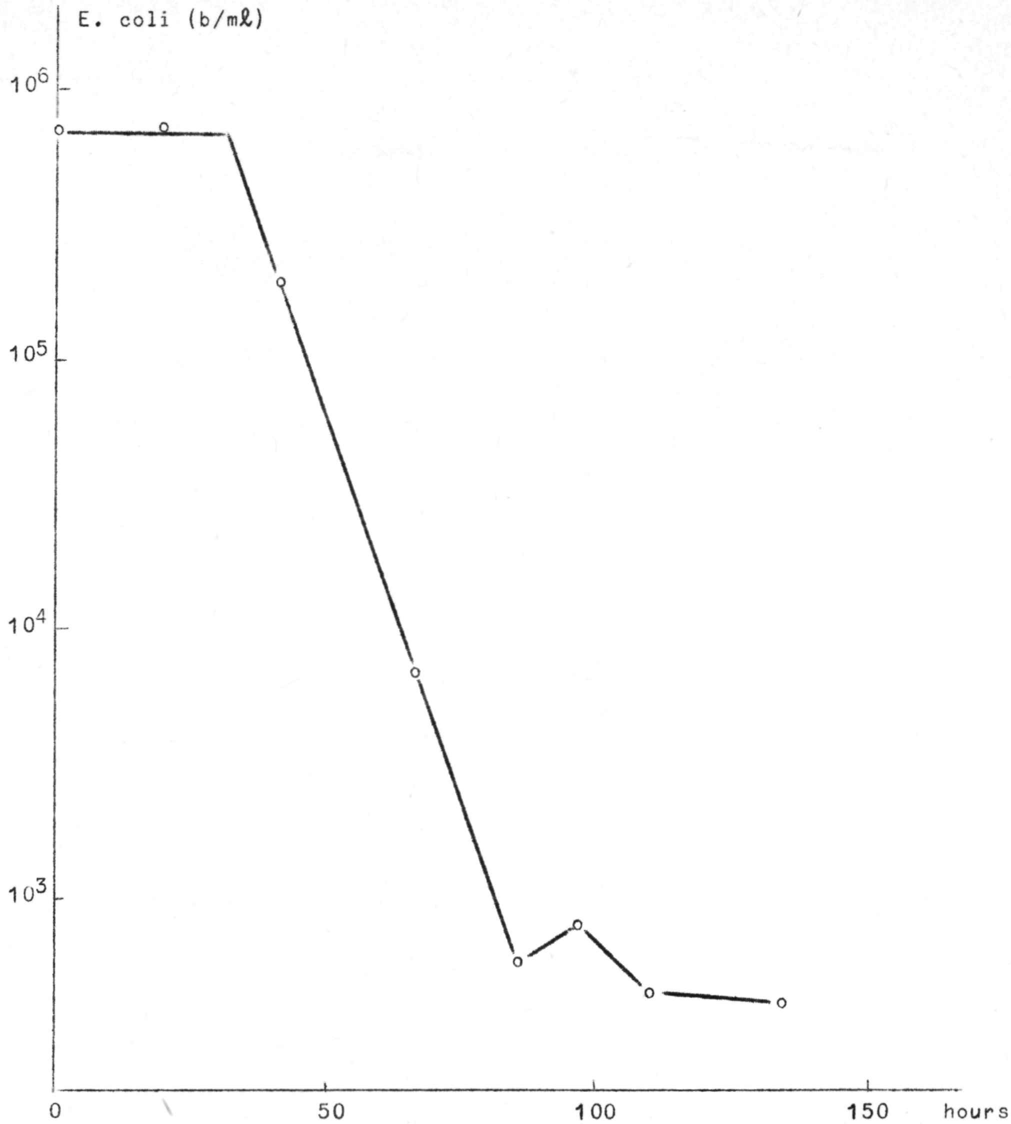

fig. 6.29.
Evolution of the Escherichia coli concentration, when inoculated from a culture in fresh sea water.

c) The antibacterial properties also depend on the temperature : the latency periods are longer when the temperature is lower (Table 6.13).

d) It is possible to re-inoculate sterile sea water for anti-bacterial properties with fresh sea water; the results obtained show that the latency period is longer when less fresh sea water is added. The t_{50} of the exponential decrease remains unchanged (fig. 6.31).

e) When organic matter only is added to fresh sea water, and the *E. coli* inoculum later, the latency period after adding *E. coli* becomes

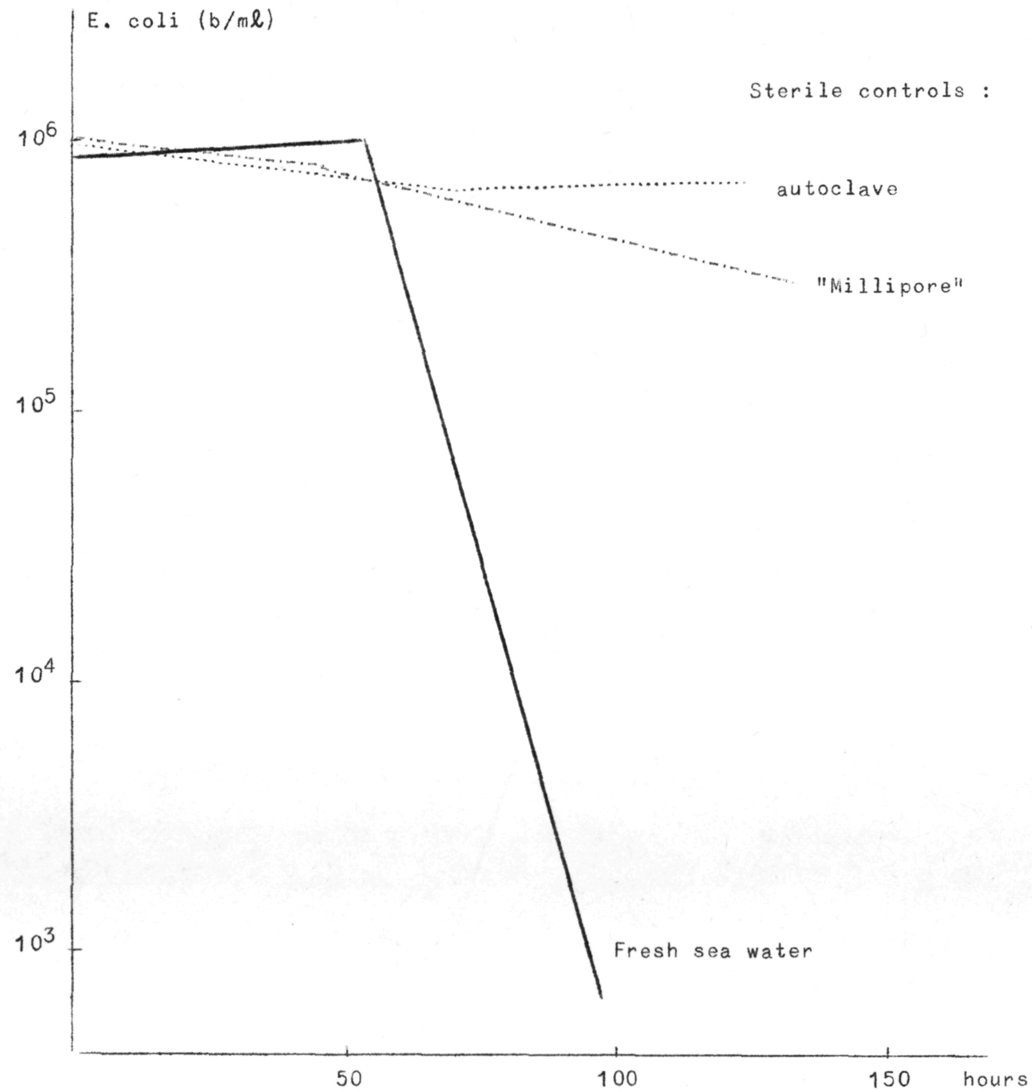

fig. 6.30.
Evolution of the E. coli concentration in fresh sea water and different controls.

Table 6.13

Disappearance of E. coli inoculated in fresh sea water :
Influence of the incubation temperature

Date	Temperature	Latency (h)	t_{50} (h)
09-10-1972	18 °C	22	2.45
	4 °C	200	4.0
12-02-1973	18 °C	48	3.30
	30 °C	26	3.0
	4 °C	> 175	-

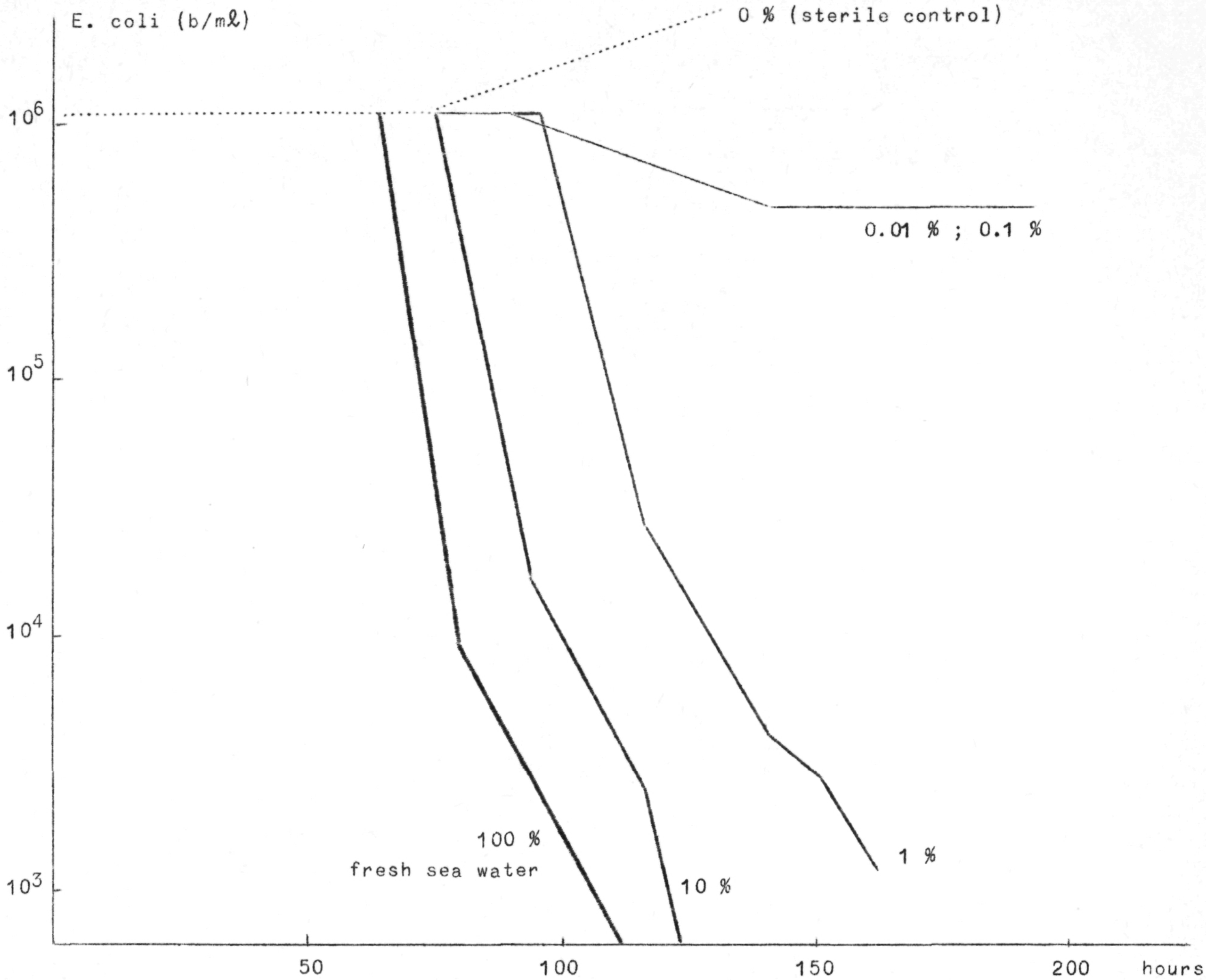

fig. 6.31.
Evolution of the E. coli concentration in sterilized sea water re-inoculated with different doses of fresh sea water.

shorter, but the "total" latency period remains constant (fig. 6.32). So, the addition of organic material can foster the development of phenomenons leading to the disappearance of *E. coli*. An hypothesis is that, at certain periods, some organisms responsible for the antibacterial effect are heterotrophs, and their growth is determined by the addition of organic matter.

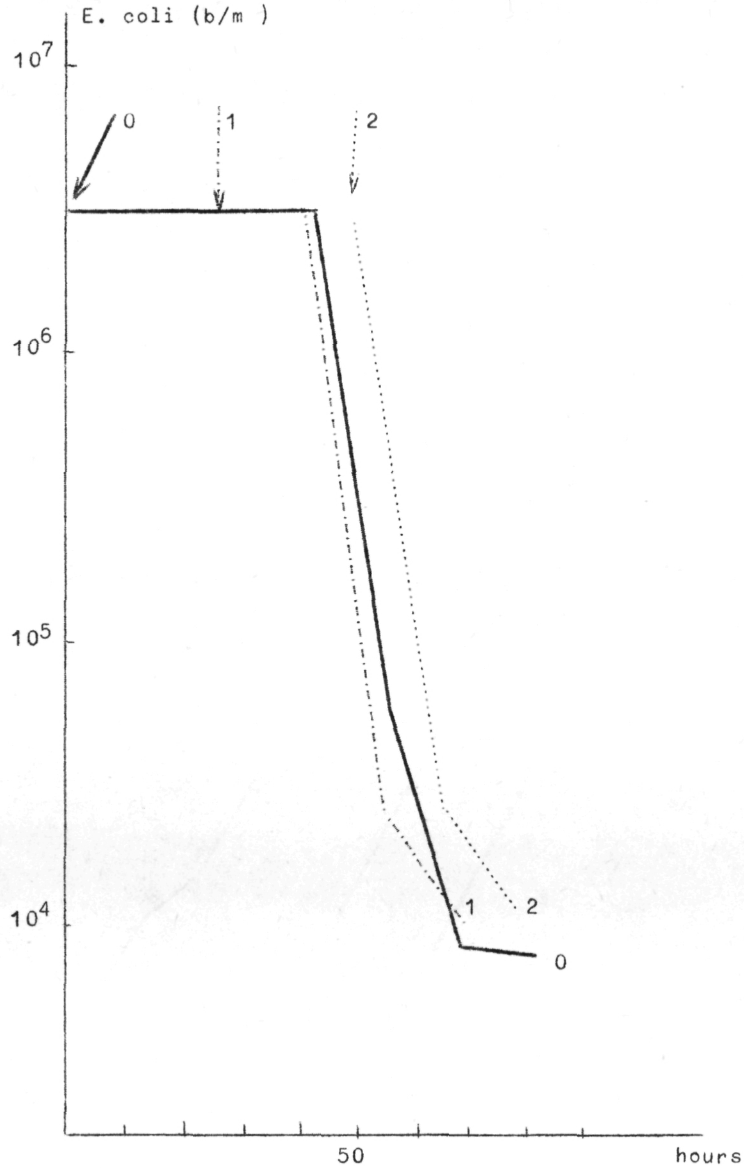

fig. 6.32.
Evolution of the E. coli concentration in fresh sea water, with addition of organic matter at time zero, and inoculation of E. coli at different times indicated by the arrows.

5.3.- Conclusions

The *in situ* observations and *in vitro* experiences demonstrate a strong antibacterial effect of the water of the North Sea against the bacteria of the pollution. The *in vitro* study clearly concerns a potential antibacterial process, because of the suppression of the temperature effects (all tests made at 18 °) and of the processes taking place during the latency phase.

The parallelism of the variations of antibacterial activity and of phytoplankton production [Polk (1972)], together with the effect of adding organic matter in the sea water, suggest that at least two types of organisms could be the main sources for antibacterial activity : phytoplankton and heterotrophs.

Their relative importance can vary spatially and temporally.

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6.- Synthetical approach – Quantitative estimation of nitrogen transfers in the Sluice Dock at Ostend and in the Southern Bight of the North Sea

As an example of dynamical approach to the ecological working of ecosystems, we present here a quantitative description of the nitrogen cycle in the Sluice Dock at Ostend and a first step towards the establishment of a nitrogen budget in the North Sea.

Nitrogen was chosen firstly because it is a general constituent of the living matter so that its circulation illustrates the general pattern of the circulation of biogenous elements, secondly because nitrogen is often the limiting factor in marine ecosystems.

6.1.- Nitrogen cycle in the Sluice Dock at Ostend

6.1.1.- Evaluation of nitrogen transfers

The obtained data (phytoplankton, zooplankton, bacteria) (fig. 6.33) allowed us to evaluate the specific contribution of each component to the nitrogen cycle.

a) Phytoplankton

Taking the $\frac{C}{N}$ ratio as 8 [Strikland (1960)], the nitrogen uptake is calculated from the CO_2 uptake data [Mommaerts (1973), Podamo Jo (1974a)].

b) Zooplankton

The uptake was calculated from the data on grazing, using the same $\frac{C}{N}$ ratio. Production, mortality and excretion was calculated as in Podamo Jo (1974b).

c) Bacteria

Values of heterotrophic O_2 consumption [Joiris (1973)] were used to calculate the ammonification by bacteria.

6.1.2.- Animal balance of nitrogen transfers

The integrated picture of the "ecometabolism" of N in the Sluice Dock is represented in figure 6.34 (period from March to September). Calculated nitrogen transfers are represented by arrows; mean values of statical masses by circles.

The high turnover of dissolved nitrogen in this ecosystem is apparent from this representation. The total mass of nitrogen initially introduced is recycled more than 10 times during the period. The high production of the Sluice Dock is made possible through this high efficiency of the recycling mechanisms. This fact is important when

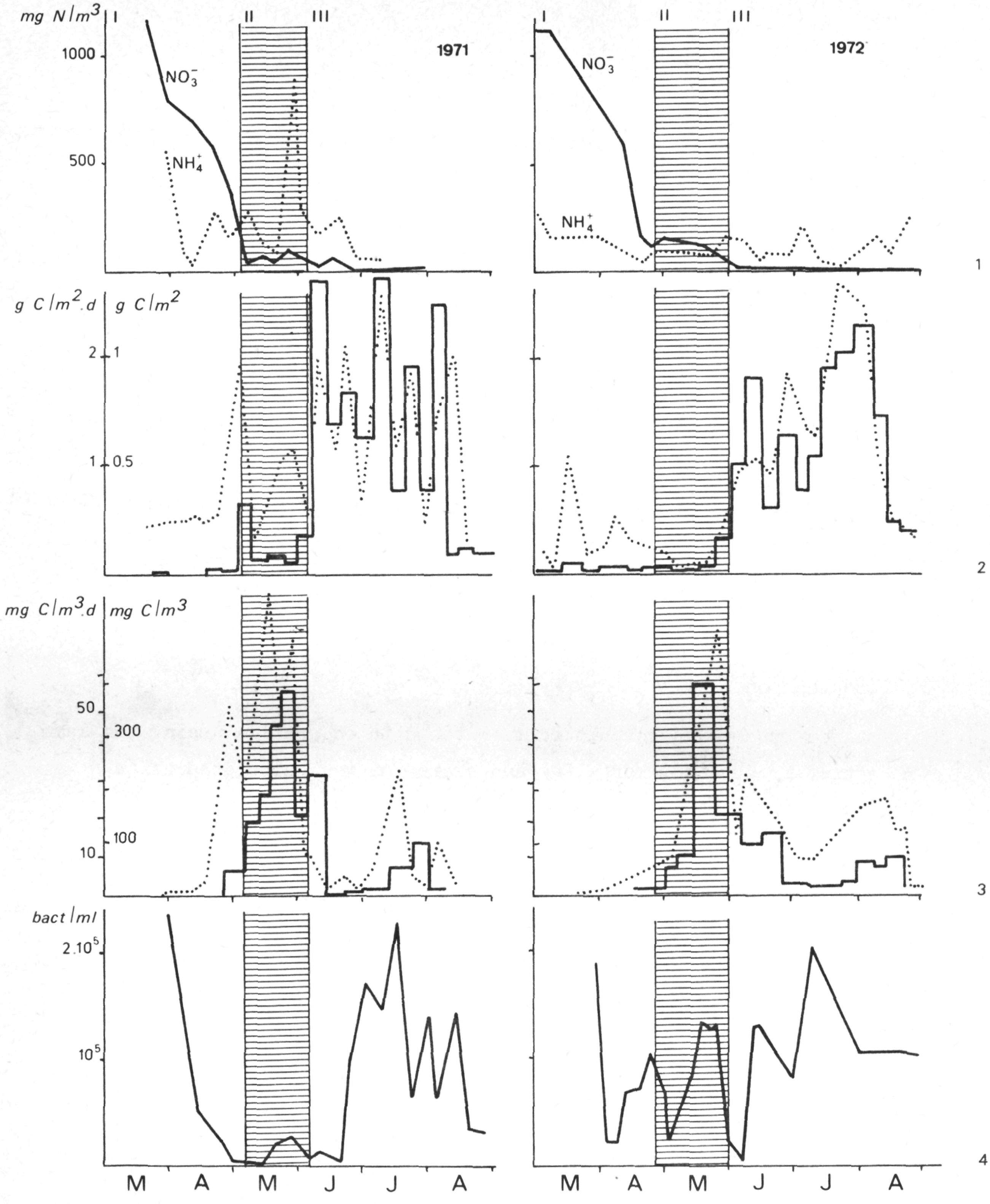

fig. 6.33.

Seasonal evolution of biological parameters in the water of the Sluice Dock at Ostend for the years 1971 and 1972.

1) Nitrate and ammonium concentration.

2) In situ production (histogram) and biomass (broken line) of phytoplankton.

3) Production (histogram) and biomass (broken line) of zooplankton.

4) Biomass of planktonic bacteria.

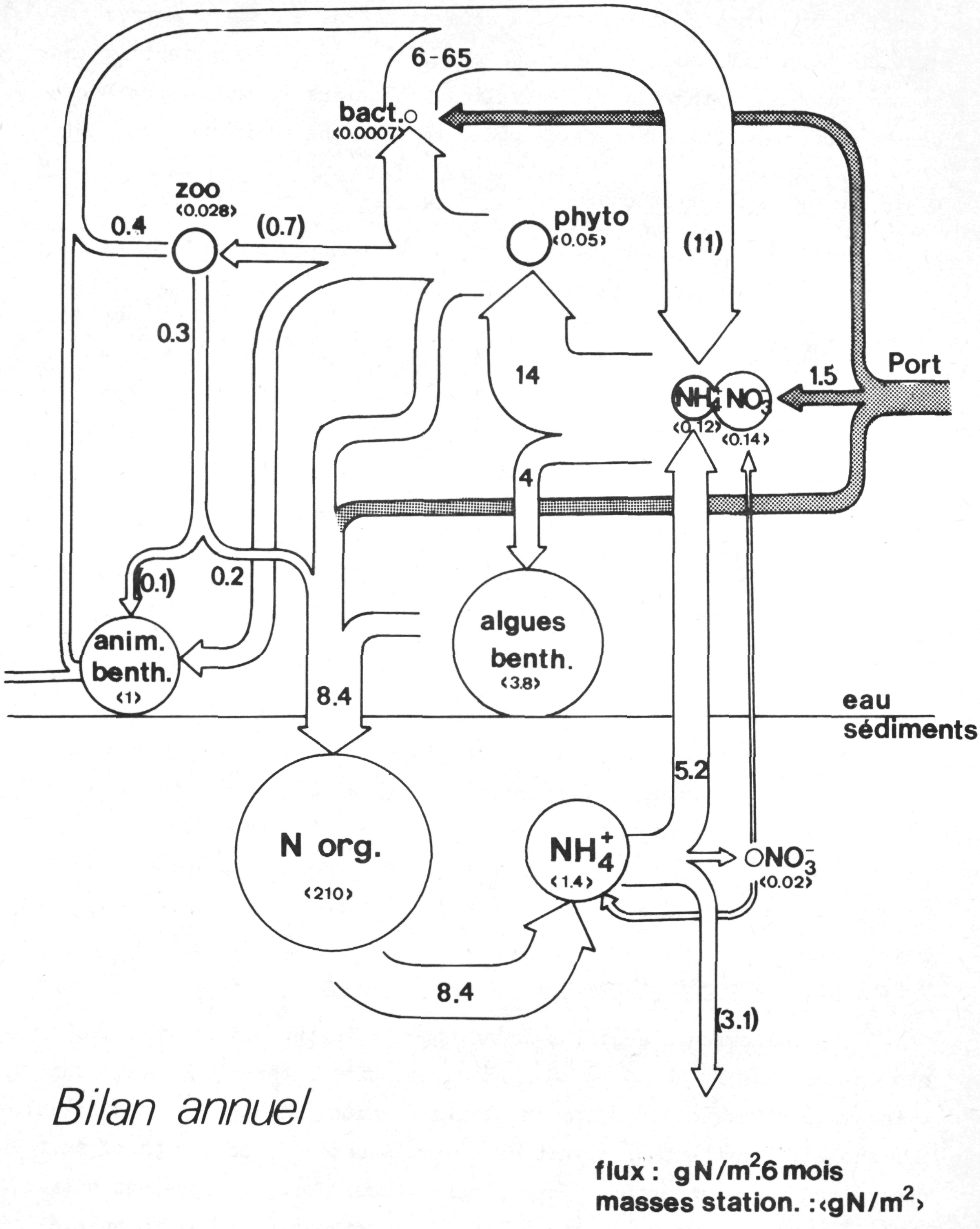

fig. 6.34.- Annual balance of nitrogen transfers between the various compartments in the Sluice Dock at Ostend.

comparing with other eutrophicated ecosystems where organic matter production occurs at the expense of an external source of nutrients without significant recycling. In the recycling mechanisms in the Sluice Dock, benthic and planktonic bacteria appear to play the dominant part.

6.1.3.- Seasonal variations

From the point of view of nitrogen ecometabolism, we distinguished three successive periods (fig. 6.33).

a) From the closing of the sluices to the end of April

The only period of *accumulation* of exogenous nutrients *without* important recycling, partly by the phytoplankton and -benthos, partly by denitrification in the sediments (fig. 6.35).

b) May

Bloom of zooplankton. Grazing and excretion are the most important factors in the recycling mechanism, together with diffusion from the sediments (fig. 6.36).

c) June-August

Massive development of the phytoplankton. The natural mortality of phytoplankton, followed by its bacterial degradation seems to be responsible for the recycling of biogenous material. The influence of zooplankton is negligible (fig. 6.37). Thus three different types of nitrogen ecometabolism succeed each other in this confined ecosystem.

6.2.- Elements for a nitrogen budget in the North Sea

The following discussion is an attempt in integrating the available biological data in the North Sea. However, time intervals between sampling were often too long for an accurate annual mean to be calculated. For whole compartments relevant data were sometimes lacking (*e.g.* sediments) and were estimated by speculation. Therefore, the present budget must only be regarded as a first working hypothesis and has to be confirmed by more accurate measurements.

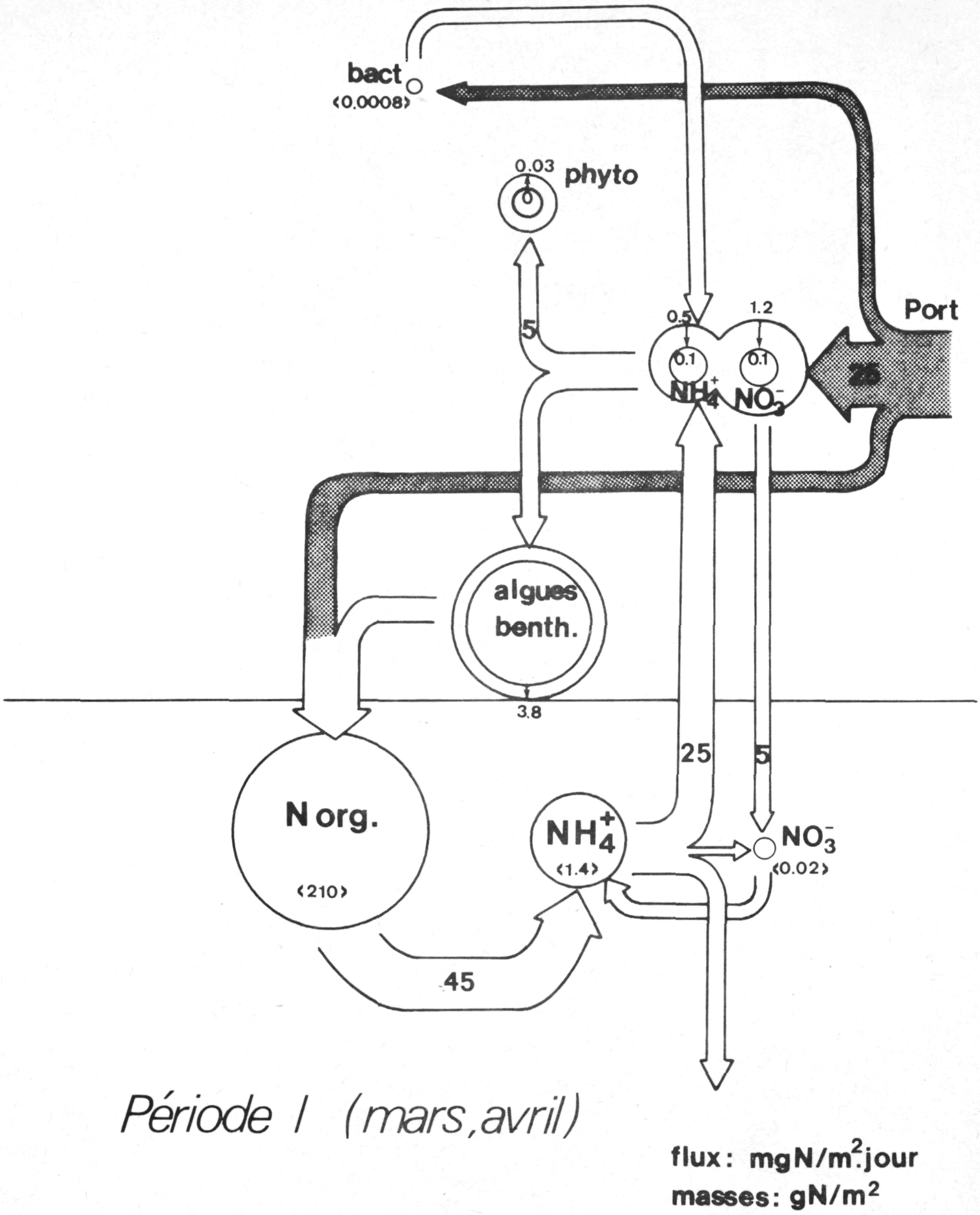

fig. 6.35.- Mean nitrogen transfers during the two first months after the closing of the sluices in the Sluice Dock at Ostend.

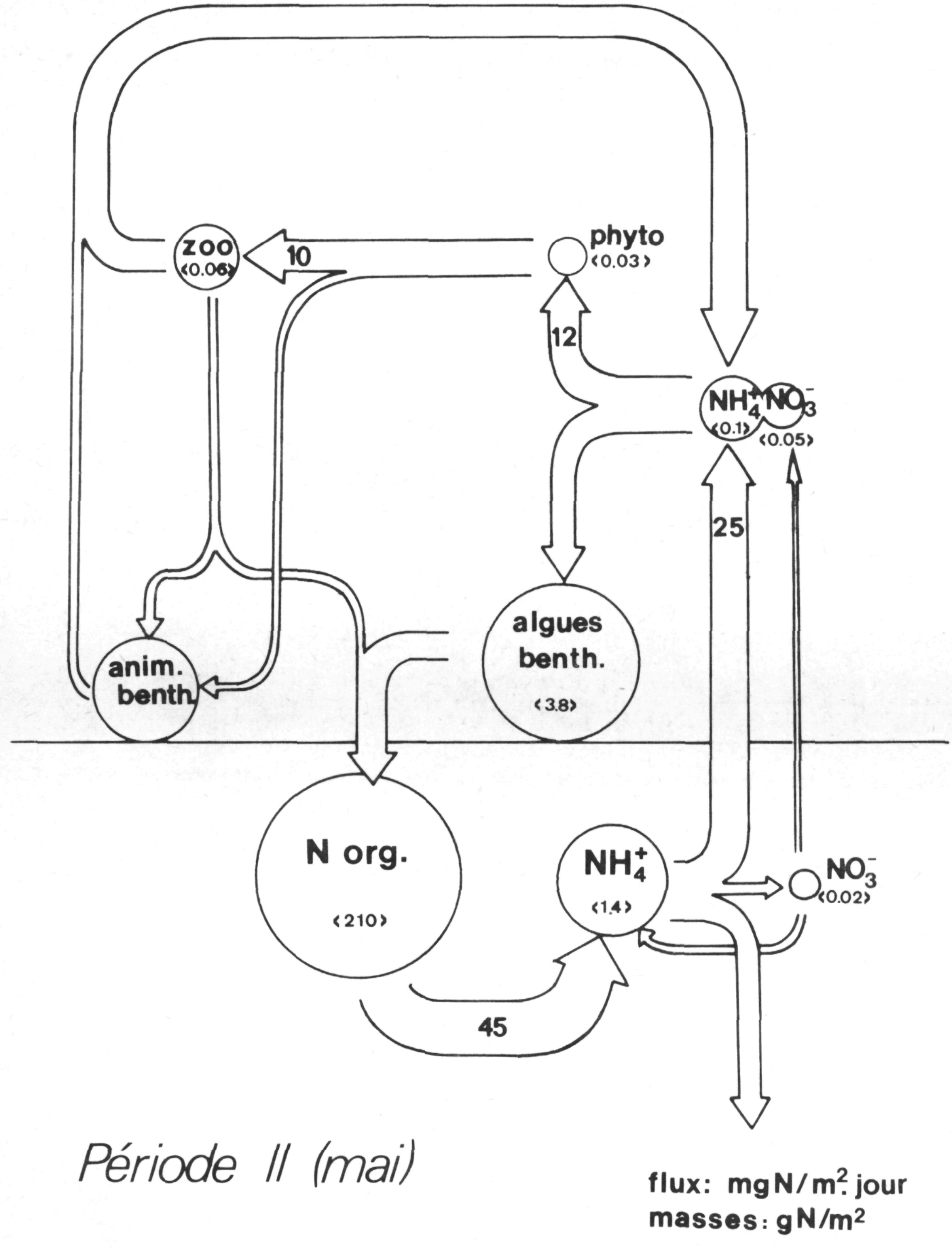

fig. 6.36.- Mean nitrogen transfers during the period of zooplankton bloom (May) in the Sluice Dock at Ostend.

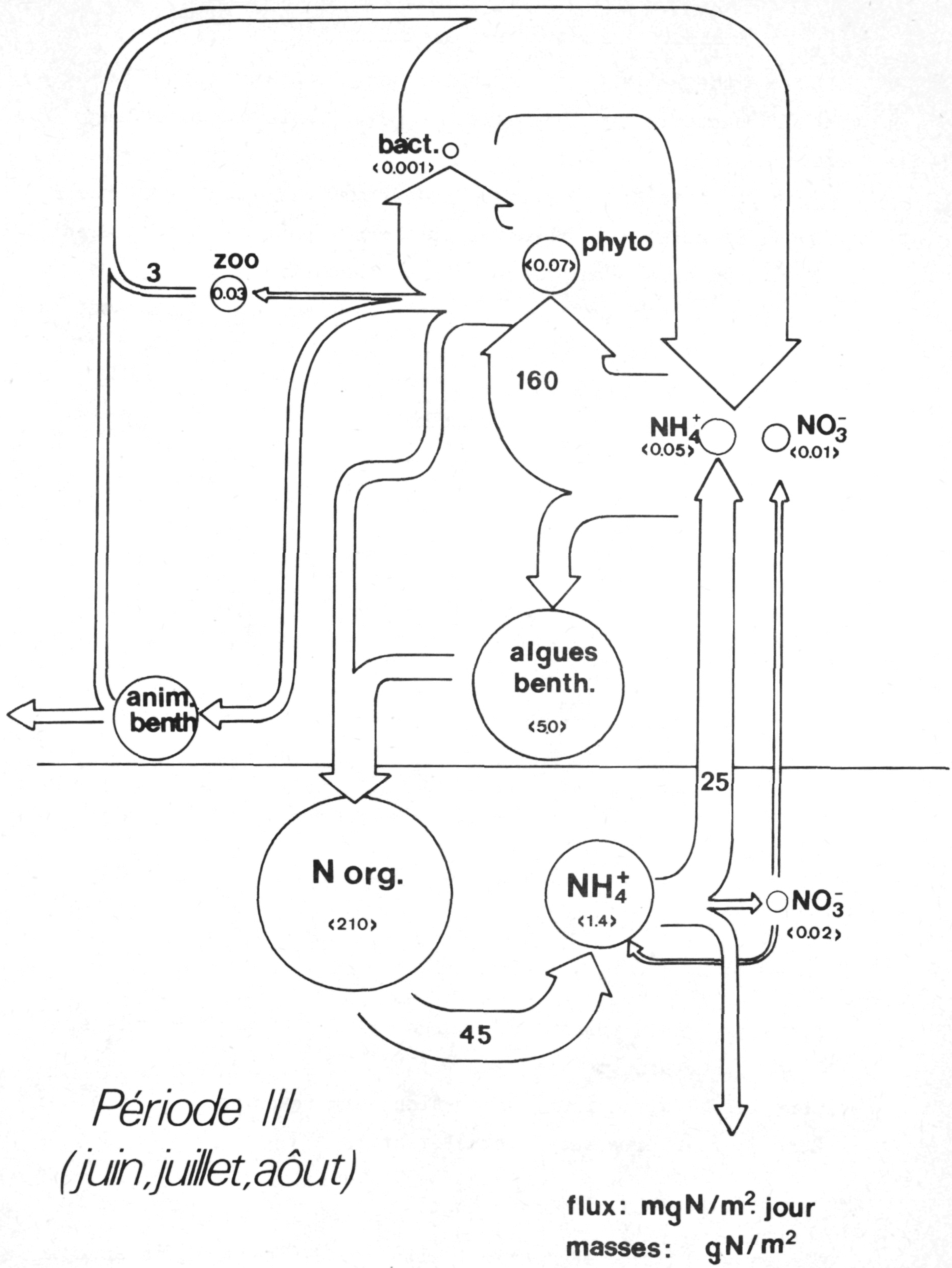

fig. 6.37.- Mean nitrogen transfers during the summer period in the Sluice Dock at Ostend.

6.2.1.- Evaluation of biological nitrogen transfers

Data on the activity of phytoplankton, zooplankton and (pelagic and benthic) bacteria have been given in details in the preceding sections.

Grossly, these data justify *a posteriori* the validity of the division of the network in three zones where significantly different types of biological mechanisms seem to be demonstrated.

In terms of nitrogen transfers, these data can be summarized as follows :

Table 6.14

Zone	Primary production (g N/m^2.y)	Zooplankton grazing (g N/m^2.y)	Planktonic* heterotrophic bacteria (b/m^2)	Benthic** heterotrophic bacteria (g N/m^2.y)
1N	29	2.75	23×10^{11}	7.8
1S	19	4.5	25×10^{11}	8
2	18	5.75	5×10^{11}	6.3

* Too few measurements of planktonic bacterial activity are available to give here a mean value per zone. The figures given are mean numbers of heterotrophic bacteria. It must however be kept in mind that bacterial numbers are a poor index of activity.

** These figures are only orders of magnitude estimated from respiration data of Hargrave (1973).

Thus :

- Zone 1N : characterized by a high primary production with small grazing;
- Zone 2 : lower primary production, high grazing;
- Zone 1S : intermediary characteristics.

6.2.2.- Hydrodynamical nitrogen budget

The area studied, in contrast with the Sluice Dock, is an open system. Thus, an evaluation has to be made of the dissolved nitrogen flows at the frontiers of our three zones. This work is facilitated as the zones have been defined in such a way they correspond accurately to different hydrodynamic regimes [as already pointed out by Elskens (1972) for the distinction between zones 1 and 2] (fig. 6.38).

With the aid of the calculated residual streams in the network [Ronday (1973)], and with the following data on the annual outflow from estuaries and sewage discharges :

Scheldt	:	$3.3 \times 10^9\ m^3/y$	[Wollast (1972)]
Rhine	:	$75 \times 10^9\ m^3/y$	[Portman (1969)]
Belgian coast	:	$0.7 \times 10^9\ m^3/y$	[Portman (1969)]
Dutch coast	:	$0.7 \times 10^9\ m^3/y$	(by analogy with Belgian coast)

A simplified hydrodynamical budget can be established (fig. 6.38). The mean salinities of the three zones calculated with this simplified model agree satisfactorily with the measured ones, as also indicated in the same figure. The budget of dissolved nitrogen can thus be grossly evaluated from the following data :

- mean NO_3^- concentration [Elskens (Technical Reports)] :

Zone 1N	:	175 μg N/ℓ
Zone 1S	:	137 μg N/ℓ
Zone 2	:	42 μg N/ℓ
Coastal Channel	:	115 μg N/ℓ

(NH_4^+ data are not available : we have chosen the same figures as NO_3^- so that a likely order of magnitude is achieved).

- mean values of concentration gradients :

1N - 2 frontier	:	1.5 μg N/ℓ km
1S - 2 frontier	:	5 μg N/ℓ km

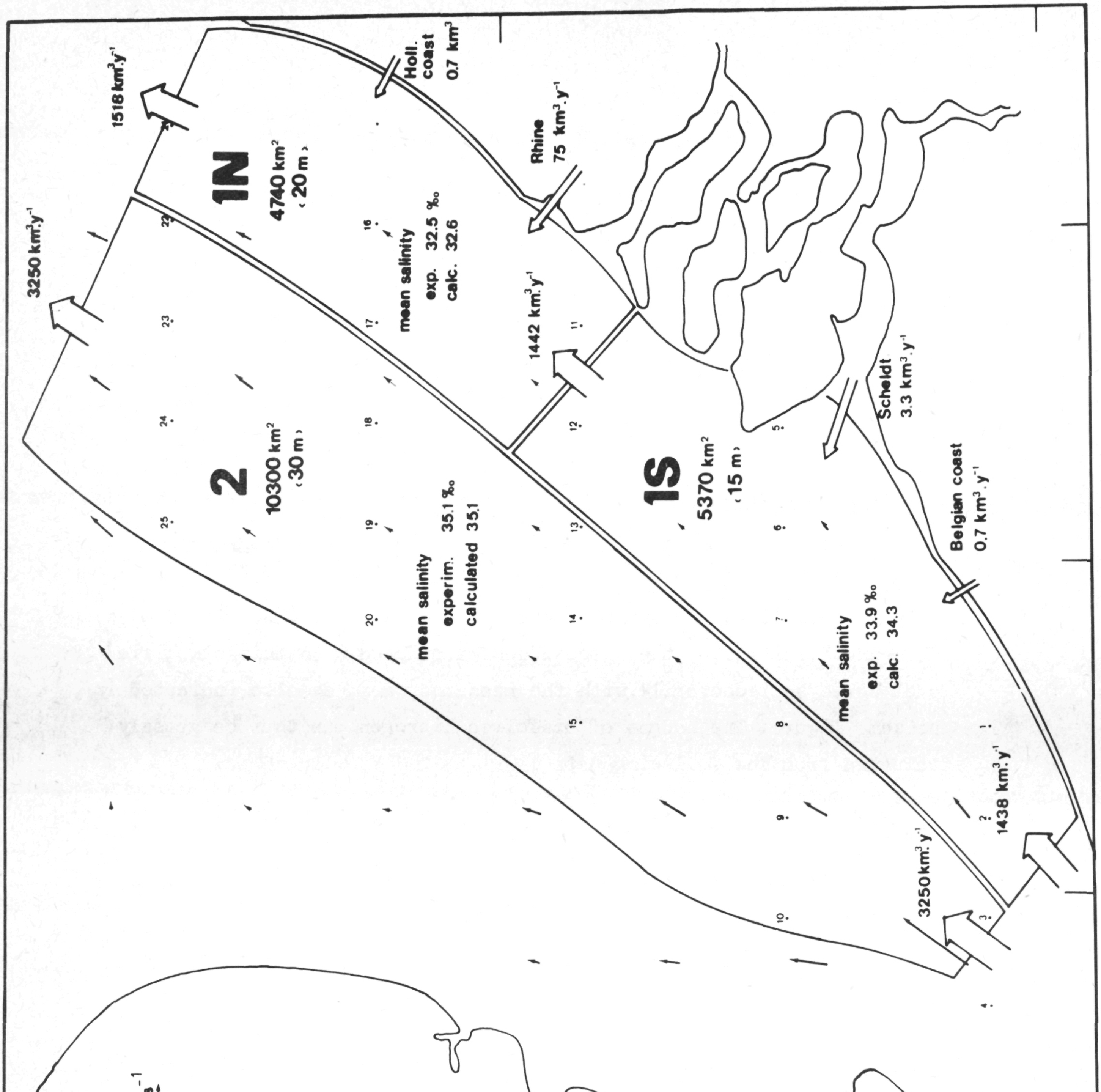

fig. 6.38.

Division of the network in three zones. These three zones, a posteriori characterized by different biological parameters, are defined on basis of hydrodynamical regime. The small arrows indicate the mean residual flows as calculated by Ronday et al. (1973). The great arrows indicate the annual water balance approximately evaluated from mean residual flows and geometric parameters.

- terrigenous imports :

Scheldt	:	46×10^3 TN/y	[calculated from Billen (1973) TR]
Rhine	:	230×10^3 TN/y	[Mead (1970)]
Dutch coast	:	36×10^3 TN/y	[Portman (1969)]
Belgian coast	:	36×10^3 TN/y	(by analogy with Dutch coast)

The circulation of dissolved nitrogen in the three zones of the network is represented in figure 6.39. From this, the net (biological) uptake can be grossly evaluated by difference between imports and exports :

Table 6.15

Zone	Total net uptake (TN/y)	Net uptake/m^2 (g N/m^2.y)
1N	129×10^3	27
1S	16×10^3	3
2	2.3×10^3	0.2

6.2.3.- Annual balance of nitrogen transfers

Figures 6.40, 6.41 and 6.42 present the global ecometabolism of nitrogen in the three zones.

It must be stressed that the given figures are approximative, at this stage of our knowledge, and have to be taken with caution. However some interesting conclusions can already be drawn by only comparing the orders of magnitude of the figures given.

Thus, it is seen that in zone 2 only an insignificant part of the nitrogen taken up by phytoplankton is of exogenous origin. Quantitatively the greatest part of the needs of the primary producers is provided by recycling mechanisms among which zooplankton grazing and excretion play an important role. Although this zone is an open system, its ecological behaviour is perfectly balanced (fig. 6.40).

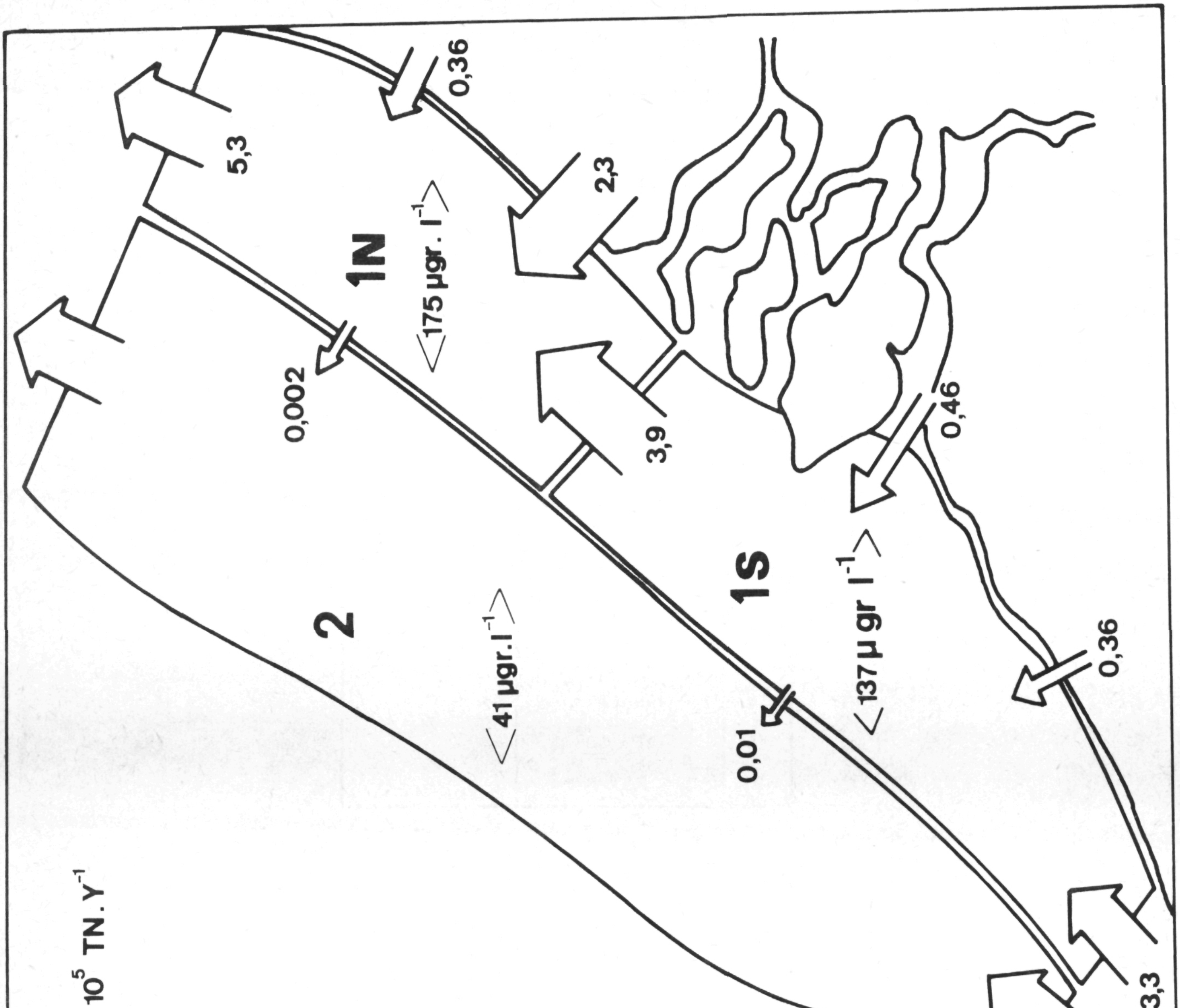

fig. 6.39.

Circulation of dissolved mineral nitrogen in the three zones of the network as calculated from the water balance of fig. 6.38 and the data given in the text.

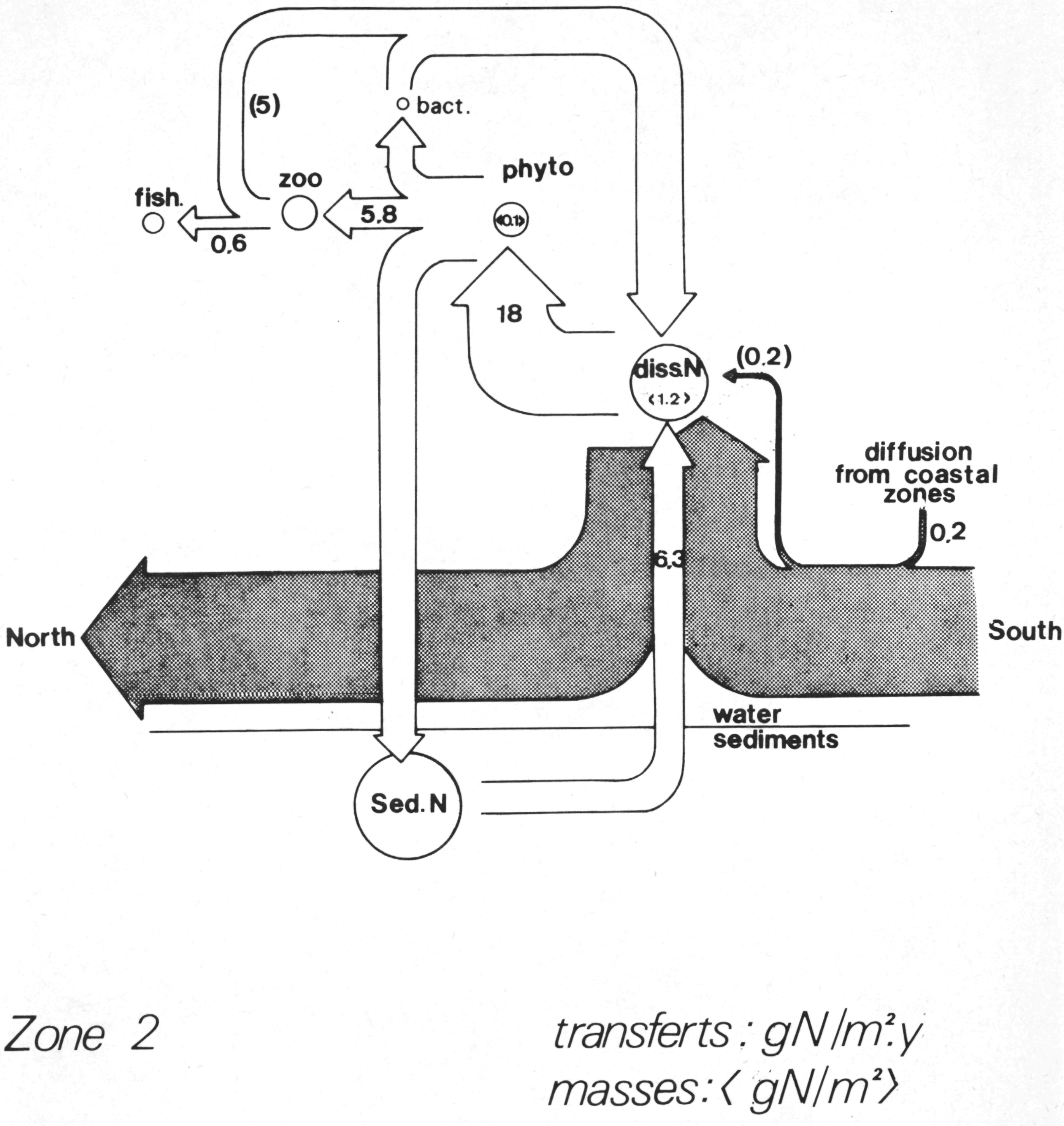

fig. 6.40.
Annual balance of nitrogen transfers between the various compartments in the offshore zone of the Southern Bight of the North Sea (zone 2).

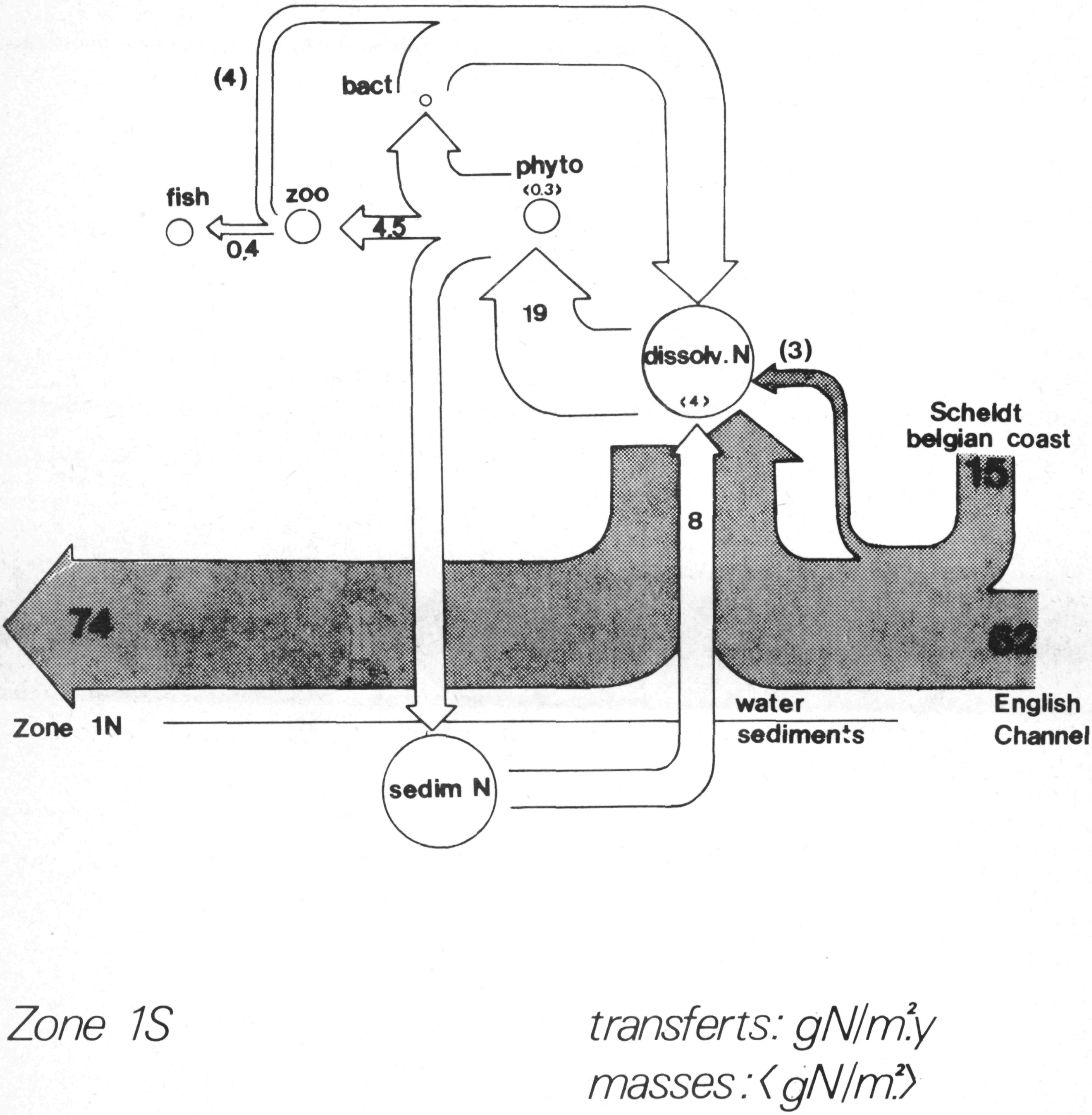

fig. 6.41.
Annual balance of nitrogen transfers between the various compartments in the Belgian coastal zone of the North Sea (zone 1S).

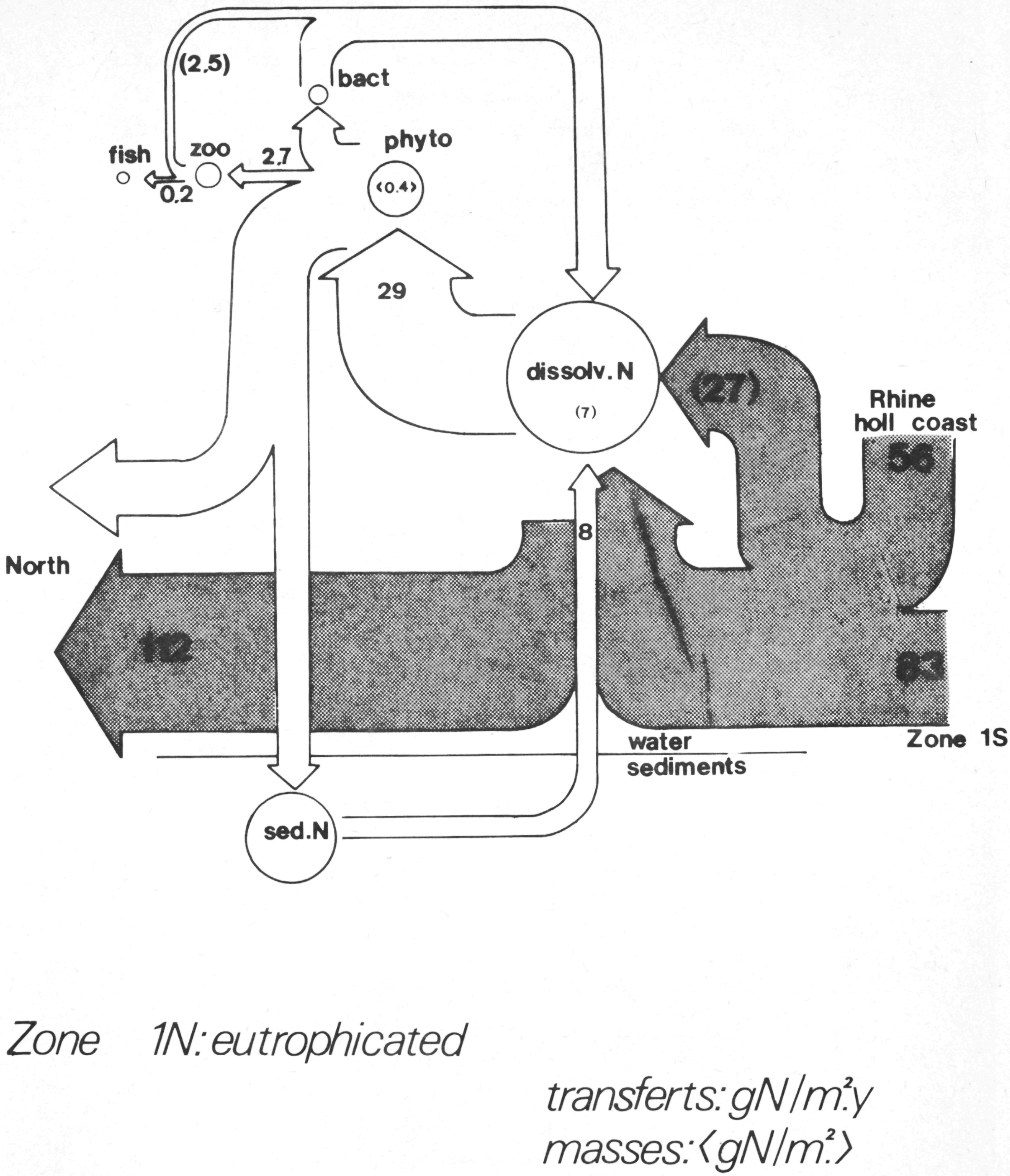

fig. 6.42.

Annual balance of nitrogen transfers between the various compartments in the Dutch coastal zone of the North Sea (zone 1N).

In zone 1 south, the exogenous nutrient utilization is a little more important. The recycling mechanisms are however still efficient. Among these, heterotrophic bacterial activity seems to play a greater role than in zone 2 (fig. 6.41).

In contrast, in zone 1 north, the greatest part of the primary production occurs at the expense of exogenous nutrients without important recycling. Accordingly, most of the biomass produced is probably either exported or sedimented (fig. 6.42). This unbalanced ecological behaviour is of course the consequence of eutrophication of this part of the North Sea.

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