THE EFFECT OF *MYTILUS EDULIS* L. EXCRETION PRODUCTS ON NATURAL POPULATIONS OF MARINE PHYTOPLANKTON.

Running title: *Mytilus* excretion effects on phytoplankton

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INTRODUCTION

The establishment of mussel cultivations on the Swedish west coast has caused concern about ecological effects. Several cultivations are situated near Tjärnö Marine Biological Laboratory, where a project is housed, studying various biological aspects of mass cultures of the blue mussel, Mytilus edulis, L.. The present paper deals with the effects of dissolved excretion products from Mytilus on growth of plankton algae.

Mytilus has been reported to excrete nitrogen mainly in the form of ammonium, to a varying degree as amino acids, and a few percentages as urea (Bayne 1973). The atomic ratio of inorganic nitrogen:inorganic phosphorus of the excretion products is about 7 (Kautsky & Wallentinus 1980). Regeneration of silicate has not been investigated.

Compared to the input from other sources the proportion of nitrogen regenerated by zooplankton and other grazers has been found to be small in inshore waters during summer (Martin 1968, Smayda 1973). However, according to Kautsky & Wallentinus (1980) in the Baltic the recycling by Mytilus is several times higher than the input from land based sources. In the case of mass cultures the local effect may be considerable.

MATERIALS AND METHODS

Description of the area.

The cultivations are situated in a sound in the archipelago south of Strömstad on the Swedish west coast (Fig. 1). The depth ranges from 7 to 25 m; below the cultivations depth is about 12 m. Salinities are between 16 and 30 $^{o}/_{oo}$, and temperatures range from -1.4 to +20^{o}C. The average tide amplitude is about 30 cm.

Primary production in the area has been estimated at some 200 g C $m^{-2}yr^{-1}$,

ABSTRACT

The effect of excretion products from Mytilus edulis L. on growth of phytoplankton was studied 1979 and 1980 in the Tjärnö archipelago on the Swedish west coast. Comparance between samples collected inside and outside cultivations showed a reduction of particulate matter - chlorophyll a, protein, carbohydrate - and photosynthetic activity <200 um of the magnitude 30 - 60 % and 15 - 50 % of particulate matter <5 um. Elevated ammonium and phosphate concentrations were found in the field; in laboratory experiments the activity of the mussels caused increase also of nitrite, nitrate, and silicate concentrations. Bio-assays showed that phytoplankton production was stimulated by nitrogen and phosphorus additions, and stimulation of phytoplankton production by excretion products from Mytilus were demonstrated both by laboratory dialysis experiments and in situ bag experiments. However, comparing assimilation rates versus biomass of samples from inside and outside cultivations, no consistent difference was detected. The in situ bag experiments indicated stimulation primarily of algae <5 um. The ecological rôle of Mytilus mass cultures was discussed and two effects were suggested: a diminishing of the amount of recirculated micronutrients and a shift from large algae to nano- - and ultraplankton.

the phytoplankton population is dominated by diatoms in spring, by nanoalgae (<5 um) in summer, and by dinoflagellates in autumn (Lännergren, in prep.). Chlorophyll a concentrations range from 0.5 mg m^{-3} in winter to about 16 mg m^{-3} during spring and autumn blooms.

The cultivations.

The cultivations are made up of buoyed long-lines from which are hanging 6 m long polypropylene bands with attached mussels. The distance between the vertical bands is 60 cm and between the long-lines 1 - 3 m. One cultivation unit of 2500 m^2 holds about 100 tons of ripe mussels.

Sampling and analyses.

11 April - 18 December 1979 samples were collected on 19 occasions at two reference stations (Stns 1 and 2, Fig. 1) and at Stn A inside cultivation A. The A cultivation was harvested in spring 1980. 7 May - 7 December 1980 on 13 occasions samples were collected at Stn B inside cultivation B (Fig. 1), and only Stn 1 was used as reference.

Water was taken from 1, 3, and 5 m depths and analysed for particulate chlorophyll a, protein, and carbohydrate in size fractions <200 and <5 um. Carbon assimilation rates of the same samples were measured in an incubator.

Chlorophyll a was quantified by fluorescence after homogenization and extraction with 90 % acteone. Phaeopigments were analysed by reading the fluorescence after addition of HCl. Protein was analysed by the method described by Dorsey et al. (1977) and carbohydrate by a method for dissolved carbohydrates (Josefsson et al. 1972), modified for particulate matter by introducing a hydrolysis step.

Carbon assimilation was measured by the ^{14}C method at 150 uE $m^{-2}sec^{-1}$ (Philips TL 40/57) at ambient temperature. 3 uCi $NaH^{14}CO_3$ were added to 117 ml sample, after 4 h the algae were collected on .45 um membrane filters, and the activity was determined by liquid scintillation.

Experimental procedures are described under their respective headings.

RESULTS

Retainment of particulate matter.

The reduction of the particulate content after passage through the cultivations was of the magnitude 30 - 50 % of the fraction <200 um and 15 - 40 % of the <5 um fraction (Table 1). Carbon assimilation rates <200 um were reduced with 40 - 60 % and <5 um rates with 25 - 50 %. The reduction of the <200 um fraction was for all parameters larger than that of the <5 um fraction. The chlorophyll *a* content was more reduced that that of protein and carbohydrate (Table 1). As a consequence the ratios protein/chlorophyll *a* and carbohydrate/chlorophyll *a* were higher of particulate matter inside the cultivations than outside (Table 2) Although the changes may have been brought about by selective grazing, it was probably caused by the presence of suspended fecal matter as suggested by comparatively low chlorophyll *a*/phaeopigment ratios from inside the cultivations (Table 2). Slightly higher protein/carbohydrate ratios were found inside than outside cultivation A; in cultivation B no difference was found.

Excretion.

In the field only ammonium and phosphate increases could be detected, and only in the immediate vicinity of, or inside, the cultivations. In Table 3, also showing retention of particulate protein and carbohydrate, magnitudes are exemplified by analyses from a transect through cultivation A on 9 July 1979. The largest increases were 1.4 umol of ammonium and 0.3 umol of of phosphate, both at 5 m depth. There was no correlation between percentual particle retention and micronutrient concentration. Particularly at 10 m depth, below the depth of the cultivation, low or negative retention was found while large increase of ammonium and phosphate concentrations nevertheless occurred.

Measurements in the laboratory were made on water going in and out of a container with about 200 3 - 5 cm mussels attached to a band of the same kind as in the cultivations. The flow rate was about 40 l h^{-1}, corresponding to 0.2 l $individual^{-1}$, which was much below the pumping rate of mussels of that size, estimated at some 2 - 3 l h^{-1} (Riisgård & Möhlenberg 1979). Phosphate and ammonium excretion was evident on all occasions. Nitrate and nitrite concentrations were elevated in the outgoing water, and so were the silicate concentrations (Table 4). Analysis of recirculated, aerated water, which after 1 h contained very high concentrations of excretion products, clearly confirmed that silicate was regenerated and that nitrate and nitrite concentrations increased due to the activity of the mussels (Table 4).

Bio-assays.

To establish wether phytoplankton growth could be stimulated by nitrogen and phosphorus additions a series of bio-assays was carried out in the period March - September 1979. Surface water was collected in 8 100 litre polythene bags. Micronutrients, trace metal mixture, and vitamin mixture were added in combinations (Table 5), and the bags were anchored floating at the surface. After 1 - 8 days samples were collected for chlorophyll determination. The content of the bags was well mixed before sampling to ensure that sedimented matter was included in the analyses.

When all three micronutrients were added, the same response was obtained as by addition of all micrunutrients plus trace metals or vitamins. Thus trace metals and vitamins did not limit phytoplankton production in the area. Stimulation of growth never was obtained by one single additive - if e.g. nitrogen alone had been limiting, similar responses would have been obtained by nitrate + phosphate addition as by addition of nitrate + silicate. In all experiments but no. 1 (9 April), the chlorophyll content increased where all three micronutrients had been added (Fig. 2). Nitrate + phosphate caused similar

increases, while phosphate + silicate, except in assay II, yielded the lowest chlorophyll concentrations.

Conclusion: Silicate never limited production, although shortage of silicate apparently occurred when phosphate + nitrate had been added (assay II and III). Since phosphate + silicate did not stimulate growth, in contrast to nitrate + silicate (exceptions: assays II and III), phosphorus alone was limiting to a lower degree than nitrogen alone. Limitation of growth was generally due to shortage of phosphorus and nitrogen in combination.

Dialysis experiments.

The effects of dissolved excretion products on growth of natural phytoplankton populations was studied by a dialysis technique in four series of experiments in May and June 1980. The arrangement is shown in Fig. 3. Each of four 250 ml Pyrex glass test tubes was filled with 125 ml of filtered (200 um) sea water from the cultivation area. Running sea water from the aquarium system at the laboratory passed through the samples through dialysis tubing (A. Thomas Co.) Two of the four samples recieved water which contained excretion products from the mussel container mentioned above. According to the manufacturer the dialysis tubing allows passage of compounds with a molecular weight of up to 12 000. Thus low-molecular compounds in the two test tubes serving as controls were in approximate equilibrium with concentrations in unperturbed sea water, while concentrations in the two other test tubes approached those in water contaminated with excretion products.

Growth was measured as carbon assimilation rates (DPM) in 25 ml samples collected after 2 and 4 or 3 and 5 days. They were incubated for 4 h with 0.5 ml of $NaH^{14}CO_3$ solution (3 uCi ml^{-1}) with the same light source as during dialysis. When the experiments were terminated samples were taken for microscopical identification and cell counts.

Consistently higher ^{14}C activities, between 1.1 and 9.5 times, were obtained in the samples which had recieved sea water + excretion products compared to the controls (Table 6). There was no tendency towards larger differences between the two kinds of samples with time, and the agreement between parallels was generally poor.

Cell counts showed that with the exception of the first experiment, the numbers of microzooplankton (tintinnids and ciliates), thecate flagellates, and Nitzschia closterium (Ehrenberg) W. Smith were highest in the presence of excretion products, the numbers of naked flagellates were highest there in all experiments but the second, and Skeletonema costatum (Grev.) Cleve in all experiments was most abundant in samples recieving excretion products (Table 7). The S. costatum cells were small, with a diameter of about 3 um and connecting silica structures were badly developed. Ennumeration of naked flagellates was rather arbitrary, since counting was performed without phase-contrast.

In situ bag experiments.

In order to study phytoplankton growth in water contaminated with excretion products from Mytilus under as natural conditions as possible, two experiments were carried out in situ in the cultivation area in August and September 1980.

One 100 litre polythene bag was filled by a Scuba diver with water from 3 m depth inside cultivation B, and one bag was filled with water from the same depth at a distance from the cultivation of about 100 m against the current. Samples were taken for cell counts and chlorophyll analysis in size fractions <200 um and <5 um, and the bags were anchored at 3 m depth. Chlorophyll and cell count wamples were taken again after 2, 4, and 6 days (exp. 1) or 1, 2, 3, and 4 days (exp. 2). In experiment 2 the bag outside the cultivation was lost after the second day.

Experiment 1: Initially the chlorophyll concentrations in both fractions were reduced to about 1/4 inside the cultivation (bag A) compared to outside

(bag B), see Fig. 4. The <5 um concentration in bag B remained about constant throughout the experiment. In bag A it increased 5-fold to day 2 and was on that day higher than on day 0 in bag B. After day 2 it decreased to the same value as on day 0. Chlorophyll concentrations <200 um in bag A increased to day 2 due to the increase of the <5 um fraction, and after that remained at about the same level to day 6. In contrast, the <200 um fraction in bag B first decreased and from day 2 increased to a concentration on day 6 being 3 times that in bag A.

Cell counts included only organisms of about 5 um size and larger. In both bags growth was entirely dominated by diatoms, mainly Rhizosolenia spp. and Chaetoceros spp. (Fig. 5). On day 2 highest numbers were found in bag A but final numbers were about twice as high in bag B. Dinoflagellates, Prorocentrum micans Ehrenberg and Ceratium spp., were found in higher numbers in bag B, where the dinoflagellates also increased their numbers, while in bag A numbers remained low. In bag A microzooplankton were reduced to about the same extent as phytoplankton and days 2 - 4 the numbers increased to a level slightly higher than that in bag B.

Experiment 2: As in experiment 1 changes of the chlorophyll content were mainly due to the <5 um fraction (Fig. 4). On day 3 the <5 um concentration in bag A exceeded the initial concentration in bag B and was slightly higher still on day 4. Diatoms were the only algae which increased their numbers, in this experiment foremost Chaetoceros spp. (Fig. 5). The numbers of microzooplankton slowly increased throughout the experiment.

Carbon assimilation versus biomass.

In view of the stimulation which was obtained both in the dialysis experiments and in the in situ bag experiments, an enhancement of the photosynthetic activity per unit biomass might have been expected in samples collected inside the cultivations compared to samples collected outside. However, carbon assimi-

lation rates versus chlorophyll a, both uncorrected and uncorrected for phaeopigments, were inconclusive as to wether the activity of the algae was influenced by the mussels or not. The averages differed little and variations were large. That was true also for carbon assimilation versus protein and carbohydrate in cultivation A, but ratios from inside cultivation B were low relative to those from the reference station (Table 8). The low ratios from cultivation B were in accordance with the high protein / chlorophyll a ratios there (Table 2), and indicate much protein and carbohydrate bound in particles not associated with photosynthesis.

DISCUSSION

Mytilus edulis feeds on suspended, particulate matter in the size range a few um to several hundred um, covering the size of most phytoplankton species. At the same time the excretion products, mainly phosphate and ammonium, stimulate phytoplankton growth, thereby partly compensating for the loss.

It is obvious that the total amount of nitrogen and phosphorus in the euphotic zone is diminished by the feeding of the mussels (Fig. 6). Only one fraction of micronutrients bound in particulate matter is recirculated as dissolved compounds, while one fraction is bound in Mytilus biomass and one fraction is deposited as fecal matter. Mussels are perennial organisms with a high transfer efficiency, and when cultivated they are harvested while still exhibiting net growth. Nitrogen and phosphorus are therefore largely withdrawn from circulation. In contrast, when consumed by zooplankton the perticulate matter is rapidly remineralized when passing through the food web (e.g. Petipa et al. 1973). Assimilation efficiencies of Mytilus from the Tjärnö cultivations range from about 50 to 90 % (M. Larsson and L.-O. Loo, pers. commn). Assuming the same percentages of organic nitrogen and phosphorus as of total organics in the faeces, 10 - 50 % of micronutrients are deposited in the sediments,

where remineralization is slow due to oxygen deficiency. The function of the mussel cultivations therefore is that of a nutrient trap.

In the in situ bag experiments the bag outside the cultivation was filled with water which had not yet reached the mussels, and the bag inside with water with reduced particulate content and additions of excretion products. The two bags thus represented water "before" and "after" a cultivation. As was shown by the chlorophyll concentrations <5 um, which after 2 (exp. 1) or 3 and 4 (exp. 2) days were higher "after" than on day 0 "before", the excretion products caused a net increase of the <5 um fraction. Experiment 2 indicated a time lag of at least 1 day, and analyses of particulate matter (Table 1) did not indicate momentaneous increase of the fraction <5 um, nor was there a momentaneous increase of the photosynthetic activity (Table 8). The final diatom cell numbers and chlorophyll concentrations <200 um were considerably higher "before" than "after" in experiment 1, illustrating the difference between short-time affects of higher concentrations of dissolved nutrients and long-term effects of lower concentrations of dissolved plus particulate bound nutrients (Fig. 6).

The results of the in situ bag experiments were in accordance with the results of the bio-assays, which showed that nitrogen and phosphorus in combination increased the chlorophyll content. Also in the dialysis experiments growth was stimulated by the mussel excretion products. However, in those experiments there was a continuous supply of nutrients and no difference between short- and long-term effects could occur. It was remarkable that both in the bag and dialysis experiments diatoms, Chaetoceros spp. and Rhizosolenia spp. in the former and Skeletonema costatum in the latter, grew better than e.g. dinoflagellates, since regeneration of silicate by the mussels appeared insignificant compared to phosphate and ammonium, both in situ and in the laboratory.

The dominance of diatoms probably was caused by the experimental conditions, at least in the in situ bag experiments, as vigorous growth of diatoms was not observed in the area at that time of the year. The stimulation of the <5 um fraction, on the other hand, appears to agree with the fact that small algae have lower half saturation constants for nutrient uptake than large algae (Eppley et al. 1969) - Mytilus excretion caused only a small increase of the ambient nutrient concentrations (Table 3), which under natural conditions very likely are rapidly absorbed by the small algae and never reach concentrations high enough for growth of larger forms, such as diatoms and dinoflagellates. If this actually is the case, the effect of mass culture of mussels is two-fold: a diminishing of the total amounts of nutrients recirculated in the system, as shown in Fig. 6, and a change of the phytoplankton population from net to nano- or ultraplankton by more efficiently retaining the former (Table 1) and by the excretion products favouring the latter.

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Table 1. Reduction of particulate matter as chlorophyll a (Chl a), protein (Prot.), and carbohydrate (CHO) at Stns A and B inside cultivations A and B, respectively. Calculated as average percentages ($\bar{X}$) with standard deviations (SD) for size fractions <200 and <5 um, relative to reference stations 1 and 2. Also showing percentage reduction of carbon assimilation rates (C ass).

		A, 1979				B, 1980	
		Stns A / 1		Stns A / 2		Stns B / 1	
	Fraction	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Chl a	<200 um	47	± 22	46	± 21	53	± 26
	< 5 um	34	± 23	37	± 24	43	± 34
Prot.	<200 um	35	± 18	39	± 19	32	± 24
	<5 um	21	± 22	26	± 23	14	± 39
CHO	<200 um	43	± 18	39	± 20	29	± 31
	<5 um	29	± 16	26	± 34	23	± 18
C ass	<200 um	41	± 36	42	± 30	60	± 20
	<5 um	25	± 49	36	± 28	49	± 31

Table 2. Comparance between ratios of chlorophyll *a* / phaeopigments (Chl *a* / phaeo), protein / carbohydrate (Prot / CHO), and protein / chlorophyll *a* (Prot / Chl *a*) in size fractions <200 and <5 um at Stns A and B inside cultivations A and B, respectively, and reference stations 1 and 2.

		A, 1979				B, 1980	
		Stns A / 1		Stns A / 2		Stns B / 1	
Ratio	Fraction	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Chl *a* / Phaeo	<200 um	.72	± .20	.75	± .26	.62	± .26
	<5 um	.77	± .21	.92	± .32	.80	± .32
Prot / CHO	<200 um	1.19	± .25	1.10	± .29	1.00	± .29
	<5 um	1.13	± .24	1.10	± .26	1.08	± .32
Prot / Chl *a*	<200 um	1.30	± .34	1.23	± .38	1.61	± .58
	<5 um	1.28	± .54	1.25	± .52	1.50	± .51

Table 3. Changes relative to reference station of the content of ammonium (NH_4-N), phosphate (PO_4-P), and particulate protein and carbohydrate <200 um at 1 - 10 m depths at three stations along a transect in the direction of the current through cultivation A. Stn 1 was situated at the long side towards the current, Stn 2 in the middle of the cultivation, and Stn 3 at the side opposite Stn 1. Samples were collected on 9 July 1979.

	NH_4-N Increase (umol)			PO_4-P Increase (umol)			Protein Reduction (%)			Carbohydrate Reduction (%)		
Depth	Stns no. 1	2	3	1	2	3	1	2	3	1	2	3
1 m	-0.2	+0.9	+0.3	+0.06	+0.03	+0.06	46	41	-8	46	44	23
3 m	+1.1	+0.8	+0.2	+0.15	± 0	+0.04	49	68	14	14	62	41
5 m	+1.4	+1.3	+1.9	+0.07	+0.27	+0.30	47	64	41	55	50	56
10 m	+1.4	+0.7	+0.8	+0.15	+0.09	+0.24	-46	3	-7	14	-40	19

Table 4. (A) Concentrations (ug l^{-1}) of micronutrients in water going in and out of a container with about 200 Mytilus of 3 - 5 cm length, flow-rate 40 l h^{-1}. (B) Micronutrient concentrations (ug l^{-1}) of aerated water recirculated through a mussel container for 1 h. Differences (Δ) are given as ug l^{-1}, and atomic ratios are given for total inorganic nitrogen / phosphate (ΣN / P) and silicate / phosphorus (Si / P).

	A						B		
	Flowing-through water						Recirculated water		
	10 Sept.			29 May					
	In	Out	Δ	In	Out	Δ	In	Out	Δ
PO_4-P	7	14	7.5	4	36	32	61	465	401
	6	14							
NH_4-N	30	81	51.5	10	114	106	0	2870	2870
	25	77		10	117				
NO_2-N	3.1	3.9	0.9	0	2.5	2.5	0.8	15.6	14.8
	2.8	3.9							
NO_3-N	19	22	3	35	64	29	61	141	80
	18	21		35	64				
Si	68	66	3	-	-	-	38	419	381
	63	69							
Σ N			55			138			2965
Σ N / P			16.4			9.3			16.4
Si / P			0.4			0.5			1.0

Table 5. Bio-assays. Concentrations and compositions of additives.

	Additions to 100 l	Conc. per l.
$NaNO_3$	176 mg	290 ug N
NaH_2PO_4	15.5 mg	40 ug P
$Na_2SiO_3 \cdot 9\ H_2O$	406 mg	400 ug Si
Trace metal mixture	10 ml	
Composition (per 500 ml):		
$ZnCl_2$	156 mg	15 ug Zn
$Na_2MoO_4 \cdot 2\ H_2O$	189 mg	15 ug Mo
$FeCl_3 \cdot 6\ H_2O$	363 mg	15 ug Fe
$CuSO_4 \cdot 5\ H_2O$	98 mg	5 ug Cu
$MnCl_2 \cdot 4\ H_2O$	52 mg	3 ug Mn
$CoCl_2 \cdot 6\ H_2O$	14 mg	0.7 ug Co
Vitamin mixture	1 ml	
Composition (per 1000 ml):		
Biotin	2.5 mg	25 ng
B_{12}	2.5 mg	25 ng
Thiamin	10 mg	100 ng

Table 6. Dialysis experiments. Carbon assimilation rates as radioactivity (DPM) of particulate matter >.45 um of samples having recieved sea water + excretion products (SW + E) and sea water only (SW). Third column shows DPM ratios (SW + E) / SW. Experiments were started on underlined dates.

		SW + E	SW	$\frac{SW + E}{SW}$
11 May	14 May	53 743	23 865	2.3
		49 640	23 011	2.2
	16 May	22 554	20 671	1.1
		40 113	22 137	1.8
19 May	22 May	24 219	16 610	1.5
		24 024	2 969	8.1
	24 May	13 775	5 504	2.5
		26 715	7 790	3.4
27 May	29 May	8 309	5 091	1.6
		18 471	6 699	2.8
	31 May	20 804	5 146	4.0
		20 660	3 266	6.3
2 June	4 June	37 638	7 642	4.9
		41 723	8 430	4.9
	6 June	41 443	4 361	9.5
		22 428	5 206	4.3

Table 7. Dialysis experiments. Numbers of microzooplankton (tintinnids and ciliates) and phytoplankton cells 5 ml^{-1} in samples having recieved sea water + excretion products (SW + E) and sea water only (SW). Experiments were begun on the first date of the respective experiments, and cell count samples were collected on the last date.

	11-16 May		19-24 May		27-31 May		2-6 June	
	SW + E	SW	SW + E	SW	SW + E	SW	SW + E	SW
Microzooplankton	56	58	44	152	178	568	154	1038
S. costatum ($x10^3$)	1.2	4.9	0.1	3.6	-	4.1	-	7.3
N. closterium	400	-	400	1670	-	400	-	980
Thecate flagellates	246	258	182	314	72	1052	130	210
Naked flagellates($x10^3$)	98	264	58	41	16	96	21	48
Euglenophyceae	-	-	12	1212	-	-	-	10

Table 8. Comparance between ratios of carbon assimilation rates versus chlorophyll *a* (C ass / Chl *a*), protein (C ass / Prot), and carbohydrate (C ass / CHO) in size fractions <200 and <5 um at Stns A and B, inside cultivations A and B, respectively, and refernce stations 1 and 2.

		A, 1979				B, 1980	
		Stns A / 1		Stns A / 2		Stns B / 1	
Ratio	Fraction	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
C ass / Chl *a*[1]	<200 um	1.23	± .78	1.08	± .48	.90	± .22
	<5 um	1.17	± .81	.97	± .35	.85	± .19
C ass / Chl *a*[2]	<200 um	1.19	± .58	1.14	± .45	.95	± .20
	<5 um	1.17	± .50	1.10	± .31	.96	± .22
C ass / Prot	<200 um	.91	± .59	.95	± .49	.62	± .38
	<5 um	.98	± .80	.89	± .39	.61	± .38
C ass / CHO	<200 um	1.01	± .65	.95	± .46	.57	± .24
	<5 um	1.00	± .78	1.00	± .55	.73	± .50

1) Including phaeopigments 2) Phaeopigments subtracted

FIGURE TEXTS

Fig. 1. Map of the cultivation area, showing the cultivations and the sampled stations.

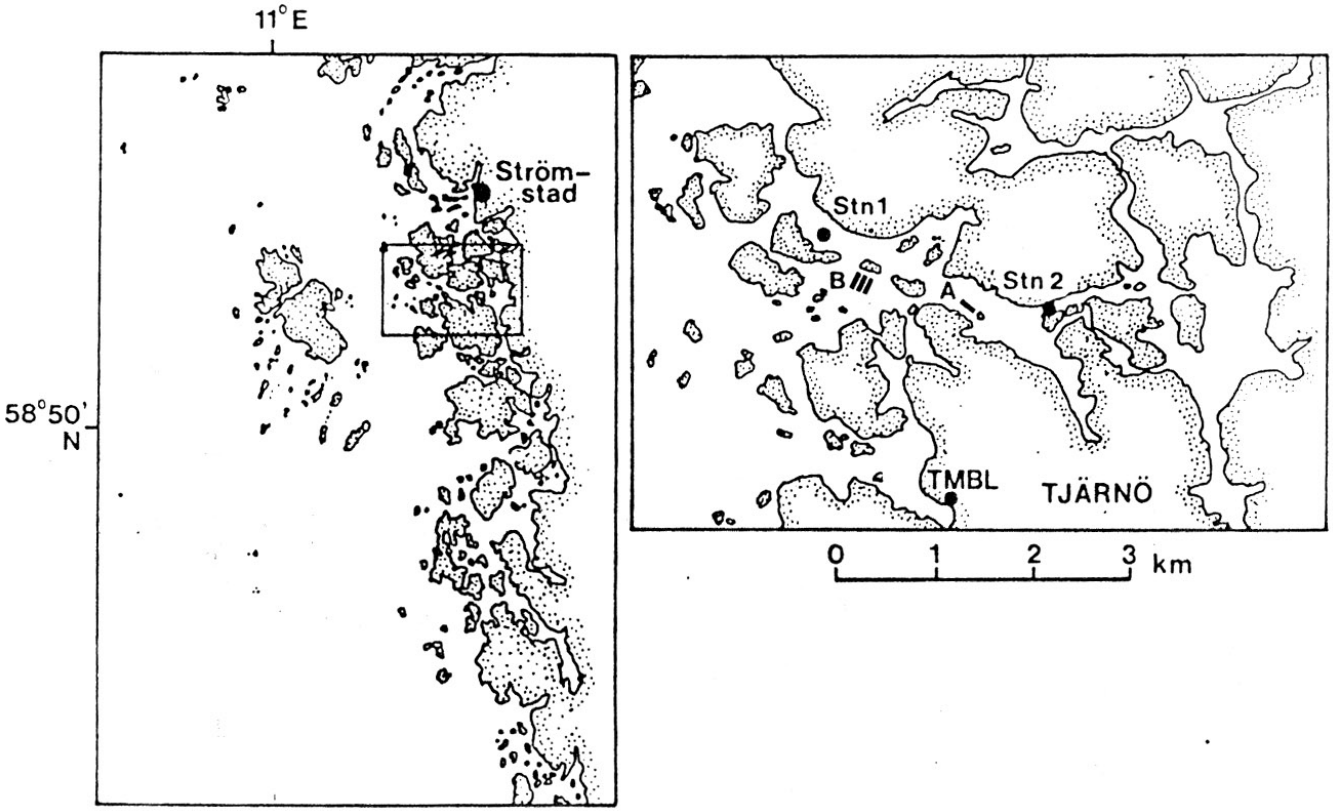
Fig. 2. Bio-assays. Chlorophyll a concentrations (mg m^{-3}) after indicated number of days. N+P+Si plus trace metals and N+P+Si plus vitamins are not shown.

Fig. 3. Arrangement for studying the effect of Mytilus excretion products on growth of plankton algae by dialysis technique. (A) 1) Ingoing sea water, 2) mussel container, 3) over-flow, 4) Pyrex test tubes with samples recieving sea water plus dissolved excretion products, 5) controls, recieving sea water only, 6) fluorescent lamps (Philips TL 40/57) delivering 150 uE $m^{-2}sec^{-1}$ at the distance of the samples. (B) 150 ml Pyrex test tube, with 1) glass tubing, and 2) dialysis tubing (A, Thomas Co., Philadelphia, U.S.A.) through which passes the assayed water. 3) plugged hole for sampling.

Fig. 4. In situ bag experiments. Chlorophyll a concentrations (mg m^{-3}) after indicated number of days in bags containing water collected at 3 m depth outside and inside cultivation B. (A) 15 - 21 Aug. 1980, (B) 5 - 9 Sept. 1980.

Fig. 5. In situ bag experiments. Numbers (10^2 5 ml^{-1}) of phytoplankton cells in same experiments as in Fig. 4.

Fig. 6. Flow of (A) dissolved, and (B) particulate bound micronutrients through a mussel (or mussel cultivation). (C) dissolved nutrients, (D) nutrients retained as mussel biomass, and (E) deposited with fecal matter.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stad
Stn1
B
A
Stn 2
TMBL
TJÄRNÖ
0 1 2 3 km

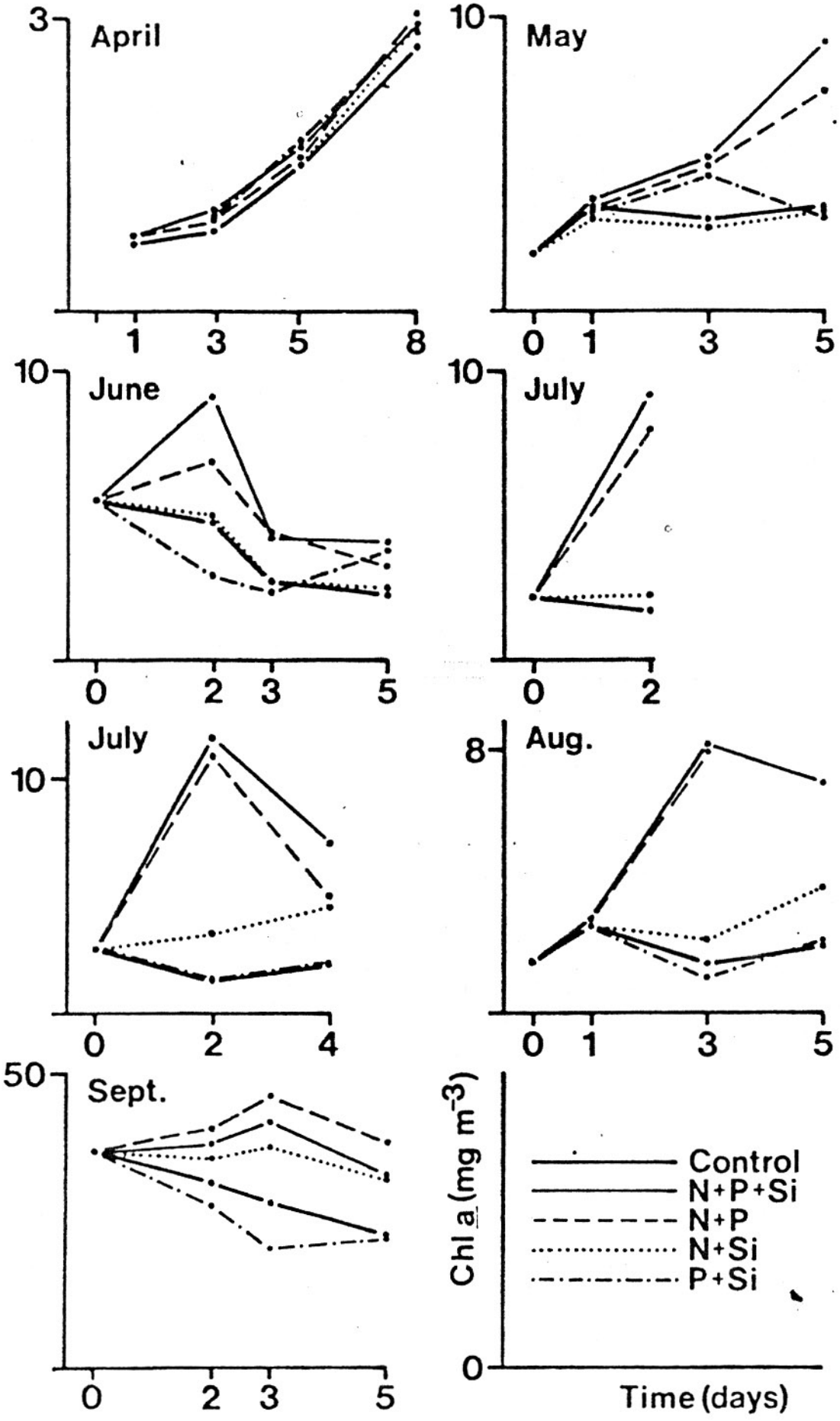

April
May
June
July
July
July
Aug.
Sept.
Control
N+P+Si
N+P
N+Si
P+Si
Chl a (mg m-3)
Time (days)

FIG. 2

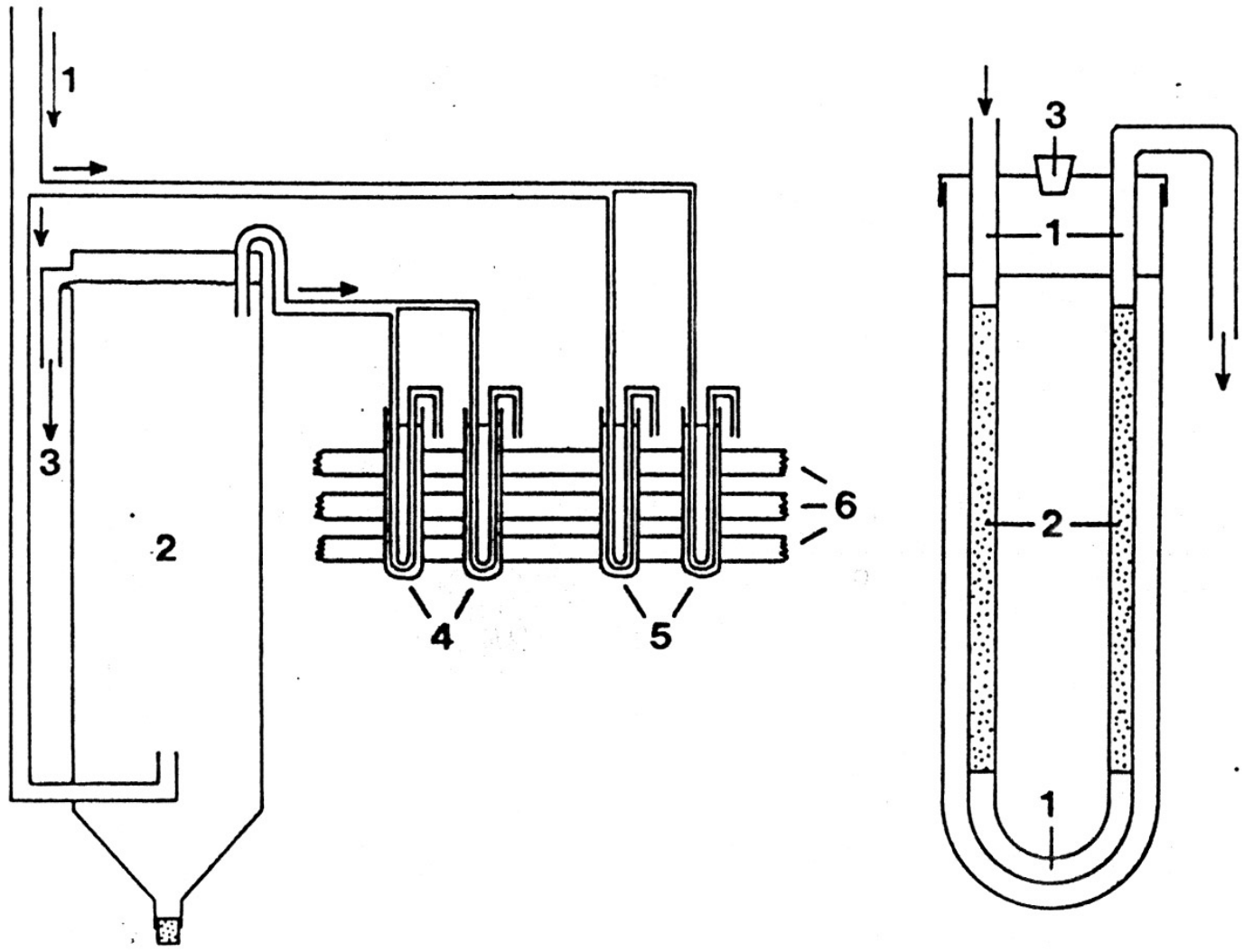


FIG. 3

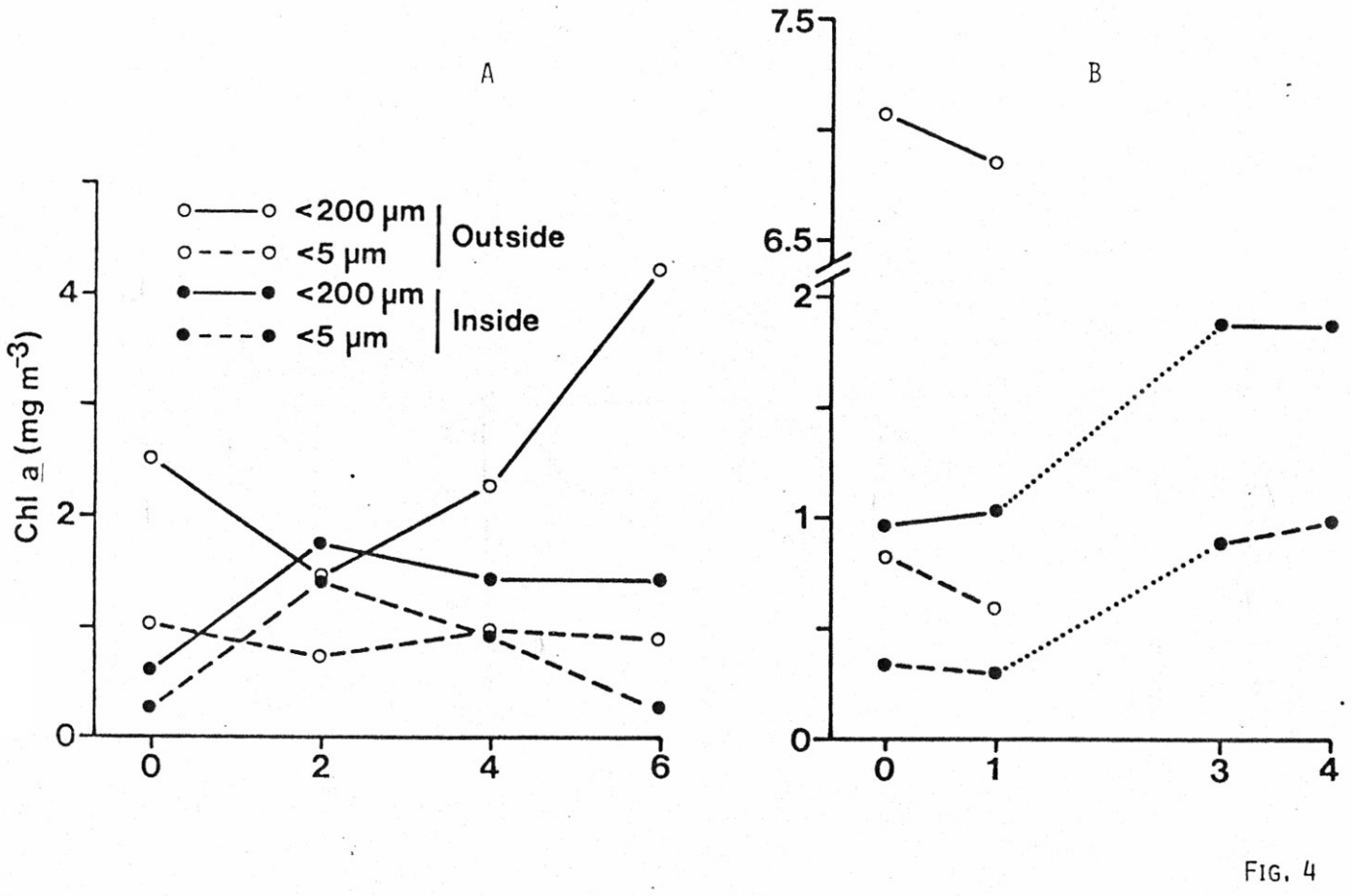
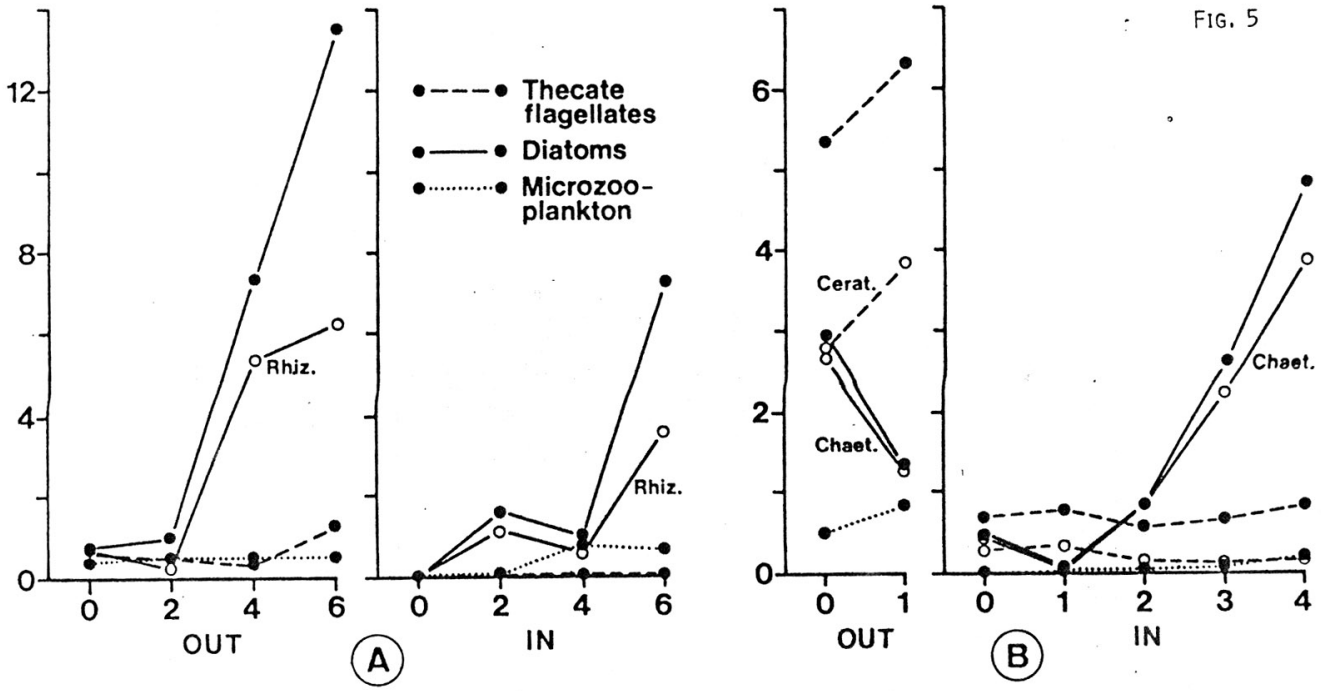

A
B
<200 µm
<5 µm
Outside
<200 µm
<5 µm
Inside
Chl a (mg m-3)
0
2
4
6
7.5
6.5
2
1
0
0
1
3
4

FIG. 4

FIG. 5


Thecate flagellates
Diatoms
Microzoo-plankton
Rhiz.
Rhiz.
Cerat.
Chaet.
Chaet.
OUT
IN
OUT
IN
A
B

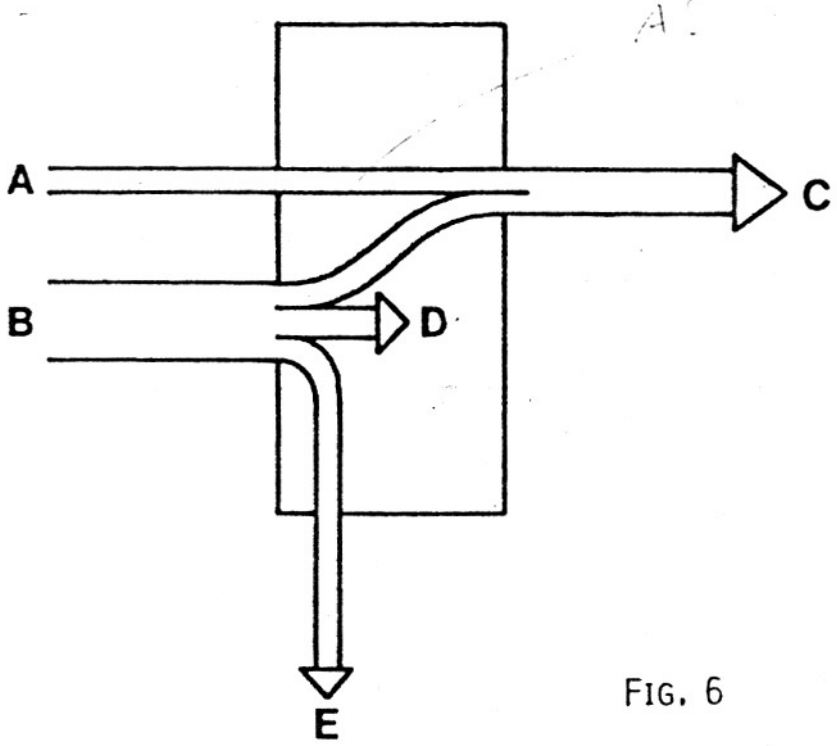


FIG. 6