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ASSOCIATION  
European Atomic Energy Community - EURATOM  
Comitato Nazionale per l'Energia Nucleare - CNEN

**STUDIES  
ON THE RADIOACTIVE CONTAMINATION  
OF THE SEA**

**Annual Report 1971**

edited by M. BERNHARD

1972



CNEN Report No. RT/BIO (71) 7

Work performed at the Laboratorio per lo Studio della Contaminazione  
Radioattiva del Mare - CNEN, Fiascherino, La Spezia, Italy

Association No. 074-69-1 BIOI

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## ABSTRACT

The eight Annual Report of the CNEN-EURATOM Contract of Association is presented. The programme laid down in this contract calls for studies of the factors which influence the uptake, accumulation and loss of radioisotopes by different inorganic and organic constituents of the marine environment. The programme is divided into two parts :

- a) the investigation of relevant radioecological and ecological factors in nature and under laboratory conditions;
- b) the investigation of the outfall area off-shore of the CNEN-TRISAIA Centre in the Gulf of Taranto (fuel reprocessing plant).

The task of carrying out this programme has been divided between six groups : Chemistry, Botany, Zooplankton, Fisheries Biology, Microbiology and Special Developments.

An account is given of the results obtained in 1971.

## KEYWORDS

FOOD CHAIN	TRACE AMOUNTS
NUTRITION	DIAGRAMS
PLANKTON	SHORES
CHLOROPHYLL	ITALY
ATP	SEDIMENTS
PHOSPHATES	CLAY
ARBACIA	FISH
POPULATIONS	ALGAE
TURNOVER TIME	ZINC COMPOUNDS
GASTEROPODS	COPPER COMPOUNDS
PROTOZOA	IRON COMPOUNDS
ZINC 65	STRONTIUM COMPOUNDS
SEA WATER	POLLUTION
CRUSTACEANS	SHORES
IN VITRO	POLLUTION
TRACER TECHNIQUES	MEDITERRANEAN SEA
MUSSELS	HYDRODYNAMICS
FOOD CHAIN	RHODAMINE
DATA PROCESSING	DIFFUSION
PROGRAMMING	EQUATIONS
OCEANOGRAPHY	TURBULENCE
RECORDING SYSTEMS	MPC
PHOSPHORUS 32	MPBB
MICROORGANISMS	CRITICAL ORGANS
BACTERIA	MAN
METABOLISM	RADIOISOTOPES
CELL GROWTH	STRONTIUM 90
RADIOAUTOGRAPHY	YTTRIUM 91
TRACER TECHNIQUES	NIOBIUM 95
MICROBIOLOGY	ZIRCONIUM 95
CELL CULTURES	RUTHENIUM 103
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ENVIRONMENT	IODINE 131
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QUANTITATIVE ANALYSIS	IRON 59
AUTOMATION	COBALT 60
SAMPLING	MANGANESE 54
RUTHENIUM 106	TRITIUM
STRONTIUM 89	

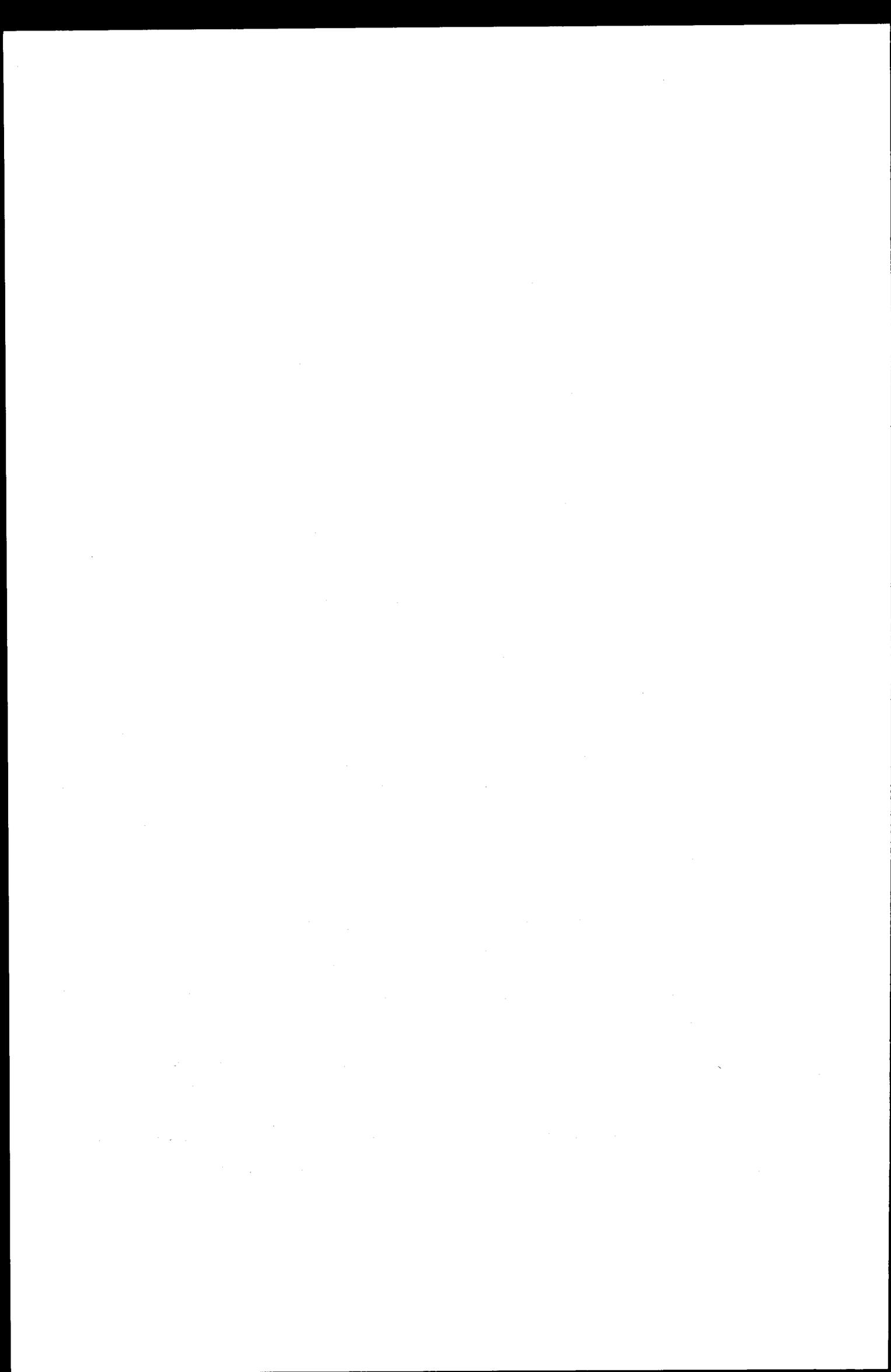
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## INTRODUCTION

In 1971 the general programme was a continuation of the previous programs (see Annual Reports 1959-70).

The activity of the laboratory is carried out by six groups which work very closely together since the study of the radiocontamination of the sea requires an interdisciplinary approach. In the field in which the laboratory does not possess direct competence, outside experts were consulted and the laboratory collaborated with other institutes.

The general programme is divided into two parts:

- 1) The investigation of relevant radioecological factors and elements in nature and under laboratory conditions.
- 2) The investigation of the outfall area off-shore of the CNEN Trisaia Centre in the Gulf of Taranto (fuel reprocessing plant).

The first part of the programme supplies the data and experience necessary to provide a sound scientific basis of the prediction of radiocontamination in the marine environment, while the second part consists in the application of this scientific knowledge to an actual site and thus represents an application of the principles derived under the first part of the programme to the solution of a practical problem.

In order to supply generalizable knowledge in marine radiocontamination in the past years our efforts were directed towards the identification of the most important environmental factors and the most important organisms in the Mediterranean marine ecosystem. This implied that sufficient good techniques had to be developed which could identify first of all the most abundant organisms and then attempt with additional information from in situ and laboratory experiment to decide which are the ecological most important organisms in this ecosystem.

In fact, in the previous years, (see Annual Reports for the years 1959 to 1970) new and in many instances automatized methods and techniques were developed to determine important environmental factors such

such as nutrient and stable element concentrations in seawater, sediments and marine organisms.

New sampling methods and abundance evaluations techniques for marine organisms had to be developed since existing techniques had been shown to estimate only part of the populations present in the ecosystem.

Although these new methods arrive at much better estimations in many instances further improvements are necessary to obtain reliable values for the abundance of marine organisms.

Based on the information obtained in the surveys the most abundant organisms were studied according to their biological and physiological characteristics.

These informations are a very important preparatory step for meaningful experiments on uptake, accumulation and loss of radioisotopes by single species and by simple model ecosystems. Furthermore since the results of laboratory experiments should be extrapolated to natural conditions without a good knowledge of the environmental conditions it is not possible to approximate these conditions sufficiently precise under laboratory conditions.

Since with a group of our size and the funds available it is not possible to study all radioecologically important isotopes and their stable isotopes a choice had to be made on the elements which should serve as model elements and on which most of the studies should center.

A model element should have characteristics common with other radioisotope of importance in marine radiocontamination and should be relatively easy to determine chemically and radioanalytically. Our choice of a suitable element fell on zinc since stable zinc can be relatively easily determined in seawater with polarographic methods which also can distinguish between different physico-chemical states.  $Zn^{65}$  is easily determined by gamma spectrography. In addition with potentiostatic electrolysis it is also possible to detect different phy-

sico-chemical species of  $Zn^{65}$  in seawater. Thus enabling us to determine both the physico-chemical state of stable and radioactive zinc in seawater and hence study the kinetics of exchange reactions between radioisotope and stable isotope when supplied to the seawater in different physico-chemical states. The data on zinc are supplemented with data on other elements and radioisotopes in order to see to what extent the informations collected on zinc are generalisable.

The final scope of the programme is to build valid models of the short term and long term behaviour of radioisotopes in the marine environment with special reference to the Mediterranean Sea. With the increasing information available both from the surveys and the in situ experiments, and the laboratory studies the precision of the models will successively improve.

The know-how acquired in the part of the programme on general principles of marine radiocontamination has been applied to the evaluation of an actual site in the Gulf of Taranto where a release of low-level wastes from a fuel processing plants are planned for the near future.

This site will also be studied in future years since it will supply a valid system to check the prediction made in a natural ecosystem.

CHEMICAL ENVIRONMENTAL FACTORS IN MARINE  
CONTAMINATION

The work of the Chemistry Group has been carried out in several directions:

- Investigation on the physicochemical forms of zinc in seawater as an example of the distribution of different physicochemical states of radionuclides in the marine environment.
- Development of very sensitive automatic methods for the study of the nutritional requirements of different sources of organic and/or inorganic nitrogen by primary producers.
- Investigation of the sorption of radioisotopes by marine sediments from the Gulf of Taranto to obtain correlations between the geochemical and grain size characteristics and the exchange and adsorption capacity of the sediments.
- Determination of trace metals (Zn, Cu, Sr, Fe) in marine organisms.
- Investigation of the effects of the pollution from sewage outfalls on nutrient distribution in seawater.

Physicochemical forms of zinc in seawater:

Since the  $Zn^{++}/pH$  curve obtained by polarographic analysis (anodic stripping) after January 1970 no longer showed the characteristic plateau in the pH range 5.5-6.5 (see Fig. 2.1), it was very interesting to know whether the zinc in the plateau-less seawater was fractionated in the same way as in the seawater with plateau. If radioactive ionic zinc is added to plateau-less seawater, even one year after addition, the  $Zn^{65}$  is distributed only in the ionic and particulate fractions, as had been observed in the seawater with plateau. This could be demonstrated by electrolysis at constant potential at pH 6 (-1.3 volts vs saturated calomel electrode (SCE)). It has been preferred to electrolyse the seawater at pH 6 instead of pH 8.1 because at pH 6 in the seawater are present only two physico-chemical states: complexed zinc and ionic zinc.

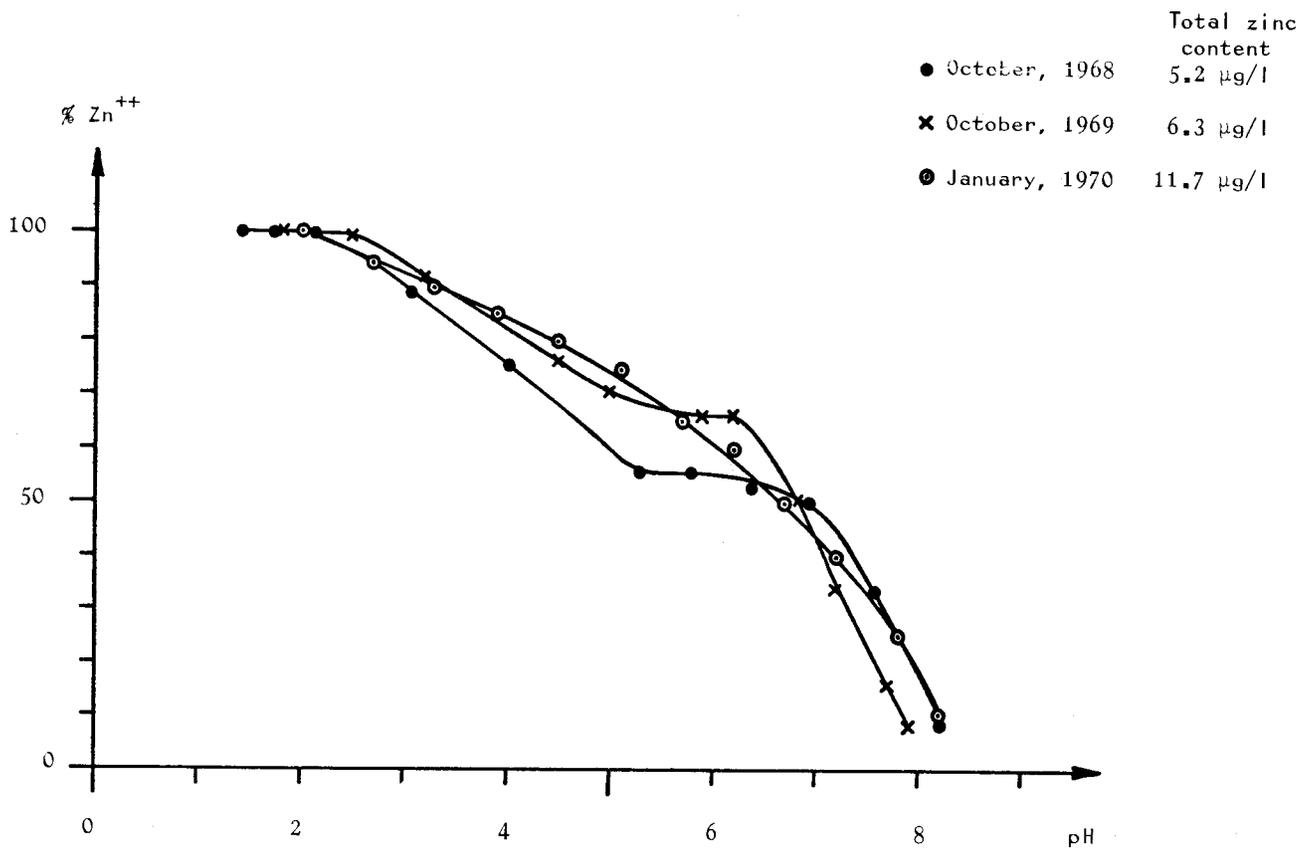


Fig. 2.1. Variation in the pH curves observed during the time interval October 1968 to January 1970 in the station 1 of the sampling zone in the Ligurian Sea. Determinations of October 1968 and October 1969 are carried out with Macchi's method (1966), of January 1970 with the modified Kemula method.

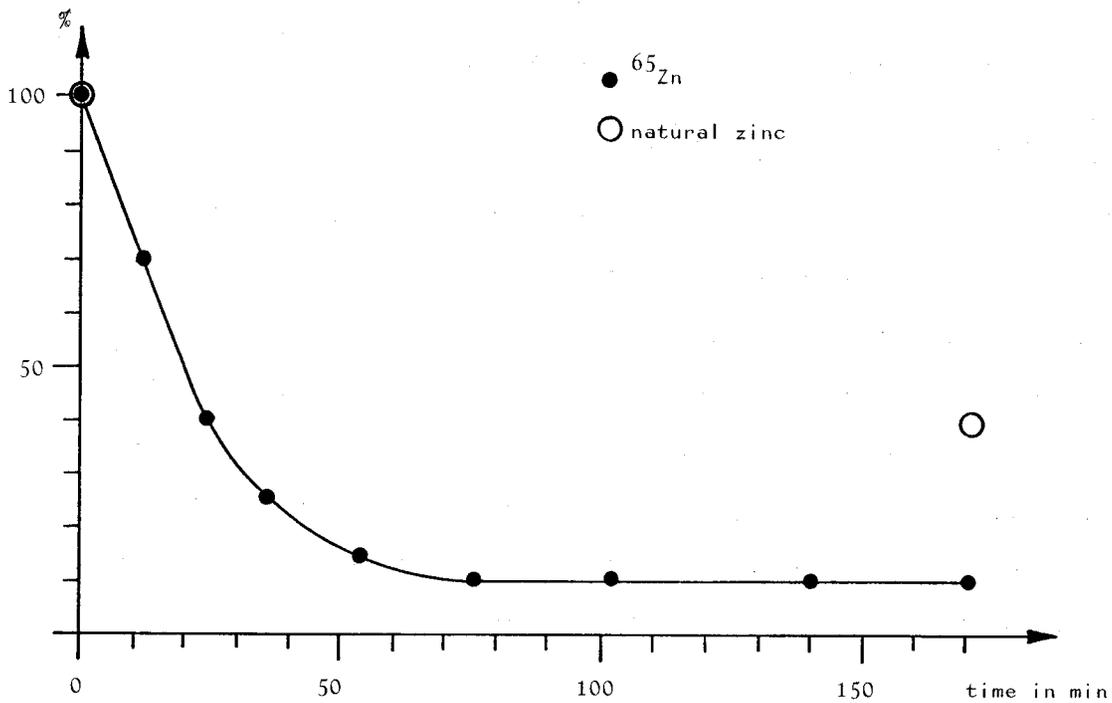


Fig. 2.2. Decrease of radioactive and natural zinc in a seawater sample electrolysed at pH 6. ( $^{65}\text{Zn}$  was added in the ionic form at the natural pH)

The particulate zinc present at pH 8.1 has been transformed into ionic zinc when the pH of the seawater was brought from pH 8.1 to pH 6 (see Annual Report 1968-69, Fig. 6). During this process all the zinc present in the ionic or labile form is reduced. As Fig. 2.2 shows, the radioactive zinc (black points) is practically all electrolyzed, while only 60% of the natural zinc can be reduced on the mercury electrode. The disappearance of the plateau therefore does not necessarily indicate an absence of the complexed form.

In order to demonstrate the presence of complexed zinc, seawater was acidified (pH 1.4) to break all the zinc complexes. At this pH, where zinc is present only in the ionic form, radioactive ionic zinc was added and then the pH brought back to the natural pH of seawater (pH 8.1). The solution was stored for about one week to allow the complexing agents to reestablish the various equilibria and then the seawater solution was electrolyzed at constant potential at pH 6. The results confirmed that a certain amount of complexing agents was able to bind zinc, i.e., the naturally occurring zinc and the added ionic zinc, in seawater at its natural pH even in the plateau-less seawater. As can be seen from Fig. 2.3, the radioactive and natural zinc are bound to the same extent. Both were reduced only up to about 50% of the total zinc, the remaining zinc being present as inert complexes.

#### Automatic methods for nutrients

A new automatic method (Autoanalyzer) for the determination of ammonia in seawater has been developed. The known modern methods (Riley, 1963; Strickland and Parsons, 1965; Riley and Sinhaseni, 1957; Grasshof, 1968; etc.) usually oxidize ammonia by an hypohalite and determine the quantity of the reaction product or the excess of the oxidizing reagent. But oxidation by hypohalites requires an alkaline pH for the sample, which may cause the precipitation of hydroxides in seawater. To avoid precipitation, complexing agents are added to seawater, but

this introduces additional sources of contamination and complicates the method.

In our method, ammonia is converted to nitrate by a dilute persulphate solution in a thermostatic bath at 80°C. Nitrate is then determined colorimetrically by our usual automatic procedure (see Annual Report, 1965). The manifold is shown in Fig. 2.4. The smallest concentration which can be detected with certainty is  $5 \cdot 10^{-9}$  g-at N/l. It should, however, be noted that the aminoacids present in the sample are also converted to nitrate. For this reason a method to separate the amino acids from the solution by means of automated dialysis is under investigation. Fig. 2.5 shows the vertical distribution of nitrates, nitrites and ammonia at a station seven miles off the coast. The analyses were simultaneously performed aboard the "Odalisca" by a set of three Autoanalyzers.

Another new automatic method (Autoanalyzer) for the determination of total nitrogen in seawater is under investigation. This method is less complicated than the methods using the automated Kjeldahl analysis, gives higher sensitivity and is more suitable for analysis aboard ship. The sample reacts with a persulphate solution under 3.5 atm of pressure and 120°C to convert all the nitrogen into the nitrate form. After eliminating the interfering oxidation products formed during digestion, the nitrate is measured in the usual way (see Annual Report 1965). At present the optimum concentration of the reagents is under investigation. The detection limit is in the range of  $10^{-8} - 10^{-9}$  g-at N/l. This limit compares favourably with the average nitrogen concentration in seawater, which is about  $3.5 \cdot 10^{-5}$  g-at N/l. When this new method has been set up the chemistry group will be able to determine simultaneously all the physico-chemical forms of inorganic nitrogen in seawater (i.e.,  $\text{NH}_4^-$ ,  $\text{NO}_2^-$  and  $\text{NO}_3^-$ ) together with the amount of total nitrogen.

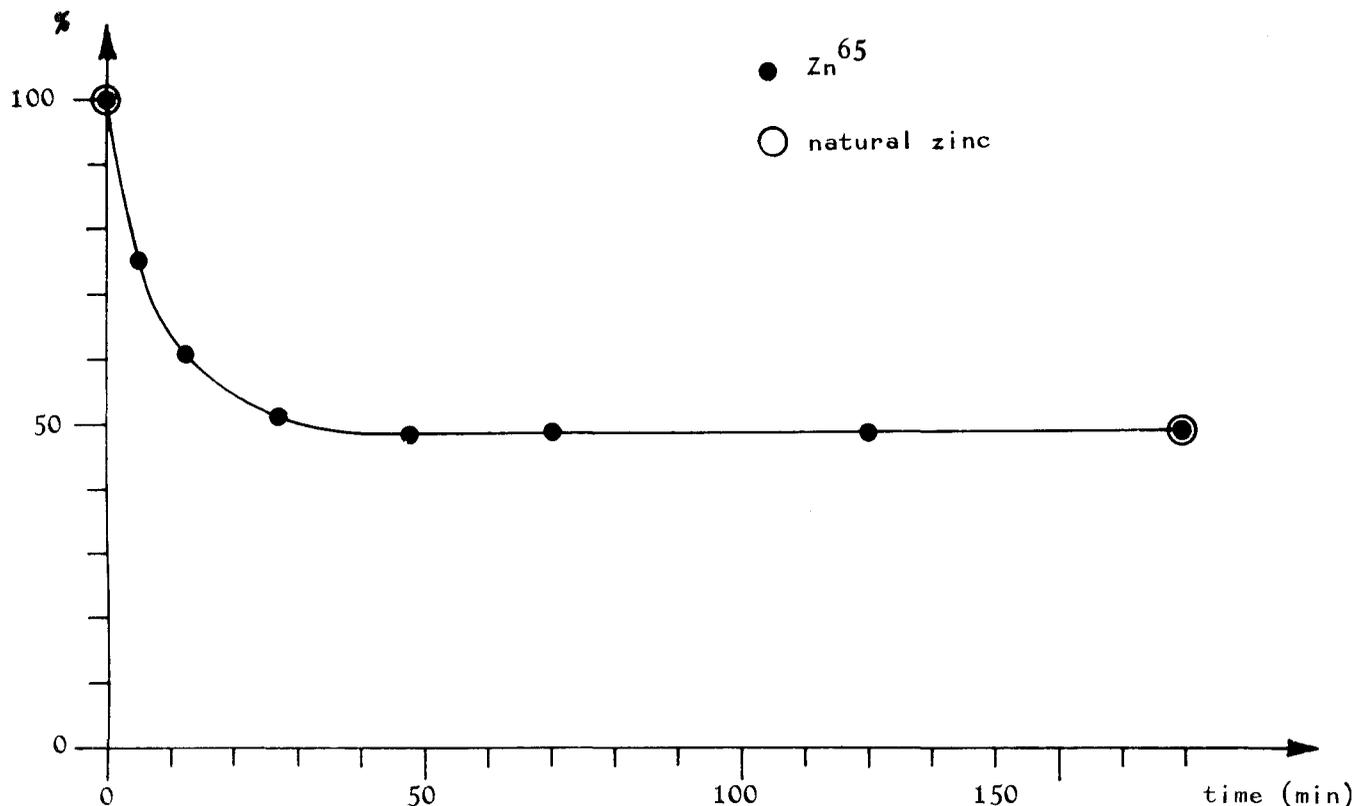


Fig. 2.3. Decrease of radioactive, and natural zinc in a seawater sample during electrostatic electrolysis ( $Zn^{65}$  was added in the ionic form at pH 1.4 after hydrolysis of the natural complexes)

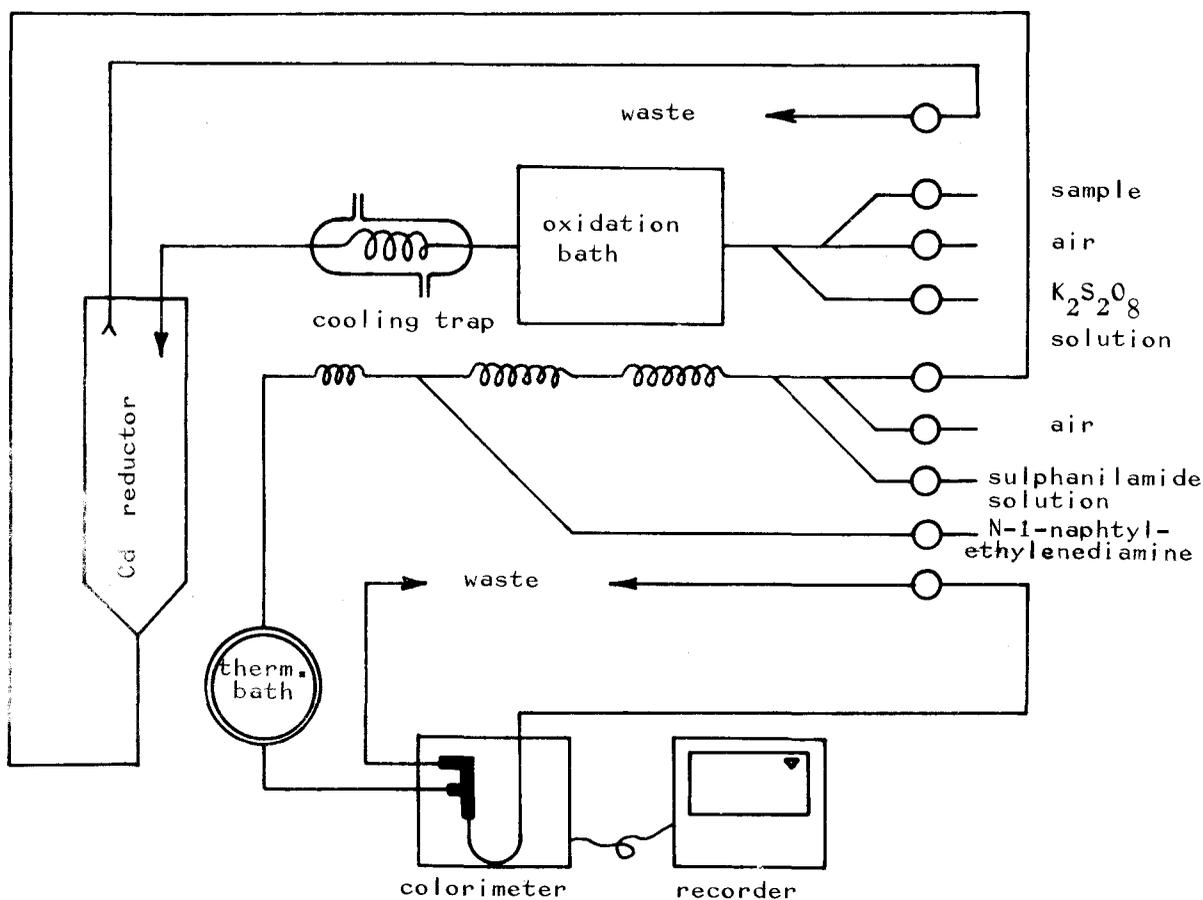


Fig. 2.4. General scheme of automated  $NH_3$  determination

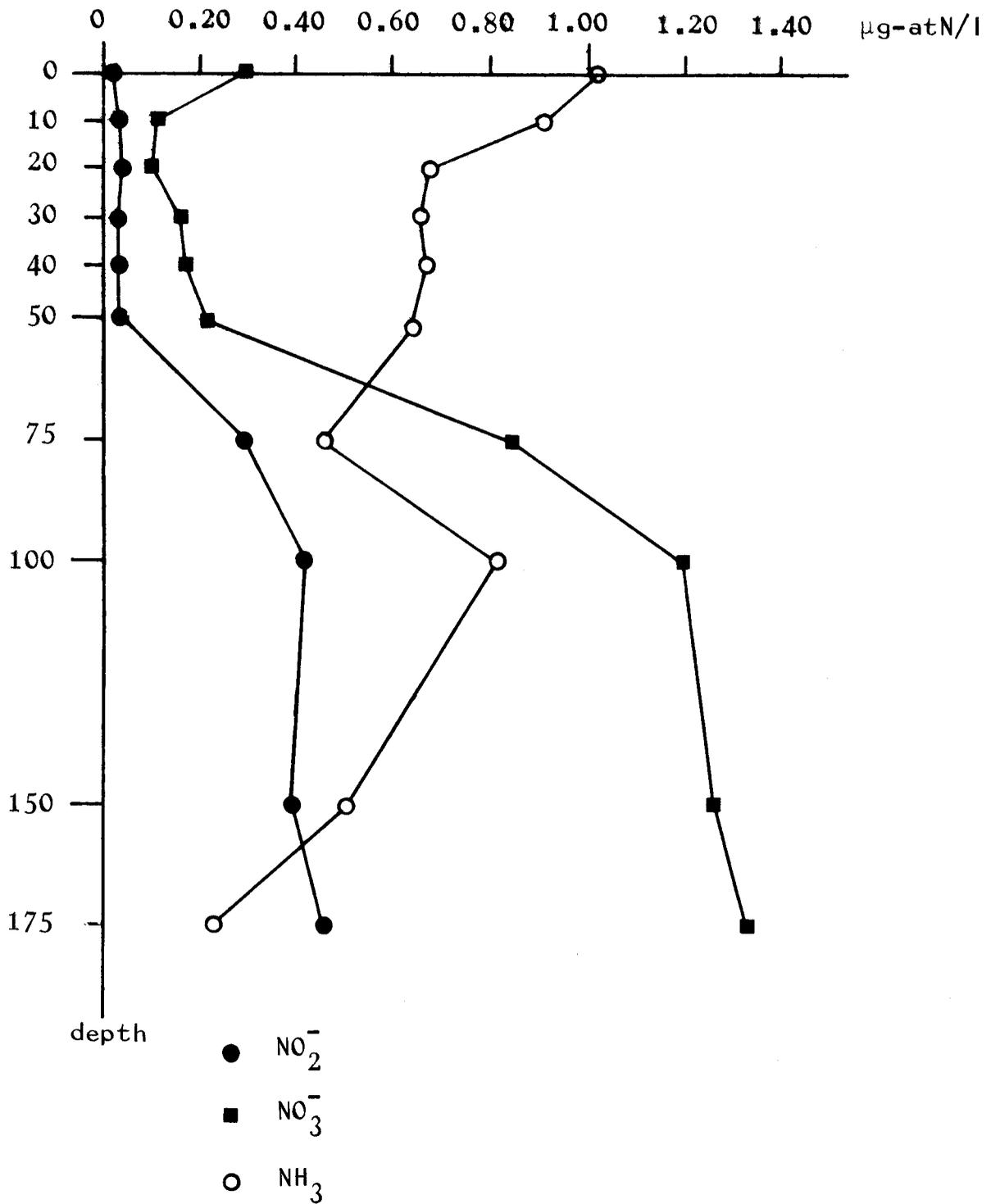


Fig. 2.5. Vertical distribution of  $\text{NO}_2^-$ ,  $\text{NO}_3^-$  and  $\text{NH}_3$  in a station seven miles off coast in the Ligurian Sea (20 April 1971)

### Sorption of radioisotopes to sediments

The investigation of the sorption of radioisotopes by the marine sediments from the Gulf of Taranto has been undertaken to evaluate the contamination of the sediments following the release of wastes from the Trisaia Centre. A six-column elutriator has been built to separate the sediment in various fractions according to grain size and the specific weight of the particles (see Fig. 2.6). After the columns and their bottles are filled with seawater, the sediment is placed in the beaker. By a variable-speed peristaltic pump, seawater is pumped through the columns carrying the sediment particles. The narrow diameter of the first tube causes a fairly high upward flow of water, so that all the particles except the coarsest can reach the first bottle. In the successive columns, which are of increasing diameter, the same volume of water passes through them with decreasing lower velocity, so that increasingly fine particles are separated. By adjusting the speed of the peristaltic pump, the desired separation can be carried out. The sorption capacity of the smallest fraction which has the highest sorption capacity, i.e., the clay fraction, was tested after  $\text{Ru}^{106}$ ,  $\text{Sr}^{89}$  and  $\text{Zn}^{65}$  had been added to a sediment suspension. Preliminary experiments show that zinc as well as ruthenium is taken up by the clay fraction (see Fig. 2.7), while the strontium concentration in the suspension remains practically unchanged. At present our efforts are directed at determining the best technique for obtaining reproducible results on the sorption onto sediments. It is known that different ways of stirring or shaking the suspension may give quite different sorption values (Duursma, 1970). Ultrasounds have been successfully used to avoid coagulation of the fine particles during experiments.

### Trace elements in marine organisms

The determination of stable Zn, Cu, Sr and Fe in marine organisms has been continued. The obtained data will be processed by computer to obtain all the possible correlations between metal concentration,

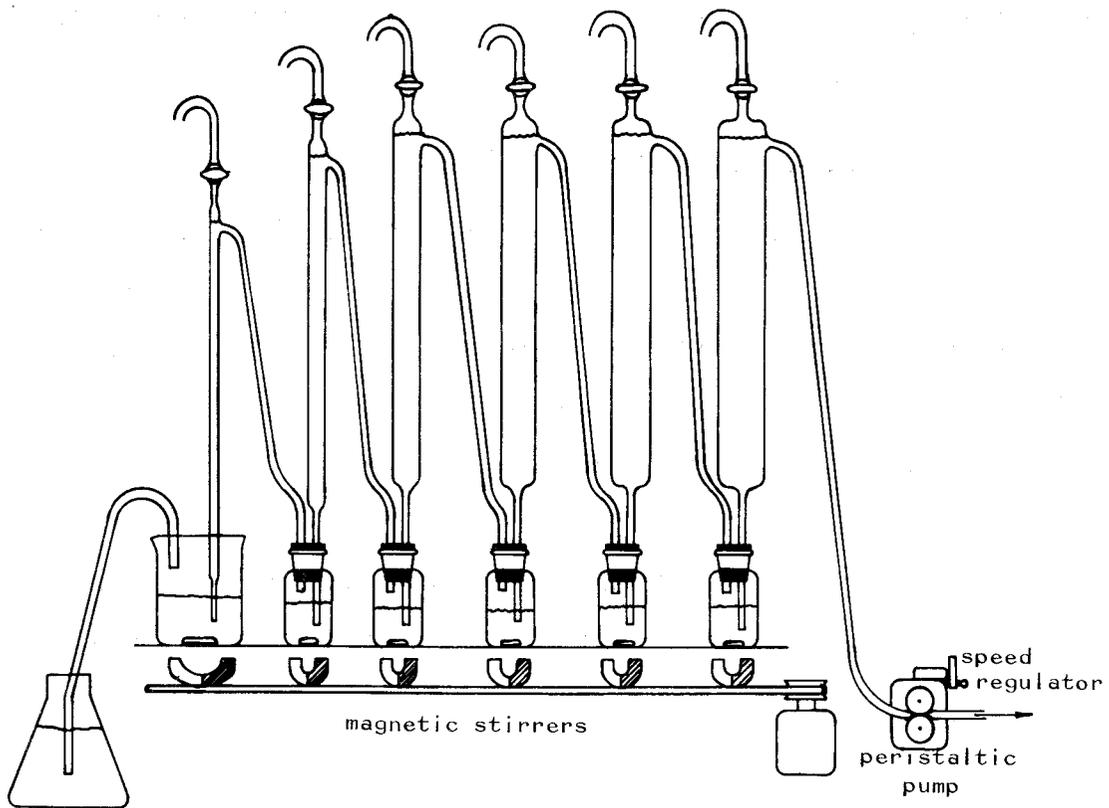


Fig. 2.6. Elutriation set for grain size separations of sediments

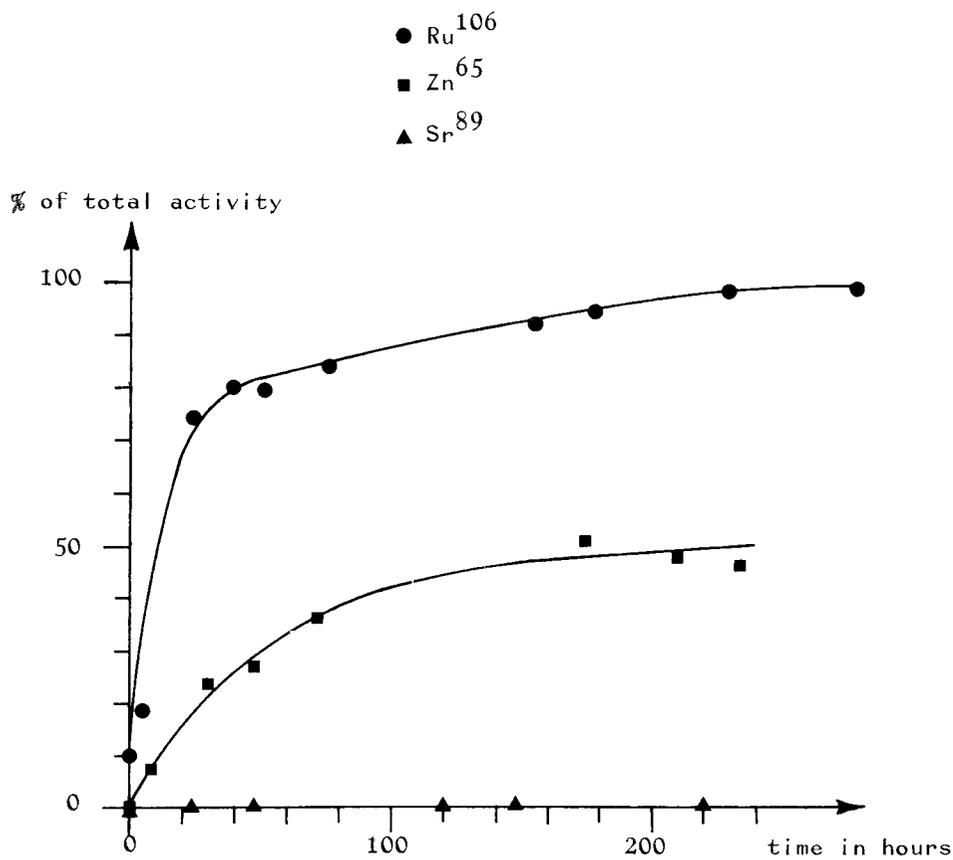


Fig. 2.7. Sorption of radionuclides by a clay fraction of the bottom sediments in the Gulf of Taranto

species, fishing zone and animal size. Table 2.1 gives an idea of the concentrations found.

#### Sewage outfalls and nutrient distribution

The survey on the influence of sewage outfalls from the town of La Spezia and the villages along the coast on the nutrient concentration in the coastal waters was continued. The analyses were performed aboard the "Odalisca" by a set of four Autoanalyzers. Fig. 2.8 shows the concentration of the reactive phosphate and the total P along the coast near La Spezia.

Furthermore, many chemical determinations were conducted by the other groups according to the requirements of the joint programmes.

Table 2.1. Concentration of some trace metals in Mullus barbatus.

S= Standard zone (depth: 30 meter)<sup>1)</sup>

E= Second zone (depth: 30 meter)

MU= Muscle

TB= Total body

DATE	ZONE	ORGAN	µg Zn/g			µg Cu/g			µg Sr/g			µg Fe/g		
			Wet	Dry	Ash									
8 May 67	S	MU	3.83	16.01	179.49	2.12	8.86	99.29	6.45	26.96	302.25	12.80	53.49	599.51
8 May 67	S	TB	22.73	85.82	604.04	3.66	13.83	97.37	7.18	27.10	190.79	22.73	85.82	604.04
25 July 67	S	MU	6.34	33.35	176.47	2.38	12.52	66.25	5.28	27.78	146.96	14.68	77.22	408.52
26 July 67	E	TB	4.63	18.13	84.00	3.69	14.44	66.90	7.90	30.90	143.13	19.77	77.34	358.23
28 July 67	E	MU	12.70	58.20	218.96	3.49	15.99	60.18	7.74	35.48	133.49	2.22	10.21	384.36
13 Nov 67	S	MU	1.71	9.92	357.55	1.24	7.20	259.60	0.54	3.15	113.61	2.92	16.92	609.82
13 Nov 67	S	MU	1.59	8.08	191.43	0.41	2.10	49.93	1.59	8.06	191.01	2.54	12.88	305.21
2 May 69	E	MU	0.78	11.39	208.33	0.096	1.40	25.72	0.11	1.62	29.72	4.15	5.17	99.36
23 Sept 69	E	MU	0.97	4.76	100.90	0.24	1.17	24.77	0.52	2.55	54.11	3.69	17.81	376.05

1) For the determination of the zones, see Annual Report 1968-69 Fig. 42

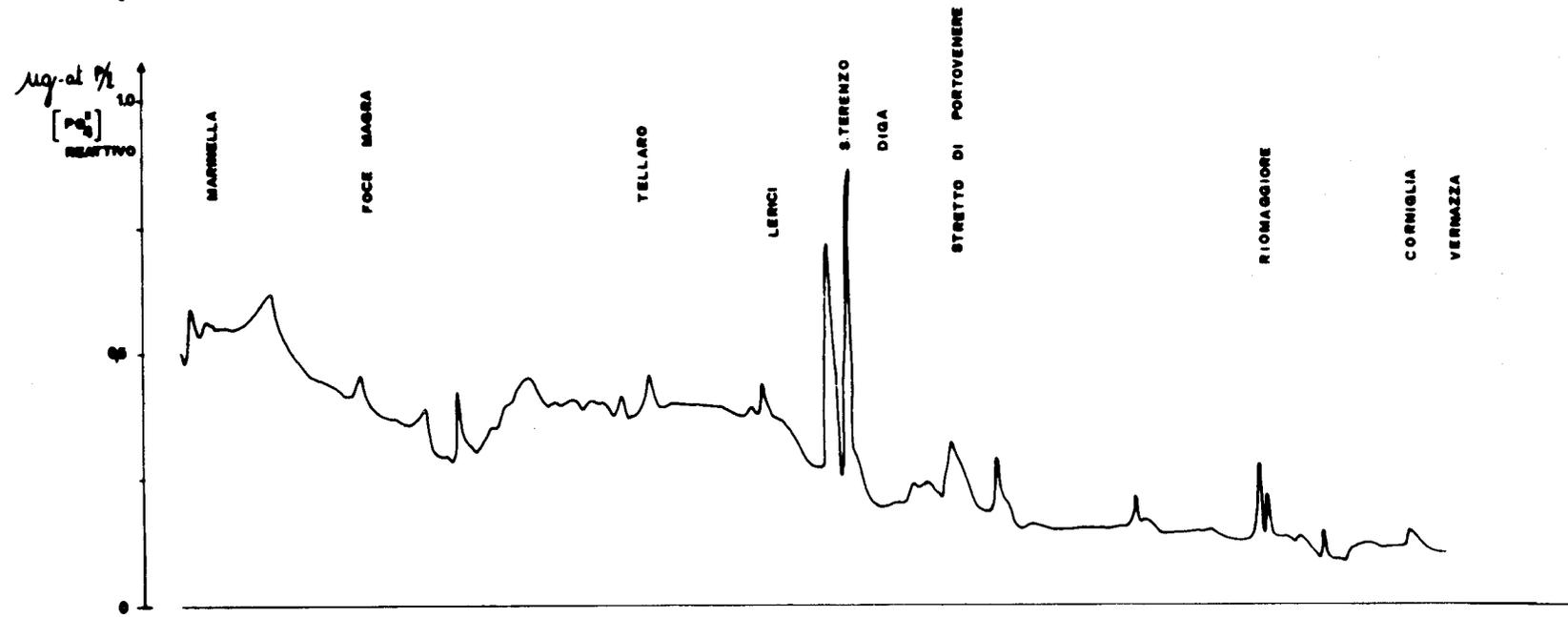
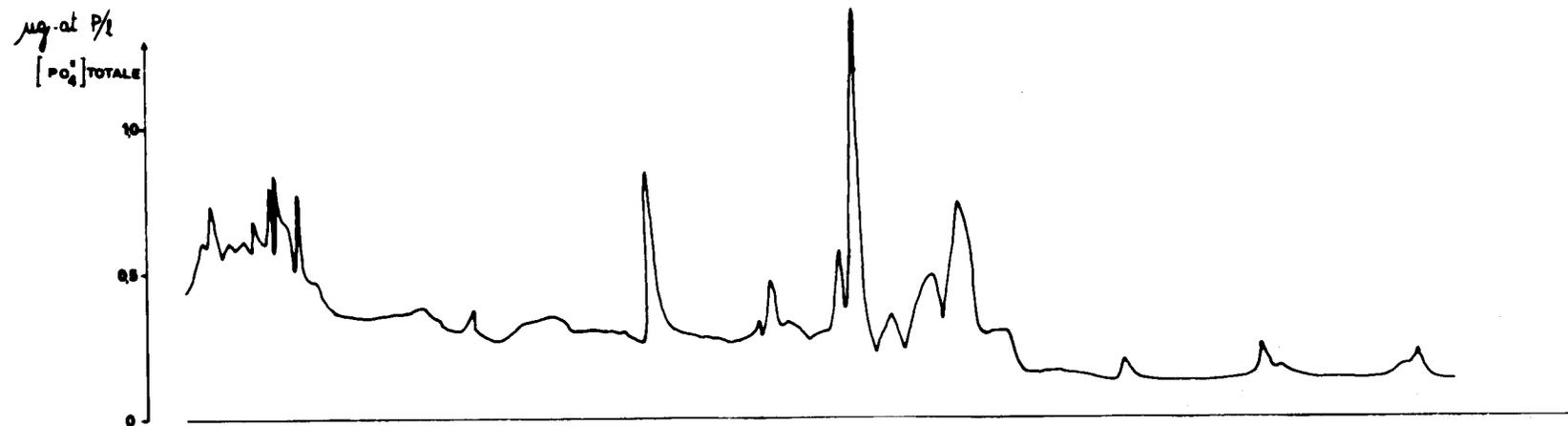


Fig. 2.8. Reactive phosphate and total P concentrations along the coast of La Spezia

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### FIRST TROPHIC LEVEL OF THE FOOD CHAIN

During 1971 the Botany Group, in close collaboration with the Special Development Group, directed a large part of its time to the collection and evaluation of the environmental data needed for estimating the receptivity of the outfall area in the Gulf of Taranto (see Chapter 8, "Environmental Investigation in the Gulf of Taranto").

During the remaining time the groups directed their attention to the following points:

- 1) the importance of plant nutrients and their different physicochemical states for the growth of phytoplankton algae and hence indirectly for the accumulation of radioisotopes;
- 2) chlorophyll concentrations as an indication of potential photosynthetic activity;
- 3) effects of conventional pollutants on growth and development with respect to synergetic effects, and
- 4) comparison of growth characteristics between natural populations and artificial populations.

At the first trophic level the uptake and loss of elements is closely related to metabolism and therefore growth and production influence the uptake and loss of radioisotopes.

We observed, for example, a good correlation between phytoplankton growth and zinc accumulation (Fig. 3.1) hence the influence of plant nutrients on growth is interesting from the point of view of radiocontamination.

Scott (1954) found that the Cs-uptake by algae is enhanced when phosphate is added to the medium.

Phosphorus is thought to be an important nutrient of phytoplankton, although its actual role in stimulating phytoplankton growth

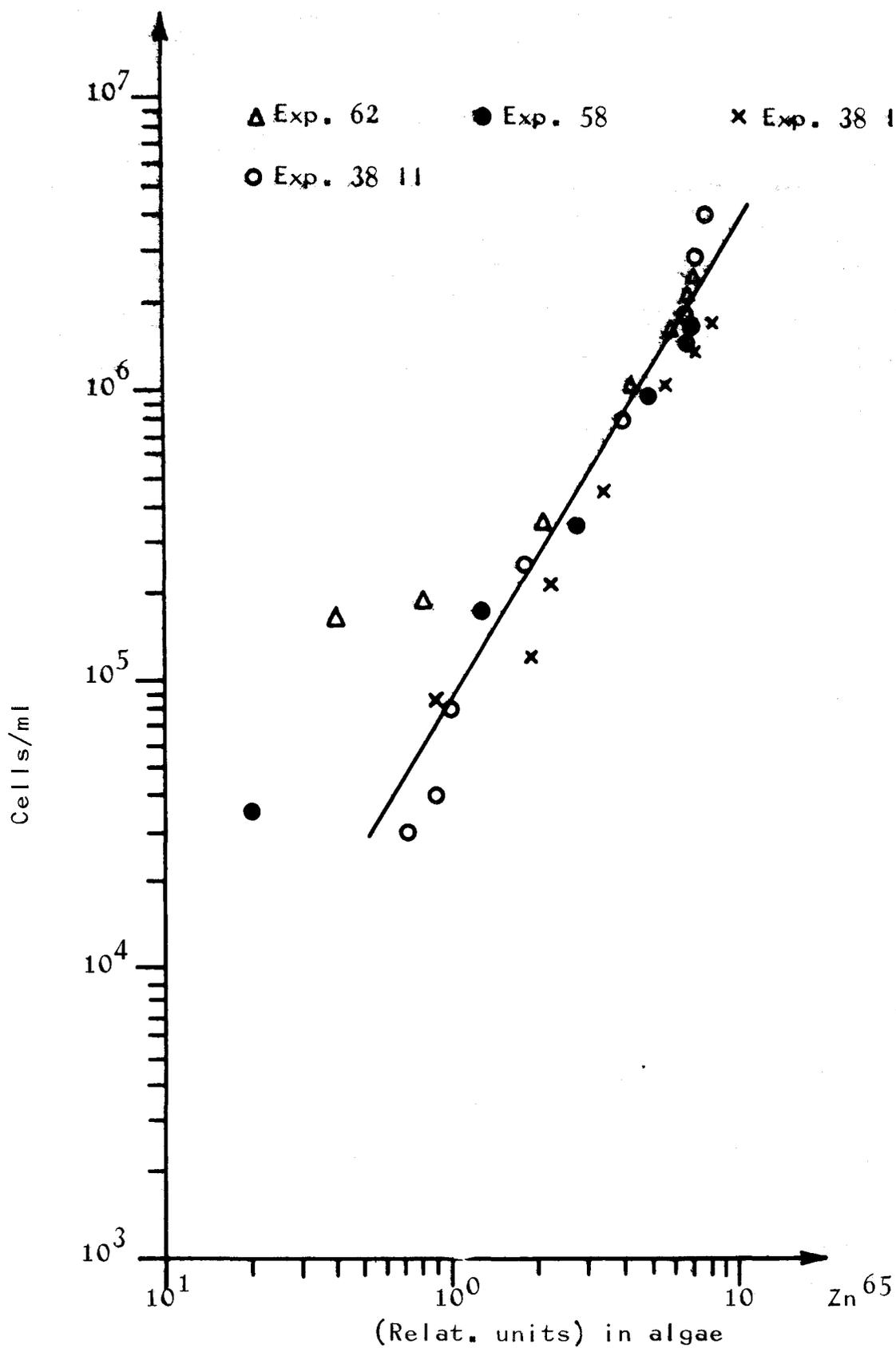


Fig. 3.1. Relation between Zn<sup>65</sup> content (in relative units) in algae population (cells/ml) for four experiments

is not understood.

The experiments on the metabolism of various phosphorus compounds and its effect on phytoplankton growth have been continued (Annual Reports 1968-69, 1970).

The supply of phosphorus as an inorganic ( $\text{Na}_2\text{HPO}_4$ ) and organic (ATP) source showed that algae prefer to take up the phosphorus in inorganic form (Fig. 3.2). On the basis of the data obtained up to now the following conclusions can be drawn:

- 1) Algae can take up phosphorus in inorganic or organic form (e.g.,  $\beta$ -glycerophosphate or ATP).
- 2) When both inorganic and organic forms are present algae take up preferentially inorganic phosphorus.
- 3) Natural population grown in a medium of low phosphate content equal to natural concentrations ( $0.25 \mu\text{g-at total P/l}$ ) showed that natural populations can reach a biomass of  $\sim 0.4 \text{ mg FW/l}$  containing  $0.62 \mu\text{g P/mg FW}$ .
- 4) Results on natural populations are in good agreement with similar ones from experiments carried out with artificial populations:  $0.2-0.3 \mu\text{g P/mg FW}$  (see Annual Report 1968-69), which corresponds to  $0.2-0.3 \mu\text{g P}/1.6 \cdot 10^7$  cells of Phaeodactylum tricornutum.
- 5) At phosphate concentrations equal to or higher than about  $6 \mu\text{g-at P/l}$ , supplied as either inorganic or organic sources, the cell density reaches a maximum value in batch cultures, which corresponds to  $2.8 \cdot 10^9$  cells of Phaeodactylum tricornutum per litre. This density is equal to  $168 \text{ mg FW/l}$  and under these conditions the algae cells contain  $\sim 1.4 \mu\text{g P/mg FW}$ . At higher concentrations of P in the medium the cell density does not increase, only the P content of the cell augments (see Fig. 2.2 Annual Report, 1968-69).
- 6) In the culture media usually employed (e.g., Erd-Schreiber) the

- ▽—▽—▽— Total soluble phosphorus
- ▽—▽—▽— Organic soluble phosphorus
- Inorganic or reactive phosphorus
- ...△...△...△... Population  $NT_0$   $6.3 \times 10^7$  cells/l

Total soluble organic P before inoc.  $2.73 \mu\text{g at/l}$

Total reactive soluble P before inoc.  $1.9 \mu\text{g at/l}$

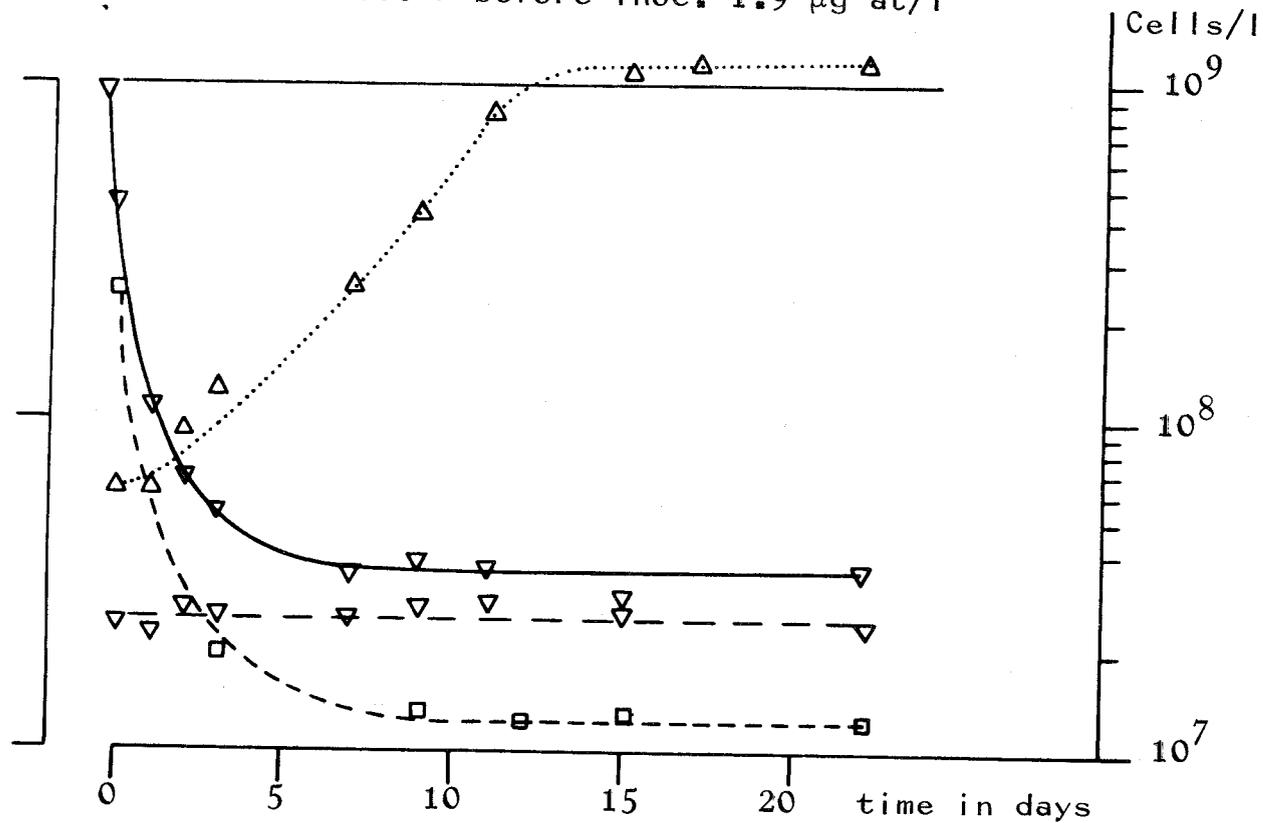


Fig. 3.2. Uptake of inorganic and organic (ATP) phosphorus by Phaeodactylum tricornutum. All data are expressed as % of total phosphorus before inoculation

concentration of phosphates is ten times higher than necessary.

A few words should be said about the problem of availability. The total phosphorus determined with an acid digestion method in natural seawater is very likely not the same as the fraction hydrolyzed by the organism with enzymatic reactions. This poses the question of the usefulness of the chemical determinations now predominately in use (e.g., Strickland and Parsons, 1965). The biologist would like to see biochemical methods used for the determination of 'available phosphate', rather than inorganic chemical methods. In order to contribute to the research in this direction, the Botany Group has again taken up the study of the hydrolyzing effects of phosphatases started in 1967 (see Annual Report, 1967).

Chlorophyll could be a good indicator of the potential photosynthetic activity of phytoplankton and hence of potential growth. In order to have data available for the most important phytoplankton species of our zone, the chlorophyll 'a' content of different species has been determined (Table 3.1). The results are comparable with those published by other authors (e.g. Fleming 1940, Yentsch and Ryther 1959, Parsons et al 1961, Eppley and Sloan 1966).

As can be seen from Table 3.2, Chaetoceros lorenzianus is the algae which possesses the highest amount of chlorophyll 'a' per gram fresh weight (FW).

It is about four times as high as that of the other algae studied.

The chemical composition of marine organisms can supply very valuable information about the maximum contamination possible of marine organisms.

In collaboration with Prof. P. Strohal (Institute Ruder Boskovic, Zagreb, Yugoslavia), the most important organisms in the food chain of the Trisaia outfall area were analysed by neutron activation

Table 3.1. Chlorophyll 'a' concentration in some phytoplankton species

Species	Chl 'a' / in mg per cell	Chl 'a' mg/g FW
<i>Asterionella japonica</i>	$8 \cdot 10^{-10}$	2.2
<i>Biddulphia mibiliensis</i>	$3 \cdot 10^{-8}$	0.32
<i>Chaetoceros decipiens singularis</i>	$3 \cdot 10^{-9}$	2.09
<i>Chaetoceros lorenzianus</i>	$10^{-7}$	15
<i>Phaeodactylum tricornutum</i>	$2 \cdot 10^{-8}$	3
<i>Thalassiosira decipiens</i>	$7 \cdot 10^{-11}$	2
<i>Thalassiosira polycora</i>	$1.2 \cdot 10^{-9}$	0.6
<i>Exuviella compressa</i>	$2.6 \cdot 10^{-9}$	5
<i>Glenodinium sp<sub>1</sub></i>	$1.1 \cdot 10^{-9}$	4
<i>Glenodinium sp<sub>2</sub></i>	$9 \cdot 10^{-10}$	3.21
<i>Prorocentrum micans</i>	$3 \cdot 10^{-9}$	0.3
<i>Coccolithus huxleyi</i>	$6 \cdot 10^{-11}$	3

Table 3.2. Determination by activation analysis of stable elements in several organisms taken off shore the Trisaia center ( $\mu\text{g/gFW} \times 10^{-2}$ ) (Strohal)

	Gadidae		Penaeidae	Cardiceae	Veneridae	Loliginidae	Ommastrephidae
	M. merluccius		P. longirostris	Cardium sp.	Venus sp.	Loligo sp.	Ommatostrephes sp.
	muscle	skeleton	edible	edible	edible	edible	total body
	$\mu\text{g/gFW}$						
Zn	220	2058	325-1100	1089	1086	776	781
Co	0.21	0.59	2.95	20	30	0.5	1.24
Sr	319	2100-9800	368-750	540	411-1200	241	408
Fe	127-655	-	115	12800	86	285-1230	1954
Sc	-	-	0.00035	2.55	6.7-15.85	0.042-0.397	0.089
Se	-	-	93-200	363	70-200	90-340	302
Eu	-	-	0.047	0.51	0.61	0.074-0.18	0.08
Ag	-	-	1-3.5	6	3.5	16	15
Hg	-	-	3-15	2-27	-	-	-
Cs	0.45	0.85-2.17	0.24	3.04	1.66-5.8	2.5-18.1	0.18

analysis.

Preliminary results for several organisms are given in Table 3.2.

The synergetic effect of conventional and radioactive pollutants may become important, especially in coastal regions near conventional pollution outfalls.

Three common pesticides inhibit only slightly the larval development of Arbacia lixula (Table 3.3). Table 3.4 shows the toxic effect of different common household detergents on the development stage of Arbacia lixula larvae and on the growth of three phytoplankton species.

At higher concentrations detergents inhibit only slightly the development of Arbacia lixula and practically no inhibition was noted in the phytoplankton growth.

In order to obtain additional data for the use of models of phytoplankton dynamics, the growth characteristics of several phytoplankton species were determined for different media.

As can be seen from Table 3.5, practically no differences were noted between the three different culture conditions.

In a further attempt to arrive at a better understanding of population dynamics, experiments were performed in situ on both natural and artificial populations.

Preliminary data indicate that natural populations have a higher growth rate than artificial populations when exposed to the same natural conditions. Since the algae of the artificial populations were previously grown in media containing higher concentrations of inorganic nutrients (see above), they may have adapted to these more favourable conditions.

Table 3.3. Mean development stage of Arbacia lixula larvae grown in RSW and VRSW media with various concentrations of three pesticides

		C o n c e n t r a t i o n $\mu\text{g/l}$			
		$10^4$	$10^3$	$10^2$	10
Simazin	RSW	5.49	5.54	5.40	5.34
	VRSW	5.62	5.35	5.36	5.24
Orthocid	RSW	5.16	5.43	5.45	5.48
	VRSW	5.07	5.41	5.33	5.31
Diditan	RSW	5.33	5.38	5.29	5.04
	VRSW	5.51	5.48	5.35	5.14
Blank	RSW				5.55
	VRSW				5.27

RSW = Natural enriched seawater

VRSW = Natural enriched seawater + Versene ( $10^{-4}\text{M}$ )

Simazin - herbicide

Orthocid - fungicide

Diditan - insecticide

Table 3.4. Effects of some detergents on the mean development stage of *Arbacia lixula* larvae and on the growth of some phytoplankton strains

Detergent mg/l	A.lixula mean dev. stage RSW	L.danicus	C.huxleyi	P.micans
		EtRSW	EtRSW	EtRSW
Blank	5.23	+ + + +	+ + + +	+ + + +
Last	1	+ + + +	+ + + +	+ + + +
	0.5	+ + + +	+ + + +	+ + + +
	0.1	+ + + +	+ + + +	+ + + +
	0.01	+ + + +	+ + + +	+ + + +
	0.001	+ + + +	+ + + +	+ + + +
Bref	1	+ + + +	+ + + +	+ + + +
	0.5	+ + + +	+ + + +	+ + + +
	0.1	+ + + +	+ + + +	+ + + +
	0.01	+ + + +	+ + + +	+ + + +
	0.001	+ + + +	+ + + +	+ + + +
Blank	5.04	+ + + +	+ + + +	+ + + +
Ariel 2	1	+ + + +	+ + + +	+ + + +
	0.5	+ + + +	+ + + +	+ + + +
	0.1	+ + + +	+ + + +	+ + + +
	0.01	+ + + +	+ + + +	+ + + +
	0.001	+ + + +	+ + + +	+ + + +
Vim	1	+ + + +	+ + + +	+ + + +
	0.5	+ + + +	+ + + +	+ + + +
	0.1	+ + + +	+ + + +	+ + + +
	0.01	+ + + +	+ + + +	+ + + +
	0.001	+ + + +	+ + + +	+ + + +
Calinda extra	1	+ + + +	+ + + +	+ + + +
	0.5	+ + + +	+ + + +	+ + + +
	0.1	+ + + +	+ + + +	+ + + +
	0.01	+ + + +	+ + + +	+ + + +
	0.001	+ + + +	+ + + +	+ + + +

+ + + + normal growth rate  
6 maximum development stage

Table 3.5. Generation time ( $G_T$ ) and growth coefficient ( $K_T$ ) of some phytoplankton strains cultivated in three different media: EtRSW - RSW - SW

ALGAE	Et R S W		R S W		S W	
	$G_T$	$K_T$	$G_T$	$K_T$	$G_T$	$K_T$
<i>Prorocentrum micans</i>	2.9	0.24	2.7	0.26	2.7	0.26
<i>Glenodinium sp<sub>1</sub></i>	2.8	0.25	6.4	0.11	6.4	0.11
<i>Glenodinium sp<sub>2</sub></i>	3	0.23	2.15	0.32	2.15	0.32
<i>Exuviella compressa</i>	2.2	0.315	2.2	0.315	2.2	0.315
<i>Coccolithus huxleyi</i>	1.7	0.41	1.4	0.50	2.4	0.30
<i>Asterionella japonica</i>	2.5	0.28	3.3	0.21	3.3	0.21
<i>Nitzschia closterium</i>	1.8	0.385	3.8	0.18	3.8	0.18
<i>Phaeodactylum tricornutum</i>	1	0.69	0.9	0.80	0.9	0.80
<i>Chaetoceros danicus</i>	3.3	0.21	2	0.35	2	0.35
<i>Chaetoceros lorenzianus</i>	2.6	0.27	1.5	0.46	1.5	0.46
<i>Chaetoceros affinis</i>	2.3	0.30	2.5	0.28	2.5	0.28
<i>Leptocylindrus danicus</i>	2.6	0.27	1.6	0.43	1.6	0.43

Et= enriched seawater plus soil extract  
 RSW= enriched seawater

SW= seawater without enrichment

If these preliminary observations should be confirmed by future experiments, uptake and loss experiments with radioisotopes must not only be carried out under experimental conditions more similar to the natural environment but also the strains used must be grown under conditions which are similar to the natural ones.

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## FIRST HETEROTROPHIC LEVEL OF THE FOOD CHAIN

The majority of the numerous species which form the zooplankton community are herbivorous copepods. They feed on unicellular algae and consequently belong to the second trophic level. Thus zooplankton forms the important link in transferring radioisotopes from algae to fishery products.

As in previous years, the activity of the Zoology group dealt with two main programmes:

- 1) The quantitative analysis of composition and distribution of the zooplankton community in the experimental zone of La Spezia and in the Gulf of Taranto.
- 2) Laboratory experiments on metabolism and radiocontamination of the most important zooplankton organisms.

The long-term purpose of the investigations at sea is to determine quantitatively the flux of organic matter, energy and radioactive substances through the zooplanktonic levels of the food chain. These data will be used to build models which will enable us to make predictions about the utilization and transformation rates for organic matter by each trophic level of the zooplankton and about radiocontamination of the most critical species or groups.

In the previous reports, the sampling and counting techniques designed to obtain a quantitative estimation of the zooplankton population were discussed. The seasonal variations of the most important species in the La Spezia zone and in the Taranto Gulf were determined. The numbers of organisms were then converted into biomass, carbon and nitrogen content using the equations for the correlation between size and dry weight determined for each important species in particular.

Further experiments conducted in 1971 enabled us to determine

the turnover time of organic matter and the potential productivity of the zooplankton populations according to seasonal variations.

Generation time, intermolt time and dry weight at each development stage were estimated for the most important species of copepods in laboratory culture. From these data, the turnover time and the daily potential production of nauplii and copepodit stages of the various species were calculated. The results, summarized in Table 4.1, showed a large variability within each species, as was already observed by Neunes and Pongolini (1965) for Euterpina acutifrons. The mean turnover time varied between 3.5 and 6 days for the seven species investigated and the daily potential production from 11 to 29 % of the copepod biomass. The total potential production expressed as  $\mu\text{g}$  dry weight per  $\text{m}^3$  was calculated for each species of copepods (Table 4.2), taking into consideration the data obtained for seasonal variations in zooplankton biomass in the zone of La Spezia and for production in laboratory experiments.

From published data (e.g., Greze 1970, Petipa et al. 1970) the production of species which do not belong to copepods ("no copepods") was estimated and compared with the production from copepods. Animals were divided into herbivorous and carnivorous (Table 4.3). The production of planktonic carnivores generally amounts to less than 5 % of the herbivorous production except in winter (36 % in December and 15 % in January). The role of "no copepods" in the total production is therefore negligible in comparison with copepods. These results suggest that exploitation of planktonic herbivorous by planktonic carnivorous is low. Most of the organic matter produced at the herbivorous level, principally copepod biomass, passes directly to the higher level of planktonic carnivorous (e.g., Sardines and Engraulis).

Only very few data are available in the literature on the micro-

Table 4.1. Intermolts, biomass turnover time and potential production of various species of Copepods in culture solutions

		Time per stage in days <sup>1)</sup>		Turnover-time of biomass in days		Potential productivity in % of the biomass/day	
		MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
<u>Clausocal. a.</u>	N.	1.5	1.16-2.5	4.15	3.22 - 6.91	24.13	14.47-31.03
	C.	2	1.33-2.5	5.66	3.77 - 6.60	17.68	15.15-26.51
<u>Centropag. t.</u>	N.	1.3	1 - 2.5	4.53	3.40 - 8.49	22.09	11.77-29.45
	C.	1.8	1 - 2.33	3.47	2.31 - 5.78	28.82	17.29-43.23
<u>Acartia c.</u>	N.	1.6	1.3 - 2.5	5.84	4.67 - 8.76	17.12	11.41-21.40
	C.	2	1.5 - 2.3	4.88	3.66 - 6.11	20.47	16.38-27.30
<u>Euterpina a.</u>	N.	1.3	1 - 2.4	5.48	3.87 - 9.67	18.25	10.35-25.87
	C.	1.5	1 - 3.3	8.62	5.75 - 19.14	11.60	5.22-17.40
<u>Oithona h.</u>	N.	1.3	1 - 2	5.92	4.44 - 8.85	16.88	11.26-22.51
	C.	1.7	1.2 - 2.2	6.79	5.00 - 9.29	14.73	10.77-19.99
<u>Temora s.</u>	N.	1.5	1.2 - 2	4.50	3.50 - 6.00	22.22	16.67-28.57
	C.	2	1.5 - 2.5	4.95	3.71 - 6.19	20.20	16.16-26.93
<u>Ctenocal. v.</u>	N.	1.5	1.16-2.5	4.15	3.22 - 6.91	24.13	14.47-31.03
	C.	1.8	1.3 - 2.3	5.26	3.83 - 6.70	19.05	14.94-26.13

1) For each of the six nauplii (N) and of the six copepodit (C) stages

Table 4.2. Mean potential daily production in  $\mu\text{g dry weight}/\text{m}^3/\text{day}$  calculated for Copepods according to seasons

	1968							1969				
	I	II	III	IV	VI	VII	X	XII	I	III	IV	VI
<u>Clausocal. a.</u>	820	220	4410	357	67	83	749	1004	522	185	842	208
<u>Oithona h.</u>	122	209	589	799	225	89	224	142	72	62	181	95
<u>Oncaea sp.</u>	331	23	14	6	18	53	65	303	275	35	83	125
<u>Euterpina a.</u>	-	4	100	52	4	-	7	23	9	19	16	2
<u>Acartia c.</u>	25	166	232	259	100	81	26	119	232	2009	146	263
<u>Microset. r.</u>	-	-	122	73	14	80	18	16	-	-	51	12
<u>Centropag. t.</u>	-	125	723	4321	573	1411	314	213	176	427	4071	352
<u>Calocal. sp.</u>	60	6	31	-	-	5	64	30	27	10	30	15
<u>Corycaeus c.</u>	142	52	351	-	-	34	40	294	62	-	69	111
<u>Ctenocalan. v.</u>	-	-	-	-	-	13	63	57	5	54	161	28
<u>Temora st.</u>	-	-	66	-	-	-	235	731	-	-	-	-

Table 4.3. Mean potential daily production in  $\mu\text{g}$  dry weight/ $\text{m}^3$  calculated for the various groups of zooplankters according to seasons

	1968						1969				
	II	III	IV	VI	VII	X	XII	I	III	IV	VI
<u>Herbivorous</u>											
Nauplii	97	394	482	257	29	94	57	55	285	72	16
Copepods	817	6946	4582	806	1333	1883	2976	1412	2549	4391	1135
Cladocera	-	-	27	369	-	12	-	-	-	-	41
Protozoa	48	69	18	-	2	14	18	221	66	3	1
Gasteropods	96	119	43	62	130	498	284	51	13	43	12
Appendicul.	16	568	39	70	30	154	301	62	201	167	29
<u>Carnivorous</u>											
Polychaet.	-	18	-	40	-	47	549	200	-	-	-
Chaetognat.	-	170	127	-	-	-	430	-	-	-	-
Coelenterat.	-	68	34	-	6	35	18	-	-	-	-
<u>Total:</u>	1111	8669	5554	1635	1595	2828	4781	2068	3225	6587	1741
% Herbivorous	100	97	97	97	99	97	79	91	100	100	100

distribution of the zooplankton organisms. Wiebe (1968) concluded from simulation experiments that zooplankton is distributed in patches of an area of a few square metres. Since no efficient apparatus for the sampling of microdistribution exists, a new sampler was designed and tested (see Special Developments). The modified continuous Hardy Sampler designed at Fiascherino permitted sampling in succession distances of 40 m over a total distance of 2-4 km. Preliminary counting showed that the microdistribution of each species of copepod is highly heterogeneous.

In order to obtain a complete identification of the small zooplankton organisms in the samples, two keys for the determination of different nauplius stages were elaborated in collaboration with Dr Rampi. The first one permits precise determination of the stage but the determination is time-consuming, since a compound microscope must be used. The second key allows faster identification because a dissecting microscope can be used, but only the species and the approximate stage are obtained.

Laboratory experiments on copepods required that these animals must first be raised in culture solutions over a long period and near to normal conditions. Inadequacy of food, both in quantity and in quality, was found to be the main reason why copepods died or do not reproduce in culture. Because of an adequate food mixture, the most important species of copepods can now be reared in laboratory for successive generations and numerous data were obtained on copepod nutrition (see Annual Report 1968-69).

Experiments on the accumulation and loss of radionuclides were initiated with zinc. Zinc was chosen since it is the element of which our laboratory has the most extensive knowledge from a chemical and botanical standpoint.

The problem of the radiocontamination of marine organisms is closely related to the mineral metabolism of these organisms (Bernhard 1968). Very little has been published on Zn metabolism in invertebrates in general and on copepods in particular. Bryan (1964, 1966, 1967 a, b) showed that Zn accumulation in large crustaceae (lobster, crabs and crayfish) is regulated independently of the Zn concentration in the medium. Also, Hiyama and Shimizu (1964) observed for molluscs that increases in the stable Zn in the medium reduced the concentration factor of Zn<sup>65</sup> in the animal. The accumulation and loss of zinc-65 increased in the presence of food (Bryan 1964). Fowler and Small (1967) showed that the molts of Euphausia pacifica contained 20 % of the total Zn<sup>65</sup> accumulated when accumulation occurred from seawater; however, only 2 % of the total amount of Zn<sup>65</sup> was present in the molt if Zn<sup>65</sup> accumulation from the seawater was performed in the presence of stable food. Zinc is probably adsorbed mainly from water but assimilated principally from food.

The importance of the physicochemical state of Zn was showed by Hiyama and Shimizu (1964) for mussels; the animals did not accumulate the complexed Zn from the medium.

Zinc is thus a metabolic element which may be exchanged by the organisms in relation to some parameters in the medium. A model representing the Zn metabolism in the organisms could be used to predict the degree of their possible accumulation or radiocontamination if Zn<sup>65</sup> is present.

Previous experiments on the accumulation and loss of stable and radioactive Zn by Euterpina acutifrons were continued in this direction.

The exchange of radioactive and stable Zn between SW and copepods without food is first considered. If introduced in NSW with a stable Zn content ( $5\mu\text{g}/\text{l}$ ) of the same order of magnitude as that of the stable Zn content in the mass culture ( $3.96\mu\text{g}/\text{l}$  in solution and  $2.95\mu\text{g}/\text{l}$  in algae), Euterpina loses its stable Zn, reaching a plateau after four days (Fig. 4.1). The stable Zn content of the copepod at this plateau is about 60 % of its initial content in mass culture. These results showed that stable Zn equilibrium in starved copepods is lower than the Zn level in solution with food.

When Euterpina is reintroduced into a Platymonas suecica solution where the zinc content in the algae and in the solution are the same as the mass culture, Euterpina reaccumulated Zn to reach a plateau after three days. The stable Zn content in the copepods at this plateau is similar to the zinc content of the copepods in the mass culture.

In previous experiments (Annual Report 1970, Fig. 4.9), where total Zn loss in Euterpina was determined by stable Zn analysis and the exchanged total Zn was calculated from  $\text{Zn}^{65}$  measurements, it was shown that the stable Zn loss after four days is about 10 times higher than the stable Zn exchanged in copepods starved in SW for four days.

The quantities of total Zn exchanged and lost by Euterpina were calculated from stable and radioactive data (Table 4.4, 4.5 and 4.6). The results showed that in NSW without food Euterpina exchanged daily less than 1 % of its body content, while the loss amounted to about 10 % of the stable Zn content of copepods in mass culture. This loss rate decreases with time: after four days Zn loss stopped and an equilibrium was reached between uptake and release by the animal. It is interesting to note that 60 % of the total Zn content of a copepod from mass culture

$10^{-3}$   $\mu\text{g}$  total Zn per Euterpina

% of initial  
Zn content

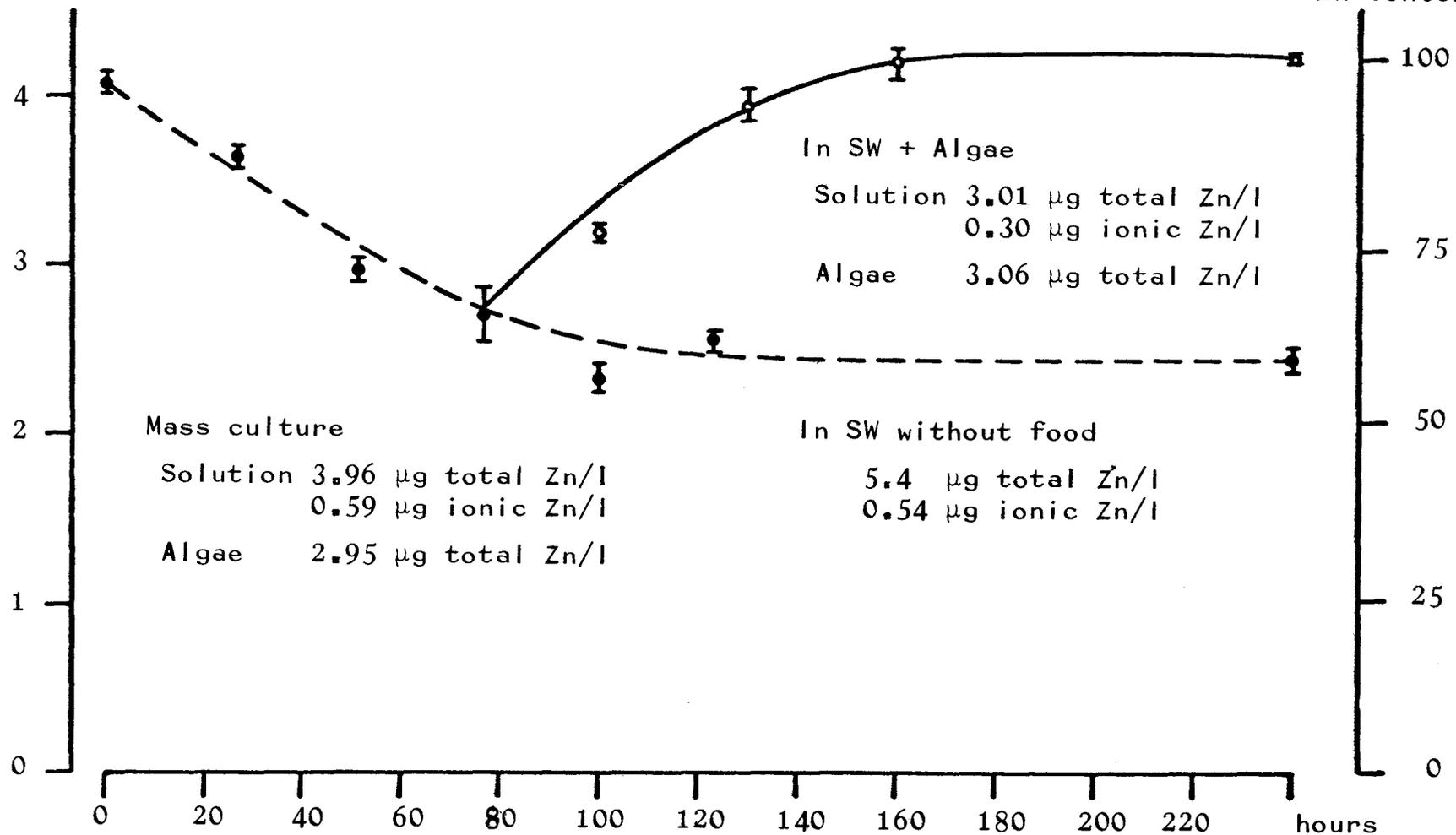


Fig. 4.1. Loss of stable Zn by Euterpina acutifrons in NSW without food and reaccumulation in NSW plus food (Platymonas suecica)

Table 4.4. Summary of the data on weight and Zn content in  
Euterpina and algae

EUTERPINA acutifrons female adult in laboratory Mass culture

or at Sea

Mean fresh weight	4.4 $\mu\text{g}$
Mean dry weight	1.1 $\mu\text{g}$
Mean zinc content	$4.2 \cdot 10^{-3} \mu\text{g}$
	or $475 \cdot 10^{-5} \mu\text{g Zn}/\mu\text{g dry weight}$
	$95 \cdot 10^{-5} \mu\text{g Zn}/\mu\text{g fresh weight}$

PLATYMONAS suecica in normal culture solution

Volume	$300 \mu^3$
Mean zinc content	$11 \cdot 10^{-4} \mu\text{g total Zn}/\mu\text{g fresh weight}$

RATIONS OF EUTERPINA

According to different algal concentrations:

1.05 to 10  $\mu\text{g fresh weight Platymonas}/\text{Euterp.}/\text{day}$   
(25 to 200% of Euterpina fresh weight per day)

$11.05 \cdot 10^{-4}$  to  $110 \cdot 10^{-4} \mu\text{g Zn}/\text{Euterp.}/\text{day}$   
(27.5 to 260% of Euterpina zinc content)

Table 4.5. Accumulation and loss of stable and Zn<sup>65</sup> by Euterpina acutifrons in NSW solutions with and without food.

	<u>10<sup>-7</sup> µg Zn<sup>65</sup>/Euterp./day</u>	<u>10<sup>-4</sup> µg stable Zn/Euterp./day</u>
Ingestion from food (Quantity *) estimated	1.5 to 14.3	11.5 to 110
Accumulation from algae and S W	2.212	8.19
Accumulation from water (5 µg Zn/l)	0.63	0.122
Loss in S W with food	2.5	9.7
Loss in S.W. without food	1.042	3.97

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\* Quantity estimated from concentration of algae ingested and Zn concentration in algae

Table 4.6. Rates of stable and Zn<sup>65</sup> exchanges expressed as a percentage of the Euterpina content

In S W with Algae (about 3 µg Tot Zn/l in solution and 3 µg Tot Zn/l in algae)

LOSS	=	ACCUMULATION
about $1 \cdot 10^{-3}$ µg Tot Zn/ <u>Euterp.</u> /day		
or $1 \cdot 10^{-3}$	$\frac{100}{4.18 \cdot 10^{-3}}$	=22% of the body content in Zn
about $2 \cdot 10^{-7}$ µg Zn <sup>65</sup> / <u>Euterp.</u> /day		
or $2.3 \cdot 10^{-7} \cdot 100$	$\frac{100}{15.73 \cdot 10^{-7}}$	=16% of the body content in Zn <sup>65</sup>

In S W without food (about 6 µg Tot Zn/l)

LOSS	>	ACCUMULATION
$4 \cdot 10^{-4}$ µg Tot Zn/E/d	>	$0.122 \cdot 10^{-4}$ µg Tot Zn/E/d
Accumulation =	$\frac{0.122 \cdot 10^{-4} \cdot 100}{4.18 \cdot 10^{-3}}$	=0.3% of the body content in Tot Zn
Loss =	$\frac{4 \cdot 10^{-4} \cdot 100}{4.18 \cdot 10^{-3}}$	=10% of the body content in Tot Zn

cannot be exchanged with the medium when a copepod is starved, the rate of exchange being too slow in relation to the life span of the animal.

Further experiments were conducted in order to determine whether stable Zn exchanges between copepods and SW without food are regulated or not (Annual Report 1970, Fig. 4.8).

When introduced from mass culture with algae into SW without food containing various concentrations of stable Zn in the range 5-30  $\mu\text{g}$  total Zn/l, the quantity of stable Zn exchanged after four days by Euterpina acutifrons was independent of the Zn concentration in solution. Bryan (1967) obtained similar results with some higher Crustacea and concluded that regulation occurs. However, the total Zn content in copepods decreased to reach an equilibrium after four days and the total Zn content at equilibrium was related to the total Zn in solution.

For concentrations of stable Zn in solutions varying from 30 to 90  $\mu\text{g}$ /l, the quantity of stable Zn taken up by Euterpina from the solution increased with the stable Zn concentration in solution. No regulation occurred. The total Zn content in copepods decreased to reach a plateau after four days but the total Zn content at equilibrium was independent of stable Zn concentration in solution. These results suggest that Zn exchanges between copepods and SW without food could be due to a non-metabolic process.

This hypothesis is confirmed by the following observation: no significant difference appeared in the quantities of  $\text{Zn}^{65}$  accumulated in 24 hours by live Euterpina, live Euterpina with penicillin and killed Euterpina by short UV exposure (Table 4.7). Fowler et al (1969) obtained similar results with Euphausia pacifica: live animals and animals killed by formalin accumulated  $\text{Zn}^{65}$  in the same quantities.

The exchanges of stable and  $\text{Zn}^{65}$  between copepods and the medium with food were then investigated. From previous experiments the quantities of  $\text{Zn}^{65}$  and stable Zn accumulated daily by one adult Euterpina in a Platymonas s. solution were calculated (Tables 4.4,

Table 4.7. Accumulation of  $Zn^{65}$  by living Euterpina ac(A), living Euterpina + antibiotics(B) and killed Euterpina(C) from solutions with various Zn stable content and without food ( $Zn^{65}$  in solution: 330  $\mu Ci/l$ )

Stable Zn in solution	Activity in 10 <u>Euterpina</u> after 24 h accumulation (in counts/10 <u>Euterpina</u> /400 sec.)		
	A	B	C
	Living <u>Euterpina</u>	Living Eut. + antibiotics	Killed <u>Euterpina</u>
5.4 $\mu g$ Total Zn/l	1536	1304	1101
	1550	915	1243
Ex. I	1813	1380	1225
	1803	1327	1043
	1456	1286	1323
	$\bar{x} = 1630$	1242	1187
<hr/>			
11.4 $\mu g$ Total Zn/l	1145	1069	989
	1240	1050	1006
Ex. II	914	1240	936
	956	1089	843
	1095	1150	1099
	$\bar{x} = 1070$	1119	974
<hr/>			
17.4 $\mu g$ Total Zn/l	1176	935	792
	1213	861	886
Ex. III	1037	897	863
	928	896	916
	1113	976	1080
	$\bar{x} = 1093$	913	907
<hr/>			

4.5, 4.6). They amounted respectively to  $2.2 \times 10^{-7} \mu\text{g Zn}^{65}$  and  $8.20 \times 10^{-4} \mu\text{g}$  total Zn per copepod /day (Table 4.5).

In order to determine loss rates in solution with food for animals in which isotopic equilibrium was reached, a mass culture of Euterpina in  $\text{Zn}^{65}$ -labelled algae mixture was initiated. Adults of the fourth generation produced in the radioactive medium were introduced in a non-radioactive Platymonas suecica solution. The stable Zn content in the mass culture solution and in the Platymonas suecica solution were similar. The decrease in copepod activity was measured periodically. The daily release of  $\text{Zn}^{65}$  was calculated as  $2.5 \times 10^{-7} \mu\text{g Zn}^{65}/\text{Euterpina}/\text{day}$  or  $9.7 \times 10^{-4} \mu\text{g}$  total Zn/Euterpina/day (Table 4.5). The quantities released daily by one Euterpina corresponded to the data for daily uptake. If the Zn turnover of copepods is calculated from stable zinc data, the turnover is 20 %. When calculated from  $\text{Zn}^{65}$  data, it is 16 % (Table 4.6). With a rate of exchange of about 20 % of the Zn content per day, the turnover time of Zn in Euterpina is thus about five days. These values are in good agreement with the values determined by Small (personal communication) for Euphausia sp.

In order to check these results indirectly, the quantity of both stable and  $\text{Zn}^{65}$  that one Euterpina should accumulate per day from ingested food was estimated as follows. From feeding experiments with Platymonas s. (Nassogne, 1970) we know that each Euterpina can ingest 1.05-10  $\mu\text{g}$  fresh weight of Platymonas per day depending on the algal concentration in the solution. In previous Zn experiments, the algal concentration was about 30 000 cells/l. Under these conditions  $6 \times 10^{-7} \mu\text{g Zn}^{65}$  and  $4.6 \times 10^{-5} \mu\text{g}$  total/Zn/Euterpina/day are ingested. If we consider that assimilation is about 30 % of the food ingested (Conover 1966), the quantity of Zn exchanged daily by copepods with the solution is  $2 \times 10^{-7} \mu\text{g Zn}^{65}$  and  $1.5 \times 10^{-5} \mu\text{g}$  stable Zn per Euterpina per day.

Comparing exchanges of Zn in the presence of food and without food, it appeared that the daily release of both stable and  $Zn^{65}$ , when food is supplied, is twice the daily release observed during the first day of starvation. Uptake from SW can be neglected when compared with the uptake from food (Table 4.7).

Further experiments were conducted in order to determine whether the decrease of  $Zn^{65}$  in the presence of food is dependent on the way in which it was previously accumulated. Fig. 4.2 shows the decrease curves of  $Zn^{65}$  from Euterpina in a Platymonas solution for animals which had previously accumulated  $Zn^{65}$  from SW for three and six days respectively. The rate of decrease in activity is faster in animals which could reach equilibrium after six days accumulation. In both groups, however, animals lost 50 % of their initial activity after about 140 hours. The remaining activity was the same when they died at the end of their life span after 8-9 days. The loss curve of  $Zn^{65}$  for Euterpina which were produced in radioactive mass culture was of the same shape (Fig. 4.3) as those for animals which had accumulated  $Zn^{65}$  from seawater without food. Although the initial activities in both groups were different, the release, expressed as a percentage of the initial activity, is similar for both groups (Fig. 4.4); 50 % of the initial activity was lost after 140 hours.

In order to determine the influence of the stable Zn content in food on the accumulation of stable Zn by Euterpina a. three cultures of Platymonas s. were initiated in three solutions of stable Zn from 5 to 29  $\mu g$  total Zn/l. After five days the algae accumulated Zn depending on the Zn concentration in solution (Fig. 4.5). Copepods were then introduced in the algae solution and fed for three days. The total Zn content in copepods after three days is related to the Zn content in the algae; the accumulation of Zn in copepods does not seem to be regulated if food is present in the solution. Further experiments are necessary in order to

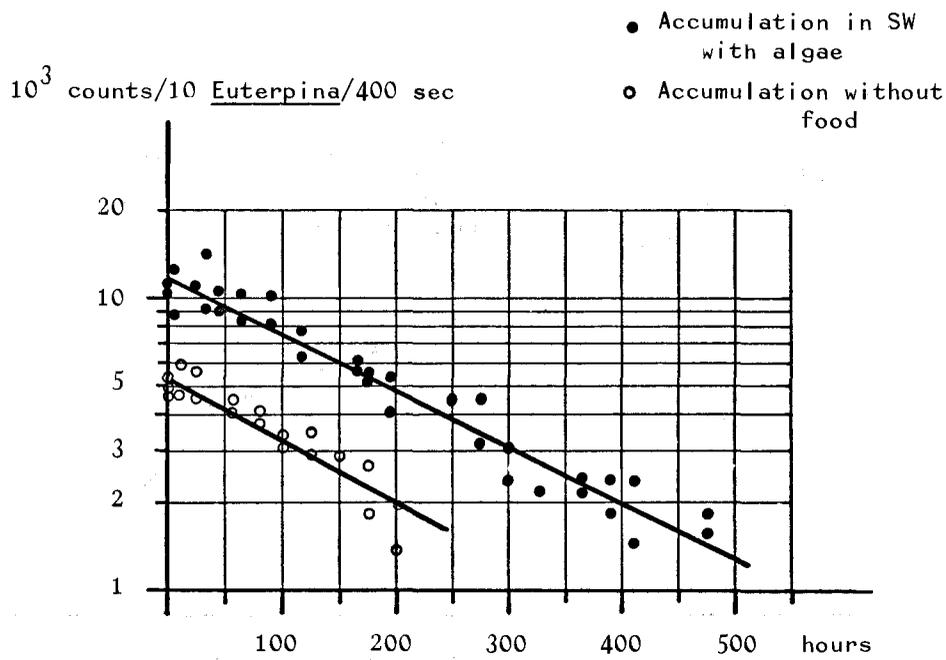


Fig. 4.2. Loss of  $Zn^{65}$  in solution plus food

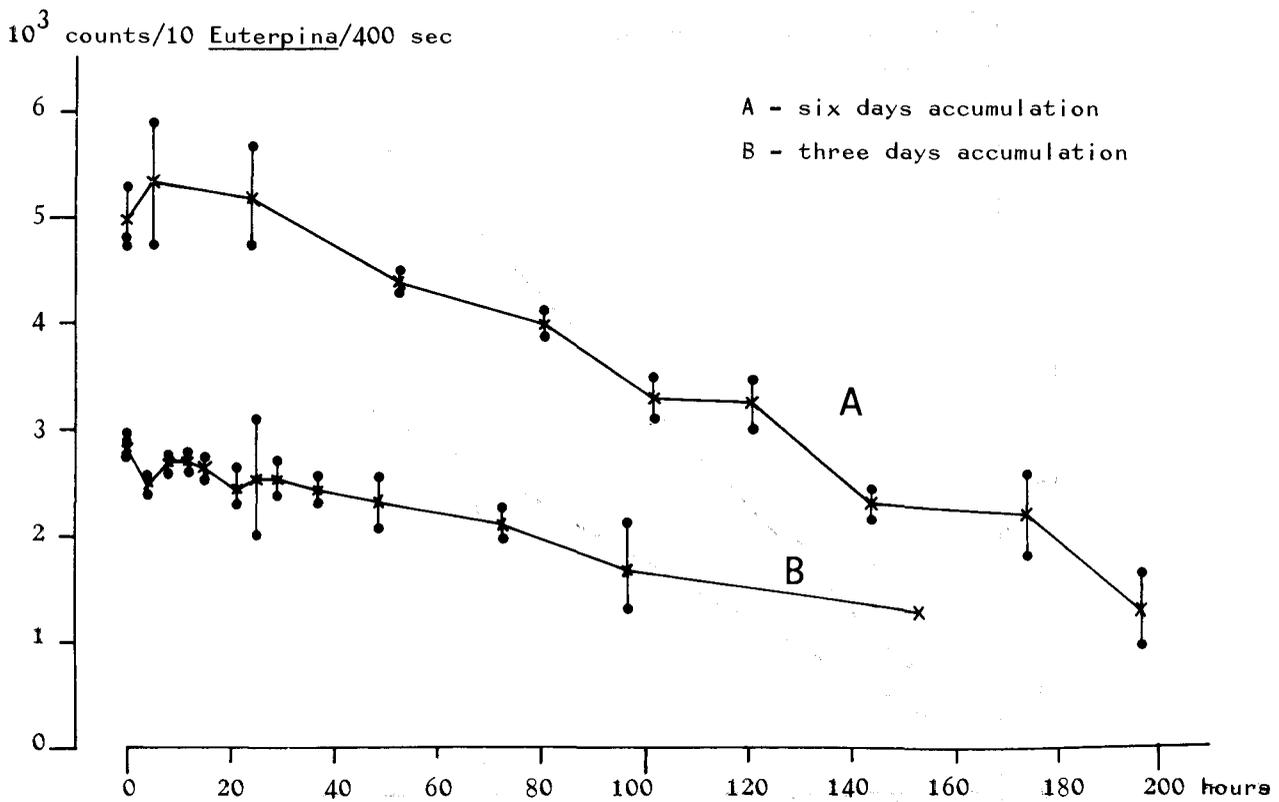


Fig. 4.3. Loss of  $Zn^{65}$  by *Euterpina acutifrons* in SW + algae after accumulation in SW without algae

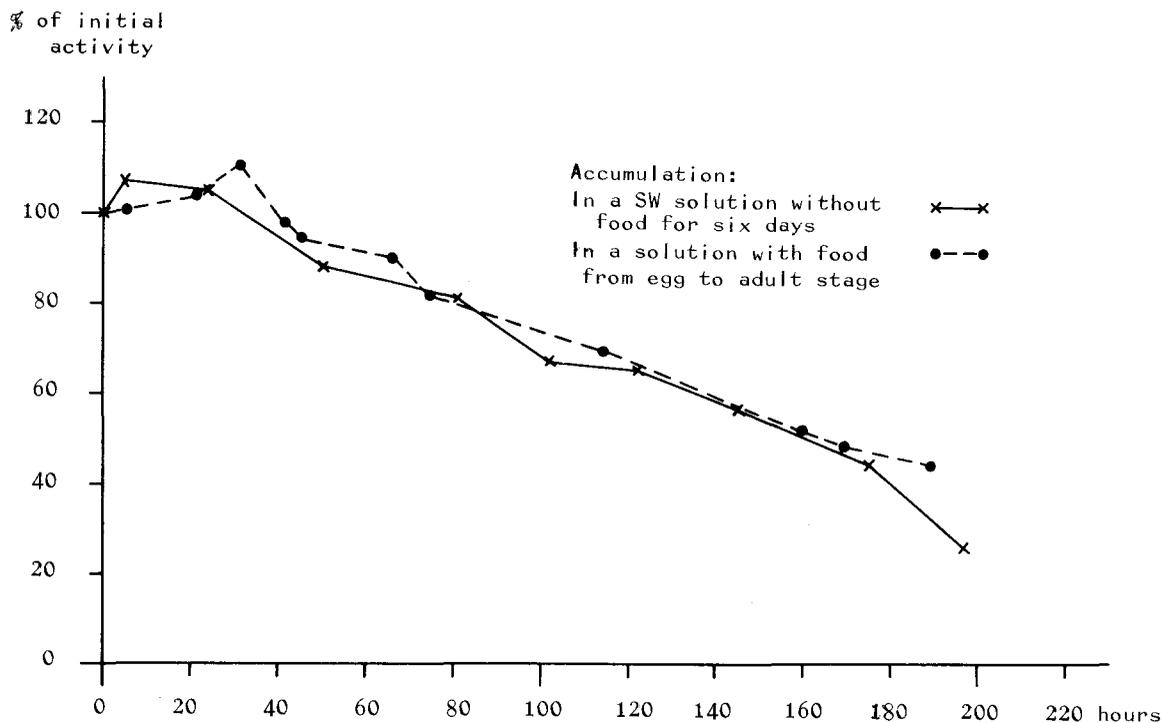


Fig. 4.4. Loss of  $Zn^{65}$  by *Euterpina acutifrons* in SW with food

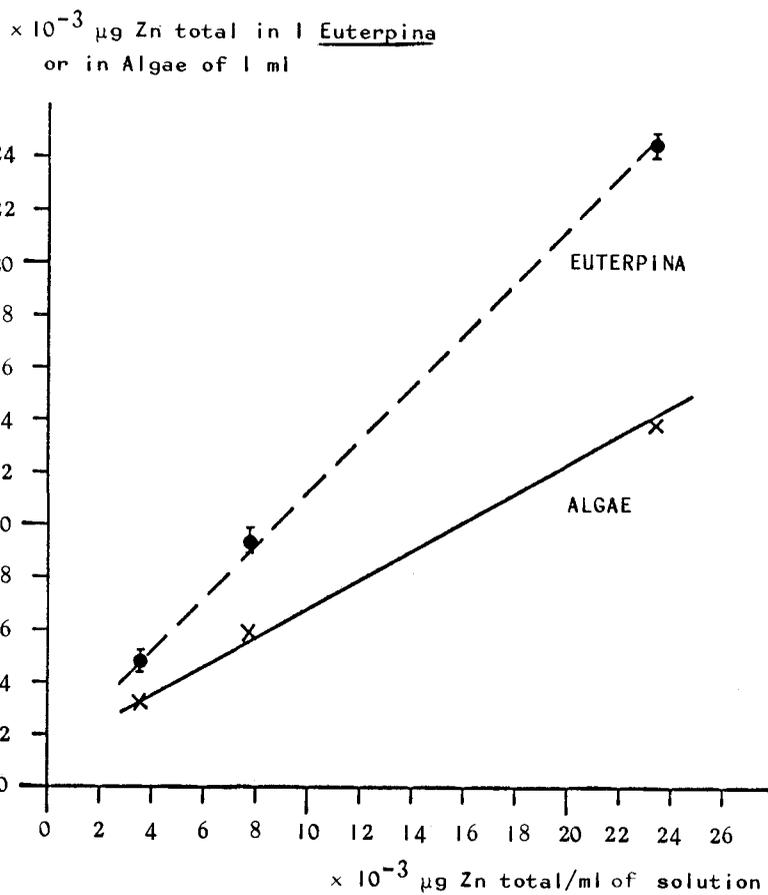


Fig. 4.5. Accumulation of stable Zn in *Platymonas suecica* after three days and in *Euterpina acutifrons* after four days vs the concentration of stable Zn in the solution

determine whether the Zn content measured in copepods was really assimilated or present in the gut as feces.

The data collected so far suggest the following conclusions:

- 1) The stable Zn content in Euterpina from laboratory culture is in the same range as in animals collected at sea when the Zn concentration in the culture medium is the same as under natural conditions.
- 2) If the Euterpina are starved for more than four days, they lose 40 % of their total zinc.
- 3) In solution with food or in solution without food, the stable Zn content in Euterpina is proportional to the total Zn concentration in the medium for concentrations of 5-30  $\mu\text{g}$  total Zn/l. For concentrations of 30-90  $\mu\text{g}$  total Zn/l in solution without food the total Zn content in the copepods remains constant.
- 4) The daily uptake from SW alone represents less than 1 % of the total Zn content of the Euterpina and is negligible if compared with the daily Zn uptake from food, which amounts to 20 % of the copepod Zn content.
- 5) The rate of Zn uptake from SW only, without food, is so slow that isotopic equilibrium cannot be reached in radioactive solutions.

These results show the importance of conducting experiments with copepods raised in optimum food conditions. They also demonstrate that experiments performed without food are misleading because the copepod contains only 60 % of its normal Zn concentration and the Zn turnover is very low (less than 1 % of total Zn content/day). Only a small fraction can thus be labelled. The results also demonstrate the need to consider the stable Zn content in animals and in solutions during radioactive experiments. Data obtained by Zn<sup>65</sup> measurements only could lead to errors in determining Zn metabolism in copepods and consequently in predicting radiocontamination hazards.

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## HETEROTROPHIC LEVEL OF MICROORGANISMS

The Microbiology Group continued to direct its attention to the role of the metabolic activity of marine bacteria in the uptake, loss and transmission of radioactive substances. In the previous reports the autoradiographic technique used to study the vertical distribution of bacteria and their metabolic activity in the marine environment was described and the results obtained in a large number of experiments discussed. By plotting the number of spots of the autoradiographs, i.e., metabolizing bacteria, against the depth, the curve shown in Fig. 5.1 is obtained.

From this curve it can be seen that there is generally a marked decrease in the number of spots with depth. Practically no spots are observed in the aphotic zone.

The absence of spots in the aphotic zone may be due to the lack of active bacteria in the water or could also be caused by the sudden drop in pressure when the samples are hauled aboard.

In order to decide between the two hypotheses, duplicate samples were collected in the surface layer at 25-50 and in deeper waters at 350-400m. They were treated in the same way already described in previous reports. These samples were compared with three samples obtained by letting the samplers, which already contained  $P^{32}$ , fill up at 350-400 m, i.e., in situ. The seawater samples were left for 12 hours at that depth so that the bacteria could accumulate the radioactive phosphorus at the environmental pressure.

From the results of two experiments (see Table 5.1) it can be seen that very few spots were obtained from the deep water samples. The ones kept in the laboratory and the ones kept under in situ conditions both gave the same results. On the other hand, as usual, far more spots developed on the films made with the surface samples.

These preliminary results indicate that the sudden decrease in pressure due to the hauling aboard of the samples is not responsible for

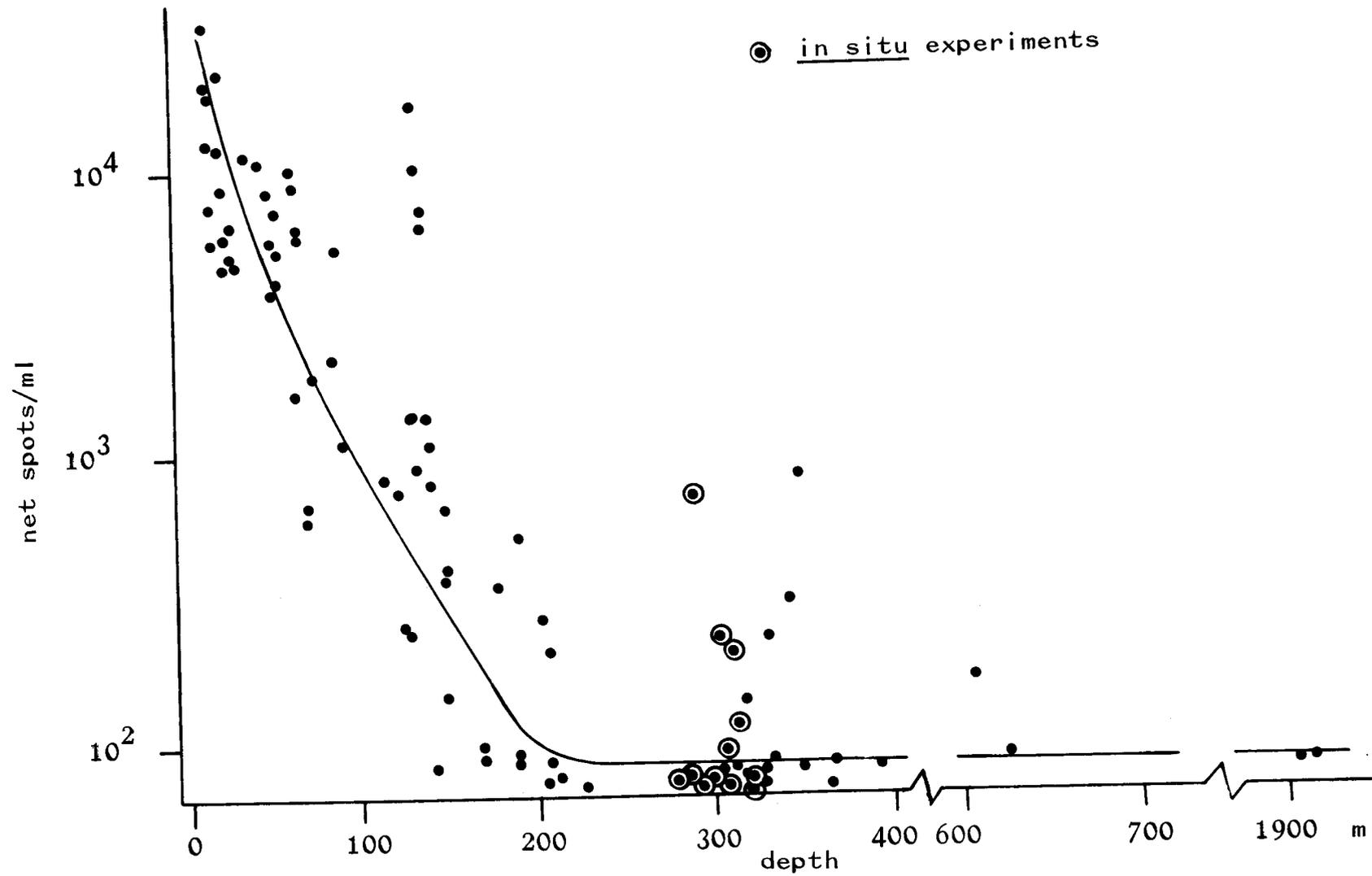


Fig. 5.1. Number of spots, i.e., metabolizing bacteria, vs depth

Table 5.1. Spots concentrations and bacteria counts in samples kept in laboratory conditions and in situ conditions

Depth (m) by reversing thermometers	Bacteria/ml			
	Net spots/ml	MPN counts	plate counts	
			before	after incubat.
Incubation 26	5943-4475	6	1	7-5
aboard 34	4687	9	3	11-6
312	← 0 - ← 0	3	7	0-3
317	178	8	4	0-0
Incubation 277	← 0 - ← 0	1.3		4
<u>in situ</u> 293	739 - 51			3
306	← 0 - ← 0			1
Incubation 30	$1.9 \cdot 10^5 - 1.9 \cdot 10^5$			$\sim 10^5$
aboard 50	8476-4175	4	5	137-37
330	9- 80	1	2	4-19
369	← 0- 74	1.3	1	3-2
Incubation 304	284- 104			2
<u>in situ</u> 310	259- 157			3
326	45- ← 0			3

the lack of bacterial activity in the deep water samples.

The absence of metabolizing bacteria at depths exceeding 150-200 m might then be accounted for by the lack of organic matter usable by bacteria in the aphotic zone. Several authors (e.g., ZoBell, 1946; Menzel, 1964; Barber, 1968; Williams, 1969) have found that organic matter in the aphotic zone is resistant to biochemical oxidation.

Also, Jannasch (1970) found no bacterial activity on the food supplies of a submarine sunk following an accident. However, he attributed this fact to the combined effect of pressure and low temperature. We think that both pressure and the lack of usable organic matter are responsible for the lack of metabolic activity. Pressures inhibit the metabolism of the majority of bacteria, whereas the unaffected bacteria are prevented from metabolizing by the lack of usable organic matter.

To test this hypothesis we are studying the growth and the  $P^{32}$  uptake of two bacterial strains in our collection ( $\lambda$  and 4Z-3-4) kept under sterilized seawater at atmospheric pressure and 40 atmospheres of pressure.

Strain  $\lambda$  was isolated from a surface sample and strain 4Z-3-4 from a deep sample (1915 m).

Strain  $\lambda$  grows at normal pressure, but its growth does not occur under high pressure (40 atm). Strain 4Z-3-4 grows in both conditions, but somewhat slower growth was observed under pressure (Fig. 5.2).

Similar results were obtained for the  $P^{32}$  uptake. Since strain 4Z-3-4 also grows at high pressure, it can be used to study the behaviour of bacteria exposed to deep sea conditions in situ. If the strain will not take up  $P^{32}$ , this will confirm that the lack of usable organic matter is the cause of the absence of bacterial activity.

A comparison was carried out between the  $P^{32}$  uptake of a surface seawater sample kept aboard in a vessel and the same sample incubated at 350 m in the sampler.

The results (see Fig. 5.3) show that only a very small percent-

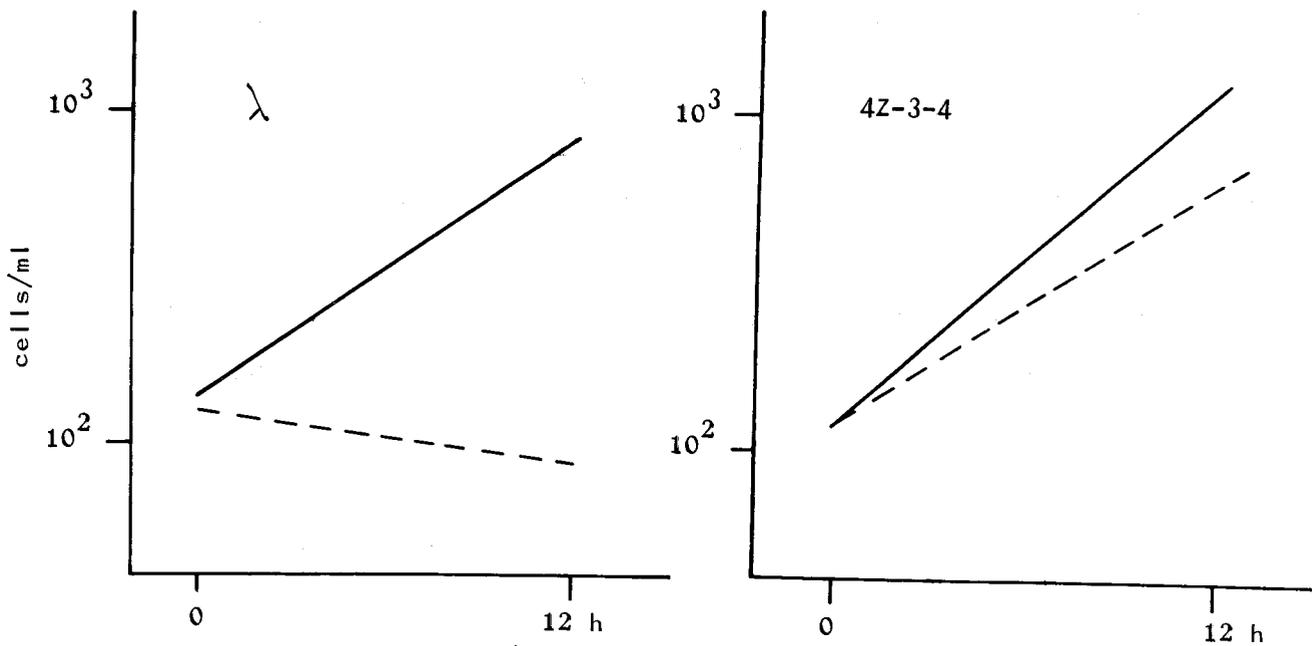


Fig. 5.2. Growth of strain  $\lambda$  and 4Z-3-4 at atmospheric pressure (—) and 40 atmospheres (-----) pressure

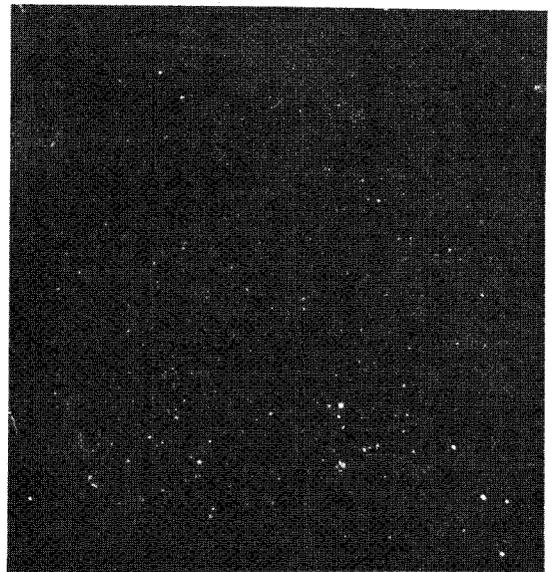
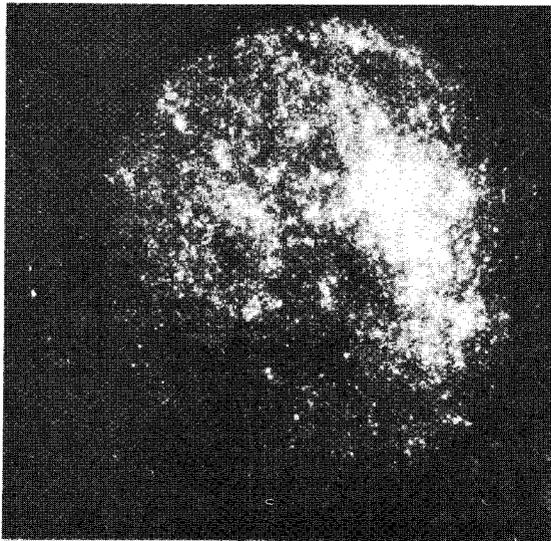


Fig. 5.3. Autoradiographs obtained from surface seawater sample kept at 350 m (left) and kept aboard (right)

age (~7%) of the spots present in the sample kept aboard are also detected in the sample kept at 350 m.

This means that pressure has selected barophilic species which can metabolize the usable organic matter present in the surface water.

In collaboration with the Zoology Group we have performed some experiments to test the role of bacteria in the transfer of  $P^{32}$  to copepods.

Although bacteria may play an important role in passing radionuclides through the marine food chain, only very few authors have investigated this problem.

Harris (1957), Rigler (1961) and Johannes (1964) found that the  $P^{32}$  uptake by aquatic crustacea was greater if the animals were kept under non-sterile conditions than under sterile conditions. The same results were obtained by Chipman and Schommers (1968), who studied the accumulation of  $Mn^{54}$  by Tapes.

Our experiments were run with copepods kept in sterile seawater ("non-sterile copepods") and in sterile seawater with 0.1% of penicillin ("sterile copepods") for 24 hours to clean them.

All copepods were washed in sterile seawater twice before being added to the radioactive seawater.

Preliminary tests were run with: a) "non-sterile copepods"; b) "sterile copepods"; c) "sterile copepods" and different amounts of bacterial strain 21-6-9 ( $10^3$ ,  $10^4$  and  $10^5$  bacteria/ml respectively).

The results (Table 5.2) show that "sterile copepods" do not accumulate  $P^{32}$  directly from the seawater and the added bacteria transfer very little  $P^{32}$  to the copepods. However, the bacterial cells accumulate  $P^{32}$ , as can be shown (right-hand column in the table 5.3), by filtering a portion of the incubation seawater at the end of the experiment after having taken off all the copepods.

It should also be noted that penicillin acts as a bacteriostatic agent on strain 21-6-9.

Table 5.2.  $P^{32}$  uptake by Euterpina acutifrons at various conditions (incubation time = 16 h at 18°C).

	Total radioactivity in the tube (counts/minute) $\cdot 10^3$	Radioactivity/10 copepods (counts/minute)	Uptake in % of total activity
1 <sup>st</sup> experiment			
"Non st. copepods"	532	4388	0.827
"Sterile copepods"	574	158	0.027
"St. cop"+ $10^4$ bac.	647	365	0.060
"St. cop"+ $10^5$ bac.	625	157	0.026
"St. cop"+ $10^6$ bac.	567	592	0.104
2 <sup>nd</sup> experiment			
"Non st. copepods"	1830	3137	0.171
"Sterile copepods"	2060	662	0.032
"St. cop"+ $10^4$ bac.	1742	525	0.030
"St. cop"+ $10^5$ bac.	1952	445	0.023
"St. cop"+ $10^6$ bac.	1856	455	0.024
3 <sup>rd</sup> experiment			
"Non st. copepods"	4417	86865	1.969
"Sterile copepods"	4803	5191	0.108
"St. cop"+ $10^4$ bac.	5016	3194	0.063
"St. cop"+ $10^5$ bac.	4684	4332	0.093
"St. cop"+ $10^6$ bac.	4868	2426	0.049

Table 5.3. Number of bacterial colonies and radioactivity in bacteria of the data described in Table 5.2

Bacterial colonies/ml		Radioactivity on the filters * (counts/minute)
At time 0	After 16 h	
192	$1.4 \cdot 10^3$	2 600
0	0	Blank (64)
$10^3$	$1.4 \cdot 10^3$	150
$10^4$	$1.8 \cdot 10^4$	250
$10^5$	$1.0 \cdot 10^5$	6 300
190	6	730
0	0	Blank (872)
$1.5 \cdot 10^3$	$2.4 \cdot 10^2$	240
1.5	$1.5 \cdot 10^3$	390
$1.5 \cdot 10^5$	$8.0 \cdot 10^5$	1 290
800	$6.0 \cdot 10^4$	60 080
1	15	Blank (5 640)
$2.0 \cdot 10^3$	$8.0 \cdot 10^2$	920
$1.8 \cdot 10^4$	$8.0 \cdot 10^4$	13 000
$2.1 \cdot 10^5$	$1.5 \cdot 10^5$	77 970

\*Blank, i.e., culture medium of "sterile copepods", was subtracted.

On the other hand, "non-sterile copepods" accumulate a considerable amount of  $P^{32}$ , which indicates that the bacterial flora associated with their digestive tract or external surfaces may be responsible for the observed  $P^{32}$  uptake.

The Annual Report for 1970 showed that the detergent attached to glassware can considerably affect the metabolism of bacteria and this may give misleading results. In continuation of this work, a comparison was made between the  $P^{32}$  uptake of bacterial strain  $\lambda$  incubated in artificial seawater (ASW) and the same strain incubated in aged surface seawater (NSW), both kept either in heated (at  $450^\circ$  for 24 h) or unheated glassware. The glassware was heated in order to destroy all the organic material. This allows us to work without any organic contamination from external sources.

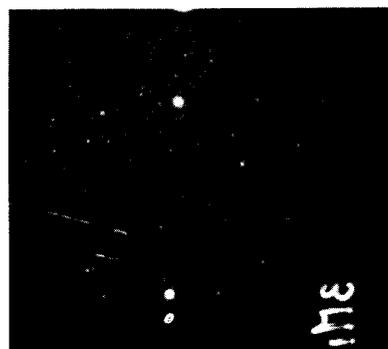
All the chemical compounds used for the preparation of the artificial seawater (ASW) were heated to  $450^\circ\text{C}$  for 24 hours in order to destroy any organic substances which they may contain.

From the results (see Fig. 5.4) it can be seen that the  $P^{32}$  uptake in ASW kept in "heated glassware" is much less than the uptake in "unheated glassware".

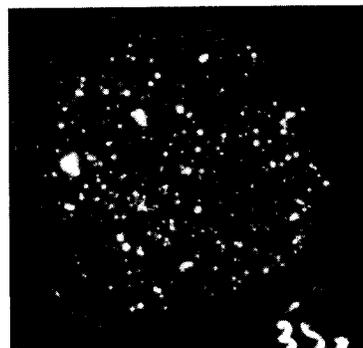
Strain  $\lambda$  incubated in "unheated glassware" containing ASW gave practically the same number of spots as strain  $\lambda$  incubated in "heated glassware" containing UV-sterilized surface seawater.

This may mean that the amount of usable organic matter contained in the detergent attached to the glassware is of the same order of magnitude as the usable organic matter in surface seawater (collected at surface 10 miles off the coast, filtered at laboratory and sterilized by UV for 30 min).

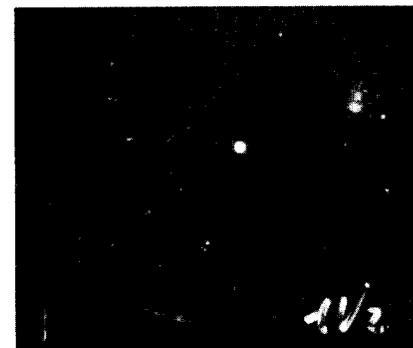
The  $P^{32}$  uptake by strain  $\lambda$  in the same surface seawater incubated in "unheated glassware" is much greater than when incubated in "heated glassware". The enhancement of bacterial metabolism by the combined effect of the organic matter in the surface seawater and the or-



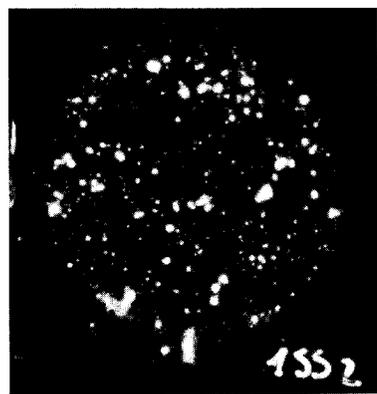
A



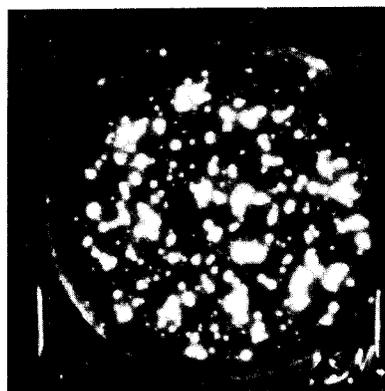
B



C



D



E



F

Fig. 5.4. Autoradiographs obtained from strain incubated in "heated glassware" containing artificial seawater (ASW) (A), in "unheated glassware" containing ASW (B), in "heated glassware" containing surface seawater (D) and in "unheated glassware" containing surface seawater (E)

C = blank ASW; F = blank surface seawater

ganic matter in the detergent can be considerable.

This shows how careful one must be in attributing bacterial activity to usable organic matter in seawater samples.

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## FISHERIES BIOLOGY GROUP

In the year 1967-69 the Fisheries Biology Group studied the distribution of fish and commercially important invertebrates in La Spezia and Taranto Gulf in order to determine which are the most important species in the marine food chain of the sampling zone in the Ligurian Sea and the cutfall area in the Gulf of Taranto (see Annual Reports 1967-69). It then became necessary to obtain accurate knowledge of the biology, i. e., life cycle, reproduction time, food requirements, uptake of food, behaviour under laboratory conditions, etc., of some of those important species in order to investigate the uptake and loss of radioisotopes.

Therefore the rearing conditions of mussels (Mytilus edulis), crustaceans (Leander spec. = Palaemon spec.), and fish (Blennius pavo, Artherina boyeri) were studied.

In collaboration with the Zooplankton Group Mr Secchini, technician of the Fisheries Biology Group, carried out first experiments on feeding Mytilus edulis and Leander spec. These studies were intensified after the new fisheries biologist took up his position on 1 September 1971.

Shrimps were kept in culture vessels in each of which there were two specimens, of 150 ml and 500 ml normal seawater aired by air bubbles. The shrimps survived when fed on dry mussels (Mytilus edulis), fresh fish (Engraulis spec.) and nauplii of Artemia salina.

These results are similar to those of Meixner (1969), who also obtained good survival and growth for Crangon crangon by feeding the shrimps with adult Artemia salina.

On the other hand, the shrimps died after two months when fed with dry fish (Mullus sp., Merluccius spec.) (Table 6.1) and after 15 days when fed with an algal mixture of the following species: Exuviella compressa, Thalassiotrix frauenfeldii, Skeletonema costatum, Platymonas suecica, Platymonas spec. (flagellatae  $\beta_{43}$ ), Chroocomonas fragarioides.

Table 6.1. Shrimp feeding experiment 1.

150 ml FSW (filtered seawater), each vessel contained two specimens; food: fresh fish (Engraulis spec.), dry fish (Mullus spec.) (Merluccius spec.), dry mussel (Mytilus edulis), nauplii of Artemia salina, mixture of algae; digital in brackets = number of animals

Food	Days of survival			
	1	4	29	76
fresh fish (0.1 g FW/d)	(1)	(1)	(1)	(1)
dry fish (0.002 g DW/d)	(1)	(1)		
dry mussels (0.005 g DW/d)	(1)	(1)	(1)	
Artemia nauplii (~ 1000 animals)	(1)	(1)		
algae mixture (50 ml ~ $4 \times 10^5$ /ml)	(1)	(1)	(1)	

The three groups of shrimps (each represented by nine specimens) were fed on fresh fish (~0.1 g fresh weight/day), dry mussels (~0.005 g dry weight/day) and nauplii of Artemia salina (~1500 animals/day). In the first days of culturing some specimens died in each of the three groups, but after the culture vessels had been connected to a filter system good survival was obtained in all groups and seven specimens are still living after five months (Table 6.2).

Mussels were cultured with the mixture of algae, resulting in a good survival. Similar observations were made by V.L. Loosanoff and H.C. Davis, (1963), but when Artemia nauplii were offered as food the mussels died after few days.

Apparently the nauplii could not be ingested.

Growth experiments with mussels performed at 14, 18 and 21°C over three months with the algal mixture as food showed no significant differences in growth increments.

This stagnancy in growth may be due to the lack of an adequate food supply.

Loosanoff (1942) and Jørgensen (1949) found that Mytilus edulis filters almost permanently and 97-99% of the time the valves were found to be open when undisturbed.

Therefore nearly all plankton-feeding lamellibranchs need a large steady food supply (Loosanoff 1939, Loosanoff and Nomeiko 1946). Probably because of a scarce food supply the mussels were just able to survive and did not grow. Experiments on the optimum food concentration for Mytilus edulis are under way.

Attempts to culture fish species of the Ligurian Sea were started. Blennius pavo and Artherina boyeri are kept in the laboratory and fed with fresh fish (Tubifex spec.) and mixed commercial dry food (Tetra Min; Tetra Phyll, Tetra - Werke, Melle, Germany; Delix, Acquario Bologna Italy; Walwil, R. Waldmann, Berlin, Germany). All four specimens of Blennius pavo are still alive after five months, while Artherina boyeri,

Table 6.2. Shrimp feeding experiment II.

500 ml filtered seawater, each vessel contained three specimens; food: fresh fish (Engraulis spec.), dry mussel (Mytilus edulis), nauplii of Artemia salina, numbers in brackets = number of animals

Food	Days of survival						
fresh fish (0.1 g FW/d)	4 (1)	5 (1)	36 (2)	48 (1)	74 (1)	95 (1)	* 155 (2)
dry mussel (0.005 g DW/d)	4 (2)	5 (1)	9 (1)	75 (1)	89 (1)		* 127 (1)    155 (2)
Artemia nauplii (~ 1500 animals)	2 (1)	5 (1)	8 (1)	18 (2)	21 (1)		* 155 (3)

\* connection to filter system after 118 days

living in a shoal, is much difficult to handle. Most of the fish in the catch are still alive since the end of September 1971, while a few have died for no obvious reason.

Continuous algae cultures were started in 10 l bottles in order to ensure an adequate food supply for the mussel culture every time. Mass cultures of phytoplankton as food for metazoans have been developed as H.C. Davis and R. Ukeles (1961).

Initial experiments to analyse the filtering behaviour of Mytilus edulis were undertaken. As a first approach the ingestion rates of three specimens measured as the decrease in algal concentration according to time were determined. Jørgensen (1949) found that the filtering rate ("feeding rate") is directly dependent on the size of the mussel. Therefore three mussels of nearly the same size (3.5 - 4.0 cm) were selected and accustomed for 15 hours each in a vessel of 500 ml filtered seawater agitated by a magnetic stirrer.

The mussels were mounted on a small support 4 cm from the bottom.

These preliminary experiments should give us an idea of the velocities of removal of unicellular algae from suspension by the eulamellibranch Mytilus edulis and supply information on the variability of swept-clear velocities in single mussels under the same environmental conditions.

The experiment was started by gently adding the algae solution without disturbing the filtering mussels. Initial algal concentrations of  $1.5 \times 10^5$  cells Platymonas suecica/ml were used (Fig. 6.1).

In the plotting of cell concentration against time in minutes, all curves showed a nearly linear part over a period of 120-180 min after commencement of the filtering activity.

Moreover, these curves show distinctly the different swept-clear velocities between the single specimens of Mytilus edulis. Similar results were obtained by J.A. Allen (1962) in three species of eulamelli-

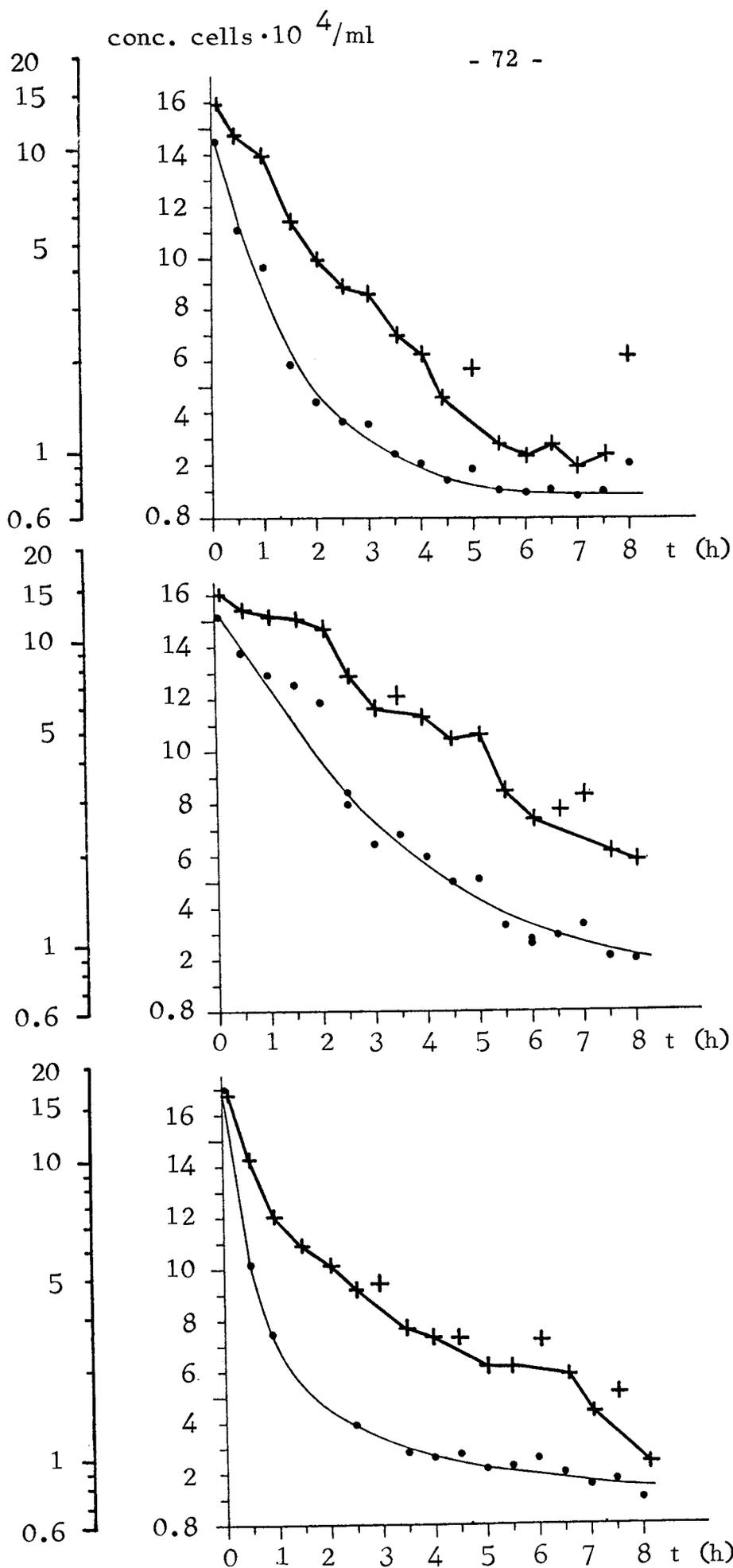


Fig. 6.1. Curves of 3 specimens of *Mytilus edulis* showing different swept-clear velocities expressed as the decrease in algal *Platymonas suecica* concentration versus time, crosses (x): values plotted against the logarithm of cell concentration. For further explanation see text.

branches (Fig. 6.2).

The swept-clear time to 10% of the initial algal concentration took 5-8 hours when a test volume of 500 ml and an algal concentration of  $1.5 \times 10^5$  cells/ml were used. Under these conditions further experiments should be performed in a period corresponding to the linear part of the curve, which is 60-90 min, since in this part the filtering rate is proportional to time (Fig. 6.3).

Further experiments are planned on swept-clear volume and optimal food concentration for Mytilus edulis as well as experiments with  $Zn^{65}$ .

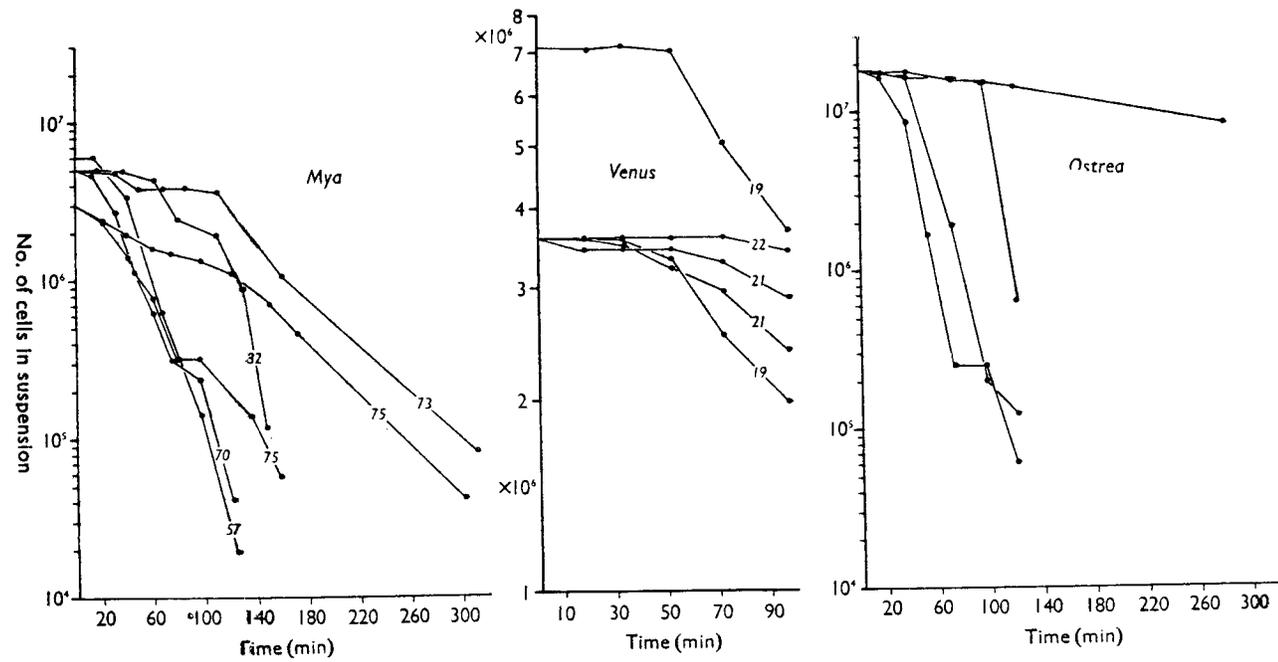


Fig. 6.2. Rates of removal of Phaeodactylum from suspension by the eulamellibranchs Mya arenaria, Venus triatula and Ostrea edulis. Shell length in italic numerals.  
(J.A. Allen, 1962)

conc. cells  $\cdot 10^4$ /ml

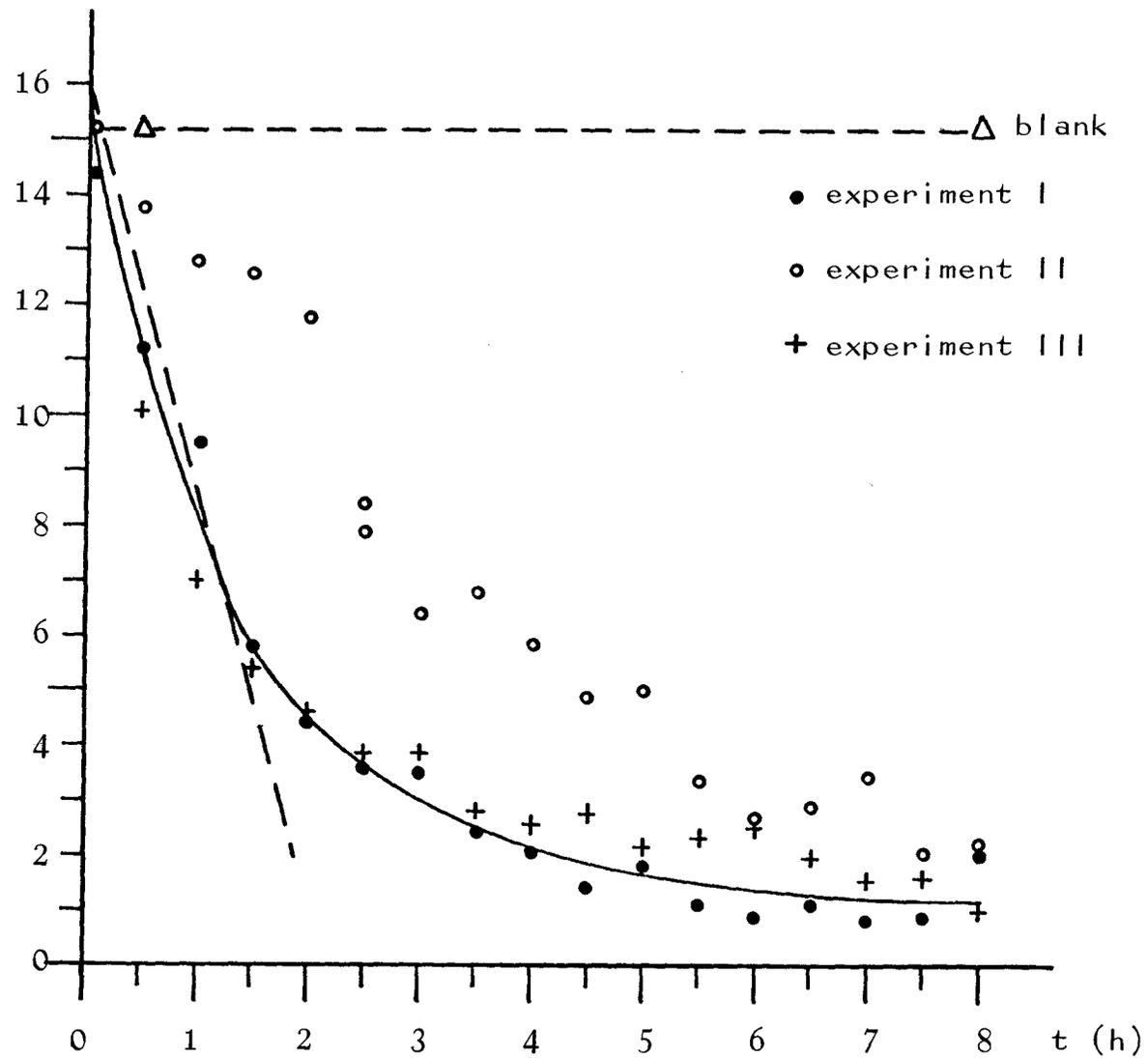


Fig. 6.3. Swept-clear velocity combining the values of all 3 experiments. Values of experiment II are not considered. Period in which the filtering rate (swept-clear-velocity) is proportional to time is indicated by the broken line; for further explanations see text.

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## SPECIAL DEVELOPMENT GROUP

During 1971 the Special Development Group actively participated in the cruises, and especially in the cruises and in the evaluation of the data collected in the Gulf of Taranto (see Environmental analysis of the Gulf of Taranto). The Group also carried out current measurements in the Gulf of La Spezia in which the local authorities were interested because of sewage outfalls.

Programs for the LABEN 70 computer greatly helped in the evaluation of the data collected. Several programs have been written in Assembler, e.g., for the evaluation of the current meter data. This program also has a graphic output for the high speed printer.

A similar program has been written for the Hydrosonde.

Further progress has been made in the automation of the evaluation of the data collected by different instruments used by the various groups, for example, the output of the Autoanalyzers has been digitalized and can now be directly evaluated by the computer. Similarly, the output of the three multichannel analyzers can be punched onto papertape for analysis with the computer.

A system has been constructed with which it is possible to link several peripherals (typewriter for console control, high-speed reader and high speed punch and high-speed printer) to the computer to replace the low-speed Olivetti teletype. Several oceanographic instruments and laboratory apparatus have been tested and improved, e.g., in the Hardy sampler constructed previously the transport mechanism of the net has been changed from one actuated by an electric motor to one driven by compressed air. In this way the net exposed to the water flow can be changed within a fraction of a second.

## ENVIRONMENTAL INVESTIGATION IN THE GULF OF TARANTO

In collaboration with Dr Cagnetti (Laboratorio per lo Studio della Radioattività ambientale, CSN of the CNEN) the Botany Group and Special Development Group elaborated the data collected also by the other groups during oceanographic cruises made in the Gulf of Taranto and studied the diffusion offshore Lerici and the Trisaia Centre (Gulf of Taranto).

The aim of these studies will be to evaluate the receptivity of the Gulf of Taranto and the marine area near the Trisaia outfall and to estimate the selective accumulation of activity in different components of the ecosystem effected by the outfall which can act as indicators for monitoring the marine environment at different distances from the outfall.

The data presented and discussed here will deal with the general circulation pattern of the Gulf of Taranto using data collected in three cruises in the years 1969-70, and with preliminary diffusion studies and estimation of the receptivity of the outfall area.

The release of the low-level activity of the Trisaia Centre will be effected at first at about 200 m from the coastline. At a later date the pipeline will be extended to about 2 km. As can be seen from the depth profile (Fig. 3.1), the release will initially be carried out at a depth of about 3 m and later at about 12 m.

The experiments (diffusion of Rhodamine and current measurements) carried out in the vicinity of the two pipeline outlets will supply us with information on the dispersion of the activity in the vicinity of the outfall, while the data on the general circulation will enable us to make predictions on the physical dilution of the activity in the Gulf of Taranto.

Once the physical dilution is known, it is possible to evaluate the reconcentration of different isotopes by the various biological and a-biological components of the environment and estimate the maximal permissible concentration of individual isotopes and mixtures of isotopes, considering internal and external exposures. The data that follow are

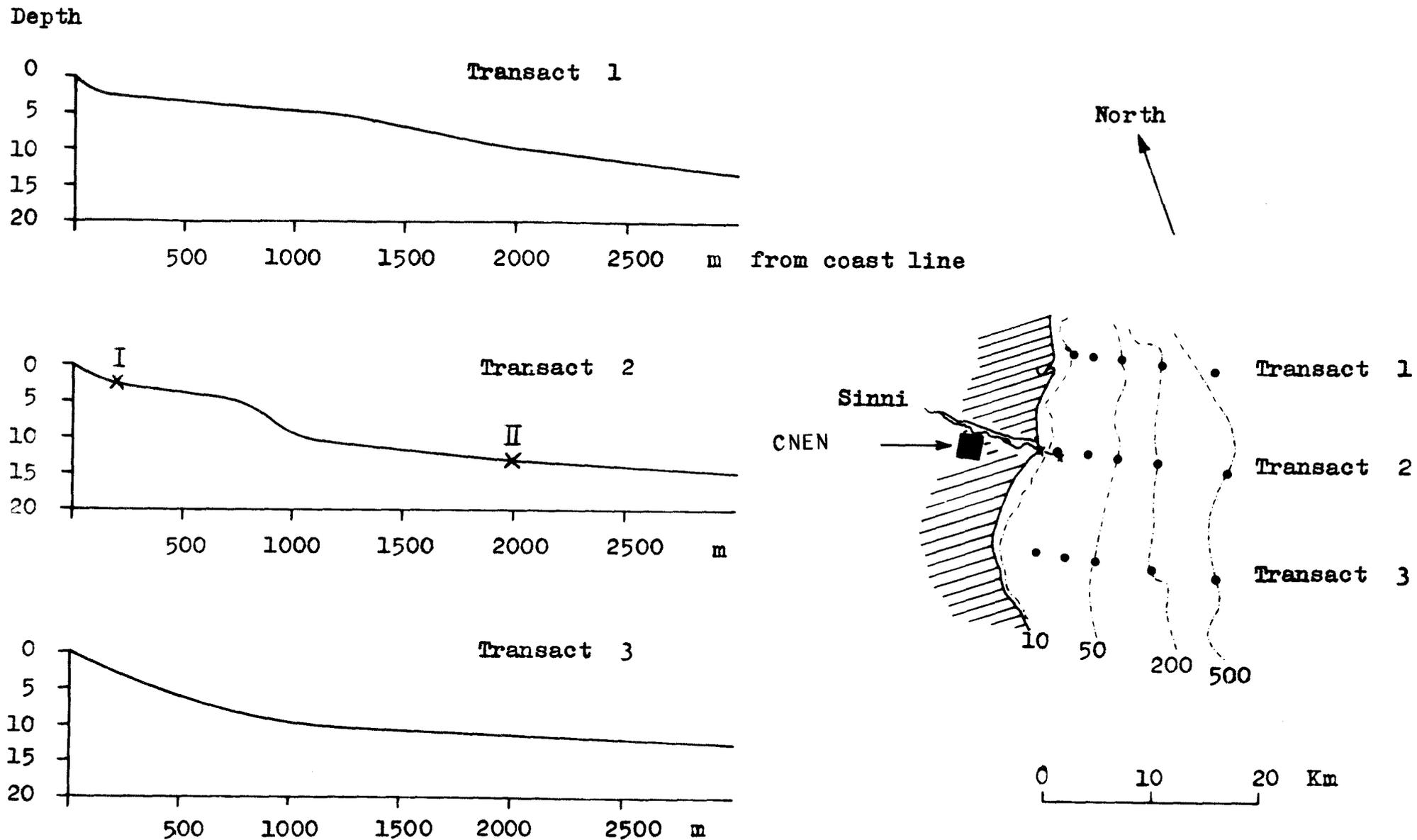


Fig. 8.1. Depth profiles off coast the Trisaia center for three parallel transacts

used to calculate a preliminary receptivity of the Gulf of Taranto and the area near the Trisaia outfall only, since so far not enough data are available.

The stability of water masses deduced from temperature and salinity data

During the months of November 1969 (cruise Taranto III), April 1970 (Taranto IV) and August 1970 (Taranto V) salinity and temperature data were collected in the Gulf of Taranto on five or six transacts (Cagnetti et al, 1971). Previously the 'Osservatorio Geofisico Sperimentale', Trieste, had carried out one cruise in July 1968 (Grancini et al, 1969).

The data of this cruise have also been considered. The thermocline, i.e., the rapid change of temperature with depth, is an indication of a transport barrier. As can be seen from Fig. 8.2, the thermocline is most pronounced in summer and autumn at a depth of 30-50 m. The thermocline diminishes during the autumn and winter, and disappears completely in spring.

The salinity temperature diagrams will give us information about the different water masses present.

For example, in station 77 during cruise Taranto V in August 1970 (Fig. 8.3) two very distinguishable water masses can be observed: one in the surface layer, i.e., between 0 and 30 m, with a low density of  $\sigma_t = 26$ <sup>4)</sup> and one at a depth greater than 100 m with a higher density  $\sigma_t = 29$ .

The exchanges between these water masses are limited, as can

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4)  $\sigma_t = 10^3(\rho_{stp} - 1)$ , where  $\rho_{stp}$  is the density expressed in g/cm<sup>3</sup>

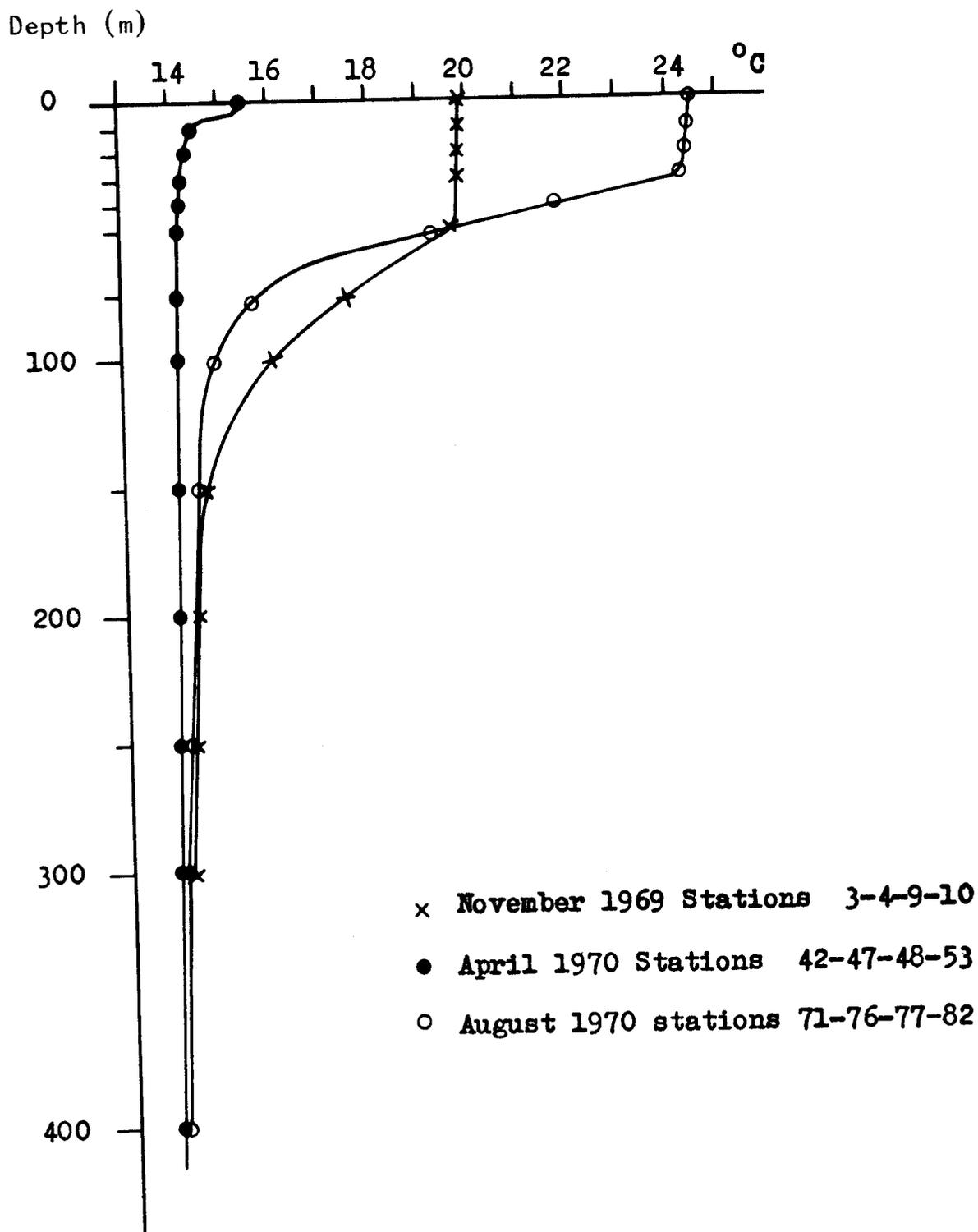


Fig. 8.2. Mean temperature ( $^{\circ}\text{C}$ ) in the center of the Gulf of Taranto for selected stations. Stations are shown in Fig. 8.4 B-C-D

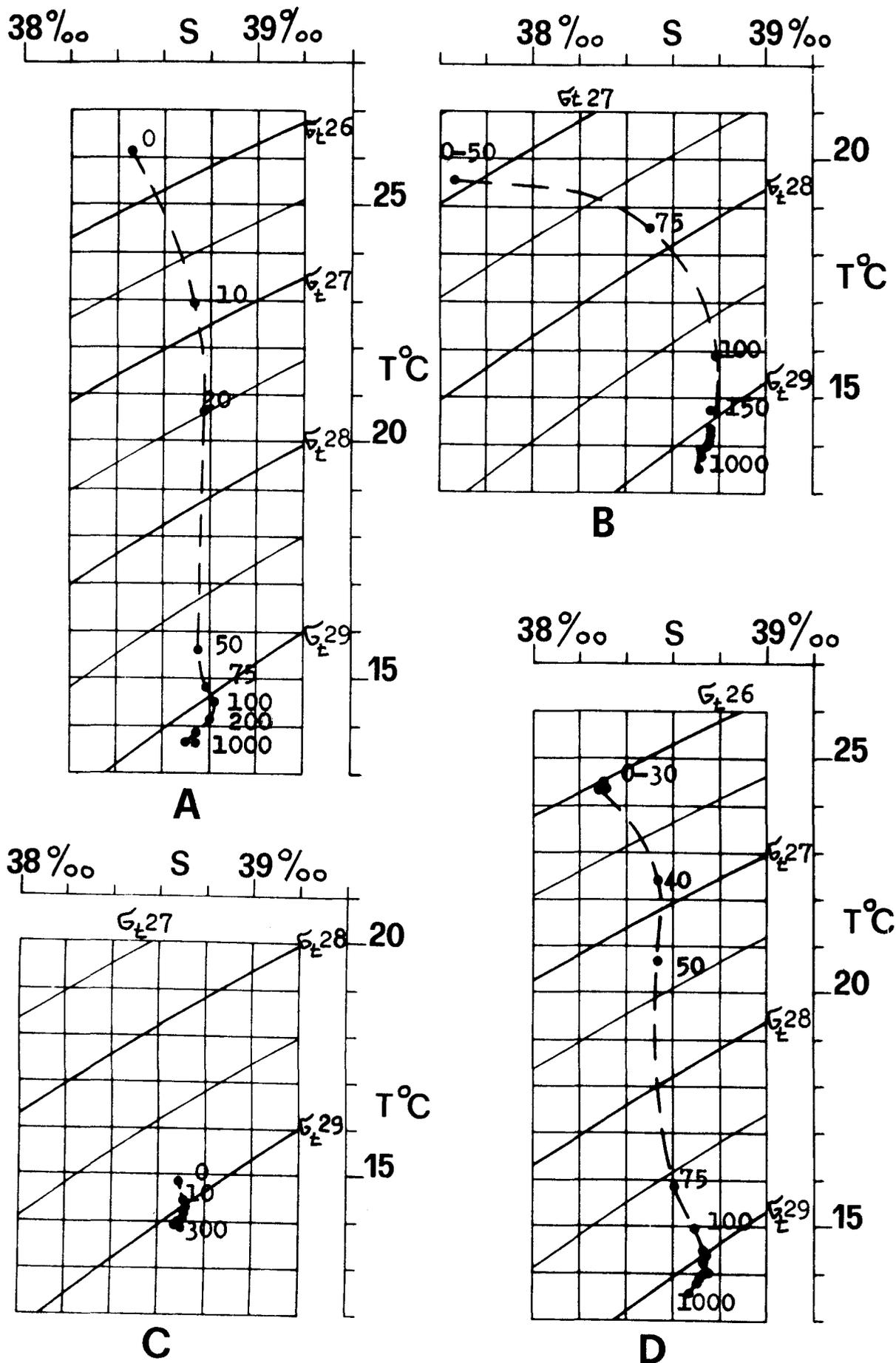


Fig. 8.3. S/T diagrams of selected stations.

- A - July 1968 station 9 (Fig. 8.4 A)
- B - November 1969 station 3 (Fig. 8.4 B)
- C - April 1970 station 47 (Fig. 8.4 C)
- D - August 1970 station 77 (Fig. 8.4 D)

be deduced from the fact that the line which connects the two runs perpendicular to the curves of equal density (isopycnets). On the other hand, the densities calculated at different depths within each water mass gave very similar densities, which indicate good mixing within the water masses.

In November 1969 the surface water mass extended to 50 m (Fig. 8.3 B). This extension coincides with a very pronounced thermocline beginning at 50 m (Fig. 8.2).

At the same time the salinity in the surface layer diminished, probably because of dilution by rain water.

In April (Fig. 8.3) the thermocline disappears and the surface water masses mixes with the water masses at greater depth, which has the same temperature and salinity and hence the same density (Fig. 8.4 C).

Fig. 8.3 refers to stations in the middle of the gulf (Fig. 8.4 C). Near the coast the extension of the surface layer decreases. In November 1969, for example, 12 km. offcoast the Trisaia centre the surface layer reaches only down to 30 m compared with 50 m in the open gulf.

In August 1970 in the open gulf the surface layer 30 m thick, while near the coast it extended only to 15-20 m.

#### The dynamic calculation of currents in the Gulf of Taranto and comparison with direct current measurements

With the so-called dynamic method (e.g., Fomin, 1964) it is possible to calculate the distribution of currents relative to an isobar surface in which the velocity of the current is known. Normally this surface is assumed to be at zero velocity ('zero-surface'). Applying this method to the data collected in the Gulf of Taranto during cruises Taranto III, IV and V the following results were obtained (Cagnetti et al, 1971). The 'zero-surface' was collocated for all cruises between 100 and 300 m depth (see Fig. 8.4). From the distance between contours it is possible to estimate current velocities (see the small graph on each dynamic relief). The directions of the currents are indicated with arrows.

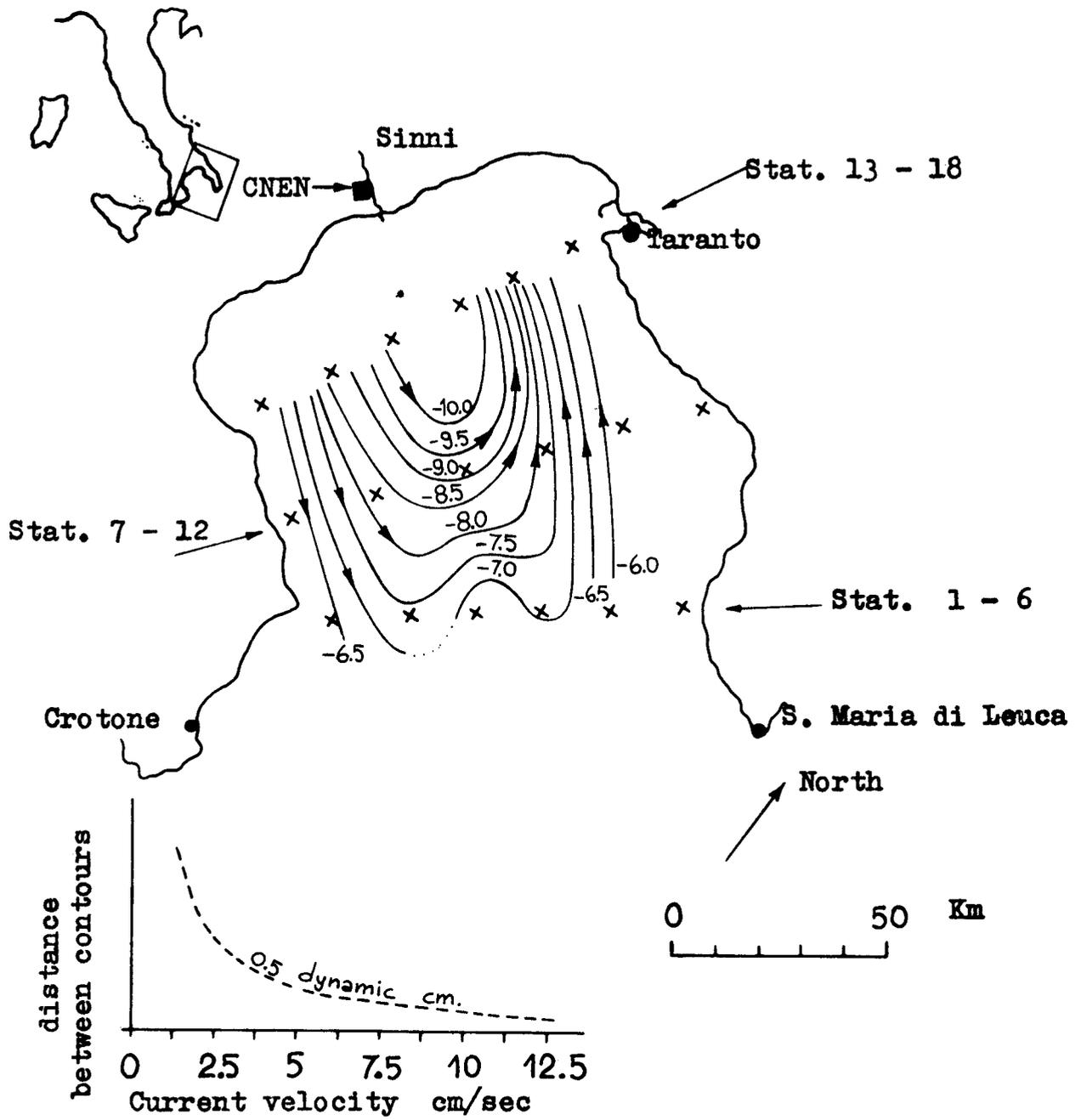


Fig. 8.4 A Circulation pattern in the Gulf of Taranto in July 1968. Reference surface 200 db. (Grancini et al, 1969)

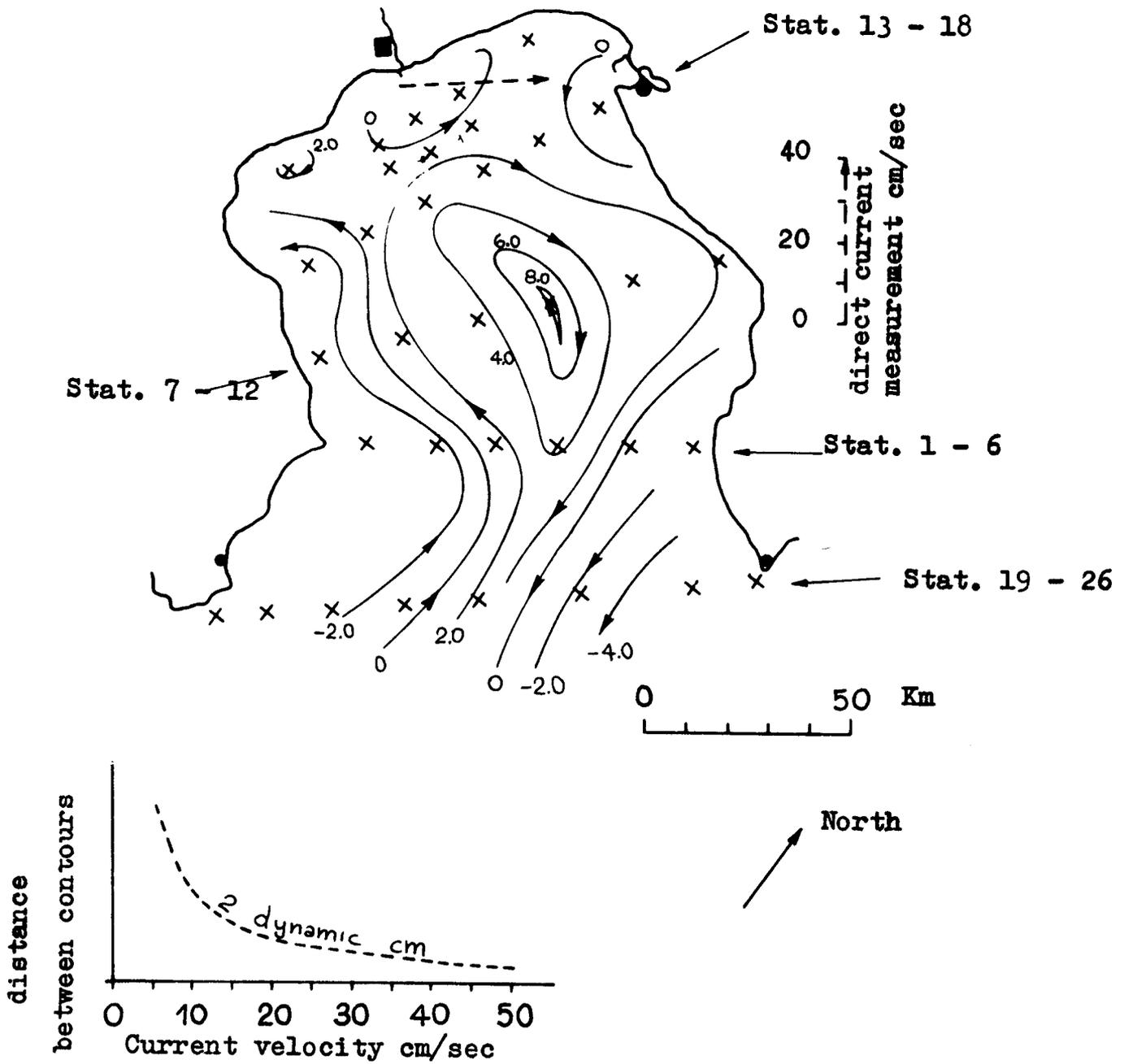


Fig. 8.4 B Circulation pattern in the Gulf of Taranto in November 1969 reference surface 150 db. Direct current measurements are indicated by broken vectors.

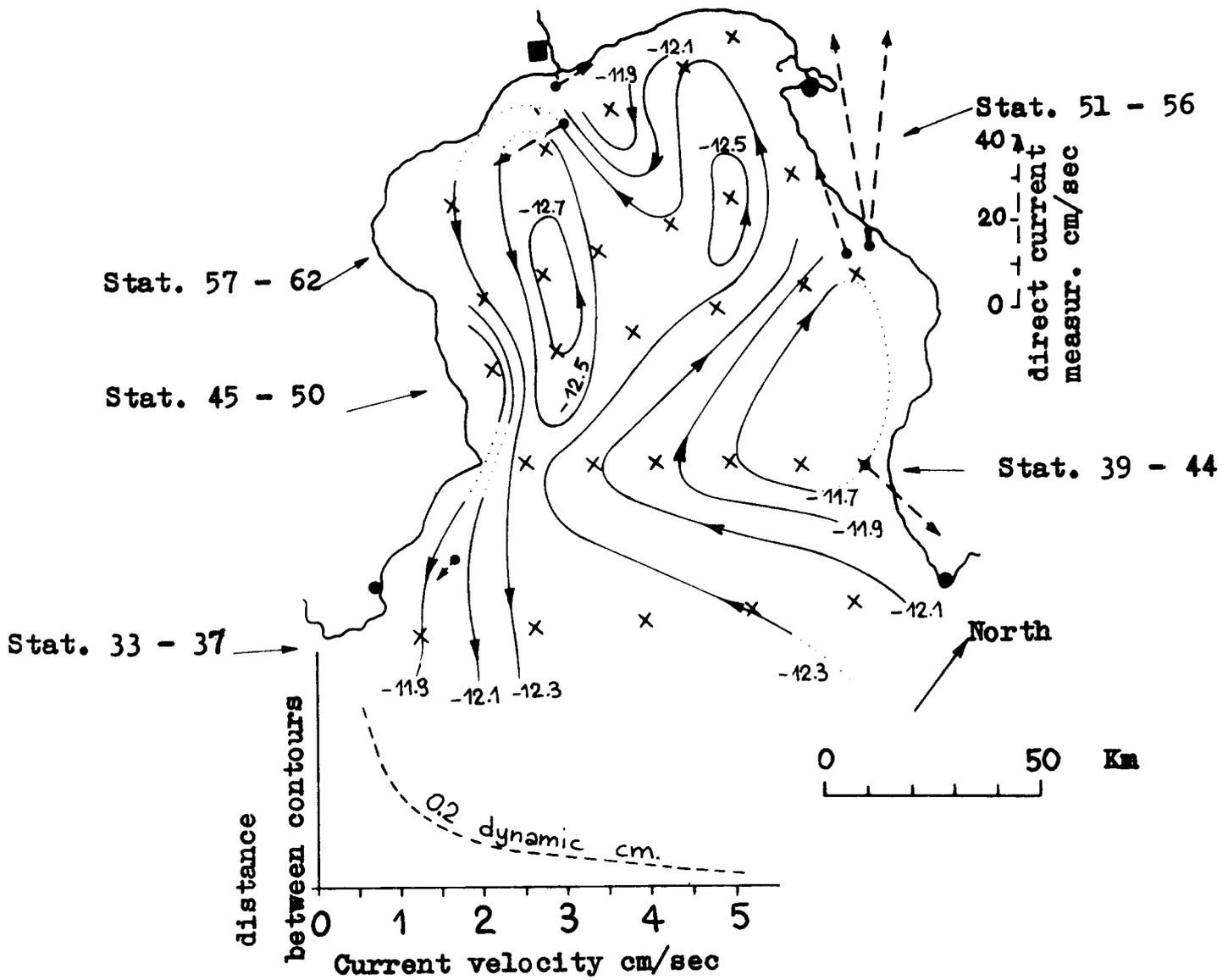


Fig. 8.4 C Circulation pattern in the Gulf of Taranto in April 1970 reference surface 150 db.

Direct current measurements are indicated by broken vectors

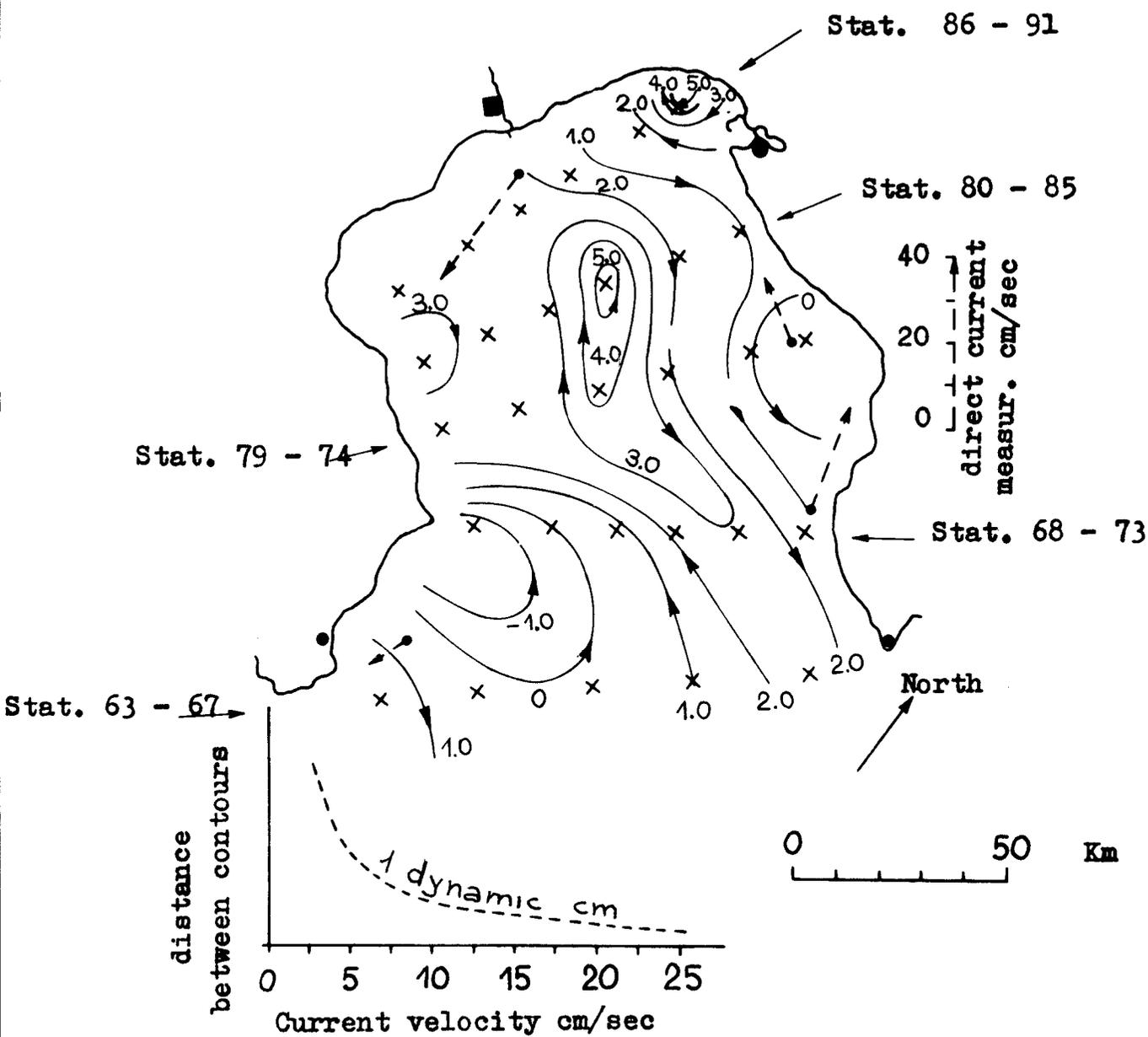


Fig. 8.4 D Circulation pattern in the Gulf of Taranto in August 1970 reference surface 150 db. Direct current measurements are indicated by broken vectors

In November 1969 (Fig. 8.4 B) the circulation was clockwise (anticyclonic), with strong dynamic gradients, which correspond to current velocities up to 50 cm/sec.

Several eddies were observed. One is of particular interest, since it is located directly in front of the Trisaia Centre. It has anticlockwise rotation. Direct current measurements (Figs. 8.5 A-B) seem to indicate that more than one eddy exists.

In April (Fig. 8.4 C) the gradients are much weaker, with currents of 10-30 cm/sec. The general circulation pattern is more or less anticlockwise with several large eddies. Again a relatively small eddy is situated in front of the Trisaia Centre. Direct current measurements carried out in three parts of the gulf show that these measurements are in quite good agreement with regard to the direction determined.

The velocities measured are, however, higher than that determined by the indirect method.

The dynamic methods show that again a relatively small eddy is situated in front of the Trisaia Centre.

In August the gradients in the dynamic relief are stronger again (Fig. 8.4 D), with velocities of 30-40 cm/sec and several large eddies.

In the centre of the gulf the circulation is now clockwise. Direct current measurements give different directions from those indicated by the dynamic method and the velocities are also somewhat higher.

The data presented by Grancini et al (1969) (Fig. 8.4 A) for the situation in July 1968 are different from our observations in August 1970, but, of course, different years may have different circulation patterns.

From these preliminary data it may be concluded that in the Gulf of Taranto there is a general circulation pattern which changes its direction during the different seasons and is probably not the same in different years either.

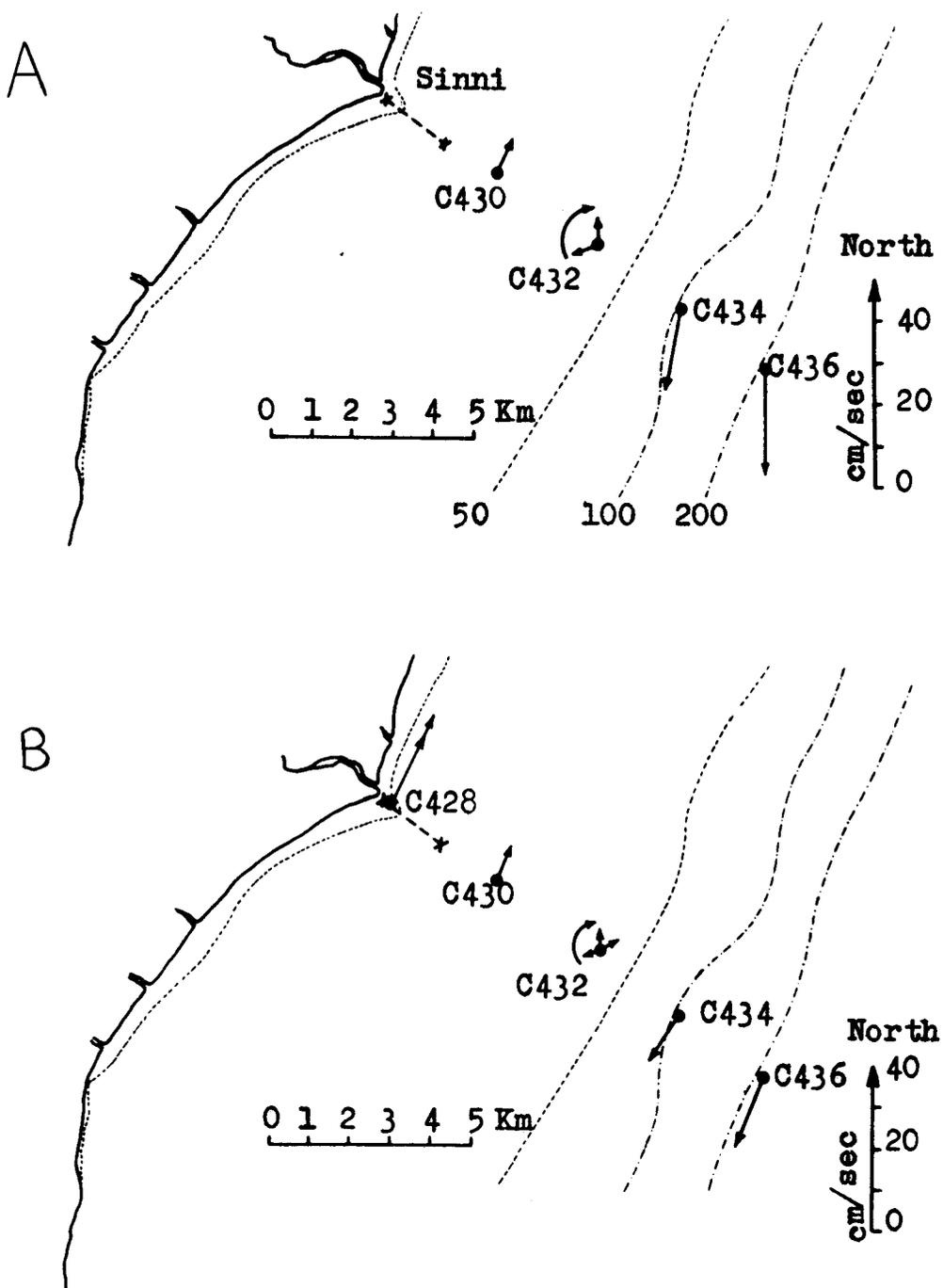


Fig. 8.5 Direct current measurements off coast the Sinni river in April 1970

Compartment model of a stationary eddy in the release area

The dynamic analysis (Figs. 8.4 B and 8.4 C) and the direct current measurements (Fig. 8.5) show that an eddy can develop under certain conditions just in front of the Trisaia Centre in the area of the planned outfall.

The diameter of this eddy can vary between 10 and 30 km.

The dye experiments indicated an even smaller eddy of only 1.5 km (Fig. 8.12).

In the first model we have assumed that the eddy extends over an area of 10 x 10 km and a mean depth of 15 m. The turnover time of this eddy will be in the order of months as regards its exchange with the remaining waters of the gulf. It seems reasonable to assume three months since our preliminary data show that the direction of the eddy changes with the different seasons.

The area of the eddy corresponds to  $10^8 \text{ m}^2$ , which is 1/130 of the total area of the Gulf of Taranto ( $1.3 \times 10^{10} \text{ m}^2$ ). The volume of the eddy, considering a depth of 15 m, is therefore  $1.5 \times 10^9 \text{ m}^3$ . The volume of the same surface layer, thought to be limited by a thermocline at 15 m depth extended over the area of the entire gulf, would be  $1.95 \times 10^{11} \text{ m}^3$ .

The compartmental model of the eddy and its exchange with the entire gulf (taken here to be of infinite size) and with the sediments of the bottom surface of the eddy is shown in Fig. 8.6.

If we indicate with  $Q_i$  the total quantity of radioactivity present in compartment i,  $C_i$  the concentration in the compartment i,  $\lambda$  the decay constant,  $k_i$  the exchange coefficients and  $k_{in}$  the rate of discharge from the pipeline we obtain:

$$\frac{dQ_1}{dt} = -(\lambda + k_1 + k_6 + k_7)Q_1 + k_2Q_2 + k_5Q_3 + k_{in}$$

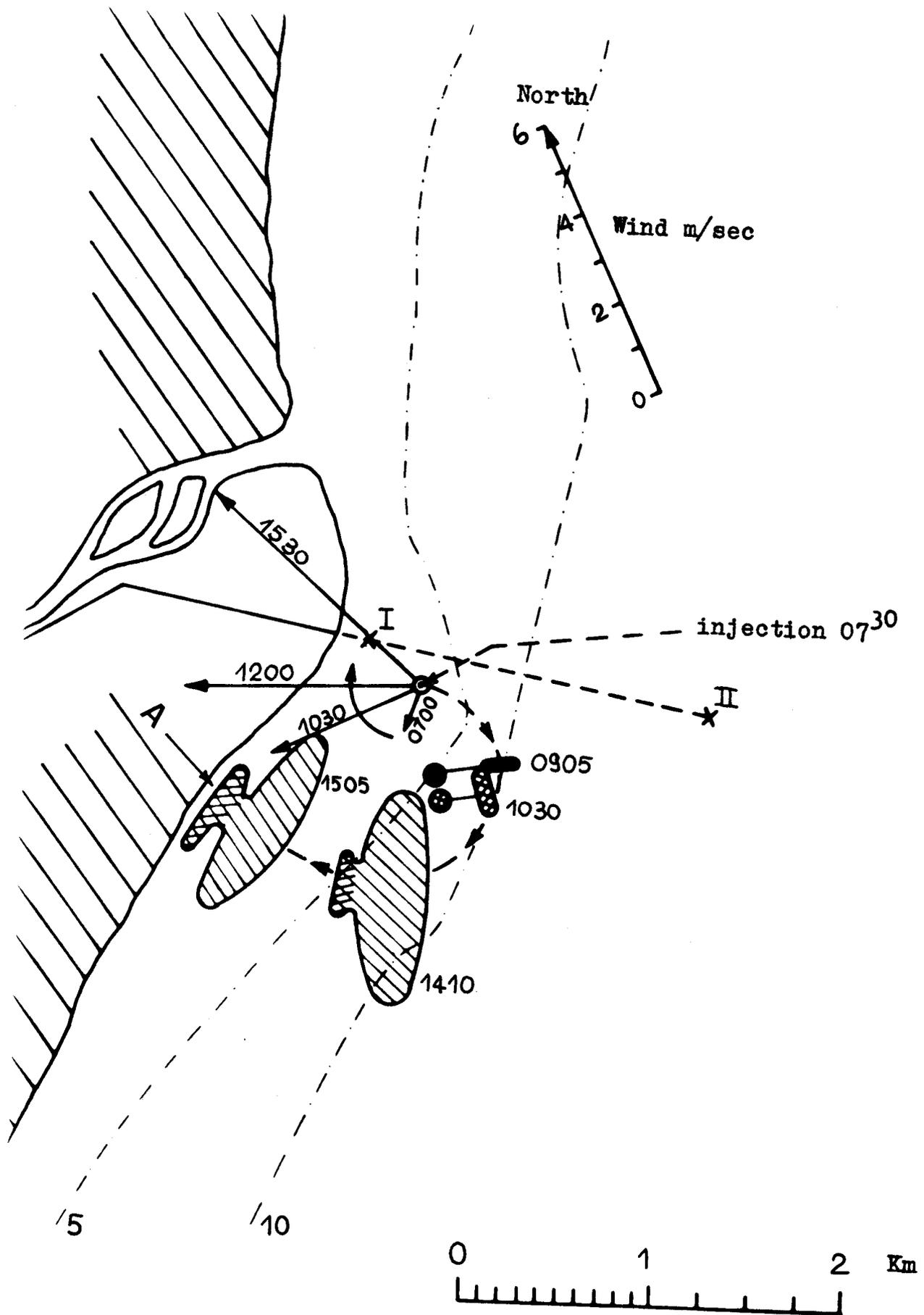


Fig. 8.12. Movement of instantaneous release of Rhodamine B and current and wind directions. Wind directions are shown in direction of air flow (22 June 1971)

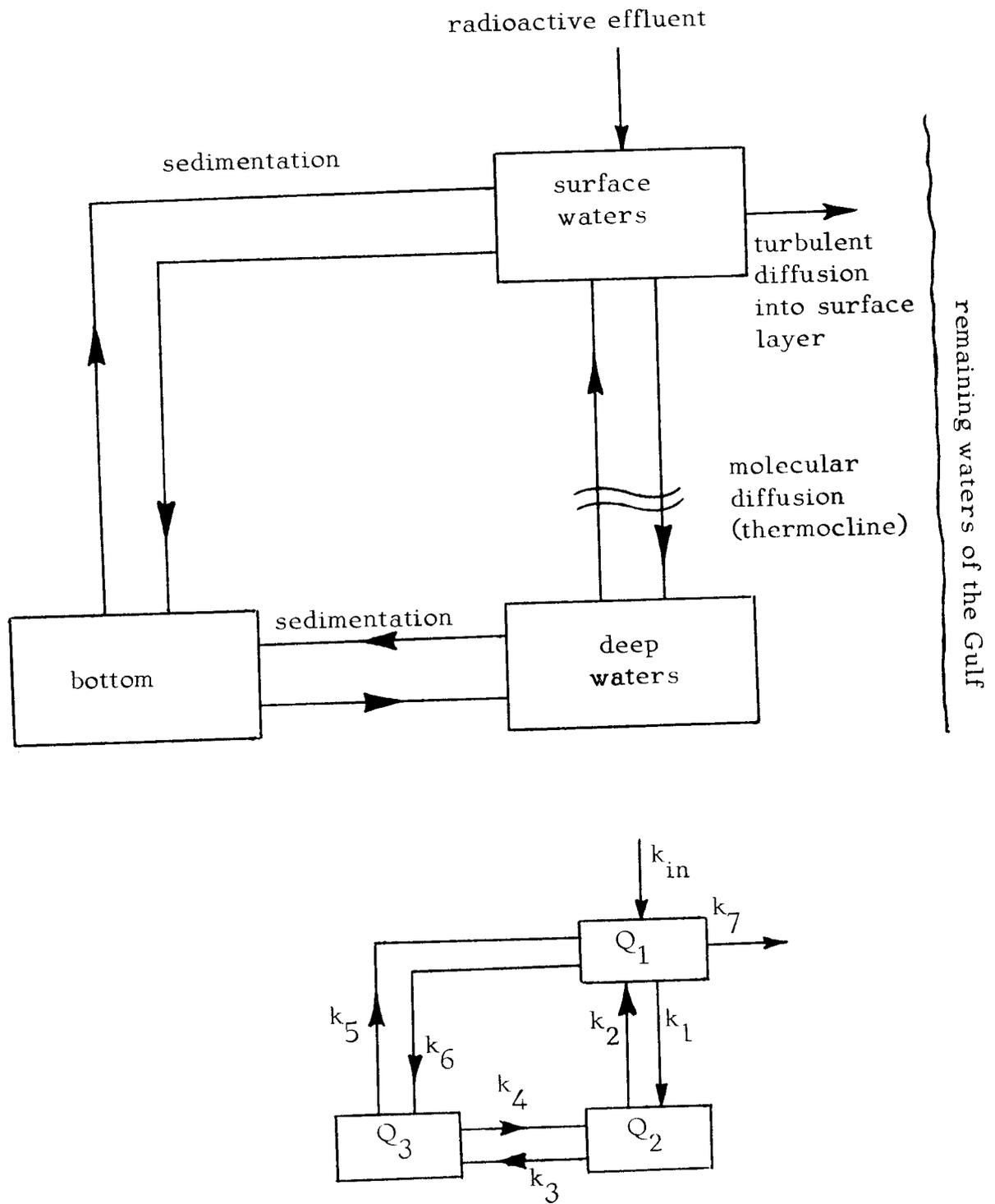


Fig. 8.6. Compartment model for stationary eddy

$$\frac{dQ_2}{dt} = k_1 Q_1 - (\lambda + k_2 + k_3) Q_2 + k_4 Q_3$$

$$\frac{dQ_3}{dt} = k_6 Q_1 + k_3 Q_2 - (\lambda + k_4 + k_5) Q_3$$

Developing the above relations and taking into consideration the equilibrium conditions, we obtain:

$$Q_1 = \frac{K_{in}}{k_7 + \lambda} \quad (1)$$

For a volume,  $V$ , of the eddy we obtain the mean concentration in the eddy,  $C_1$ :

$$C_1 = \frac{K_{in}}{V(k_7 + \lambda)} \cong \frac{K_{in}}{k_7 \cdot V} \quad (C_i / m^3) \quad (2)$$

Similarly we can estimate the maximum deposit on the bottom of the eddy under the most conservative conditions, i.e., without resuspension and redissolving of radioisotopes from the sediments into the above seawater:

$$Q_3 = \frac{K_{in} \cdot k_6}{\lambda(\lambda + k_6 + k_7)} \quad (3)$$

If the surface is  $S = 10^8 \text{ m}^2$  the deposit,  $d$ , will be:

$$d = \frac{K_{in} \cdot k_6}{S(\lambda + k_6 + k_7) \lambda} \quad (C_i / m^3) \quad (4)$$

where  $k_7 = 4 \text{ years}^{-1}$

$\lambda = \text{decay constant (year}^{-1}\text{)}$

$k_{in} = \text{release in Ci/year}$

$$k_6 = \frac{S V_d}{V} = \frac{10^8}{1.5 \times 10^9} \approx 7 \times 10^{-2} V_d \text{ (year}^{-1}\text{)}$$

$V_d = \text{sedimentation rate (m/year)}$

$$d = \frac{7 \cdot 10^{-2} V_d \cdot k_{in}}{10^8 (\lambda + 7 \cdot 10^{-2} V_d + 4) \cdot \lambda} = \frac{10^{-8} \cdot k_{in}}{\left(\frac{\lambda + 4}{7 \cdot 10^{-2} V_d} + 1\right) \lambda} \text{ (Ci/m}^2\text{)} \quad (5)$$

Let us illustrate with an example the consequences of equation (5). For a release of 1 Ci/year of  $\text{Ce}^{144}$  ( $T_{1/2} = 0.78 \text{ y}$ ;  $\lambda = 0.88$ ) and a sedimentation rate of  $10^4 \text{ m/year}$  ( $\approx 3 \text{ m/day}$ ),  $d$  becomes

$$d = \frac{10^{-8} \cdot 1}{\left(\frac{0.88 + 4}{700} + 1\right) \lambda} = \frac{10^{-8}}{(0.007 + 1) \lambda} = 10^{-8} / \lambda \text{ (Ci/m}^2\text{)} \quad (6)$$

For sufficiently fast sedimentation rates and small values for  $\lambda$  the contribution of  $\frac{\lambda + 4}{7 \times 10^{-2} \times V_d}$  to 1 is small and can therefore be

neglected.

Hence for the release of 1 Ci/y of a single isotope the deposition should be:

$$d = \frac{10^{-8}}{\lambda} \text{ Ci/m}^2$$

If the  $V_d$  is  $\gg \frac{\lambda + 4}{7 \times 10^{-2}}$  in steady state, the accumulation of activity

in the sediments will be independent of the sedimentation rate.

### Diffusion studies

In order to obtain data on the diffusion of radioisotopes in the coastal waters, experiments on the diffusion of Rhodamine B were carried out. Experiences were conducted first in shallow waters, of the Gulf of La Spezia near Lerici to set up the method and then off the Trisaia Nuclear Centre.

### Experiments off Lerici

In these experiments (2 March, 4 March and 30 March 1971) different amounts (600, 2200 and 2000 g) of Rhodamine B were instantaneously released at 1 m depth.

The distance from the coastline was 200-600 m, the depth 12 m and the sea was calm (1-2) (Figs. 8.7 and 8.8).

It is interesting to note that, during the experiment shown in Fig. 8.8. the movement of the spot and the currents measured at 4 m depth are in the same direction.

In this case the dye was moved by strong current which caused the spot to dispers rapidly (see Fig. 8.11).

Figs. 8.9, 8.10, 8.11 show the relation between time and maximum concentration of Rhodamine in the spot.

The data are well fitted by a function of the form

$$C_{\max}(t) = A t^{-n} \quad (7)$$

Applying the least square method to the logarithms of the data, we obtain:

$$\text{for example in Fig. 8.9 } C = 18 \cdot 10^3 t^{-2.1} \mu\text{g/l} \quad (8)$$

$$\text{" " " 8.10 } C = 1.32 \cdot 10^5 t^{-1.9} \mu\text{g/l} \quad (9)$$

$$\text{" " " 8.11 } C = 18 \cdot 10^8 t^{-3.4} \mu\text{g/l} \quad (10)$$

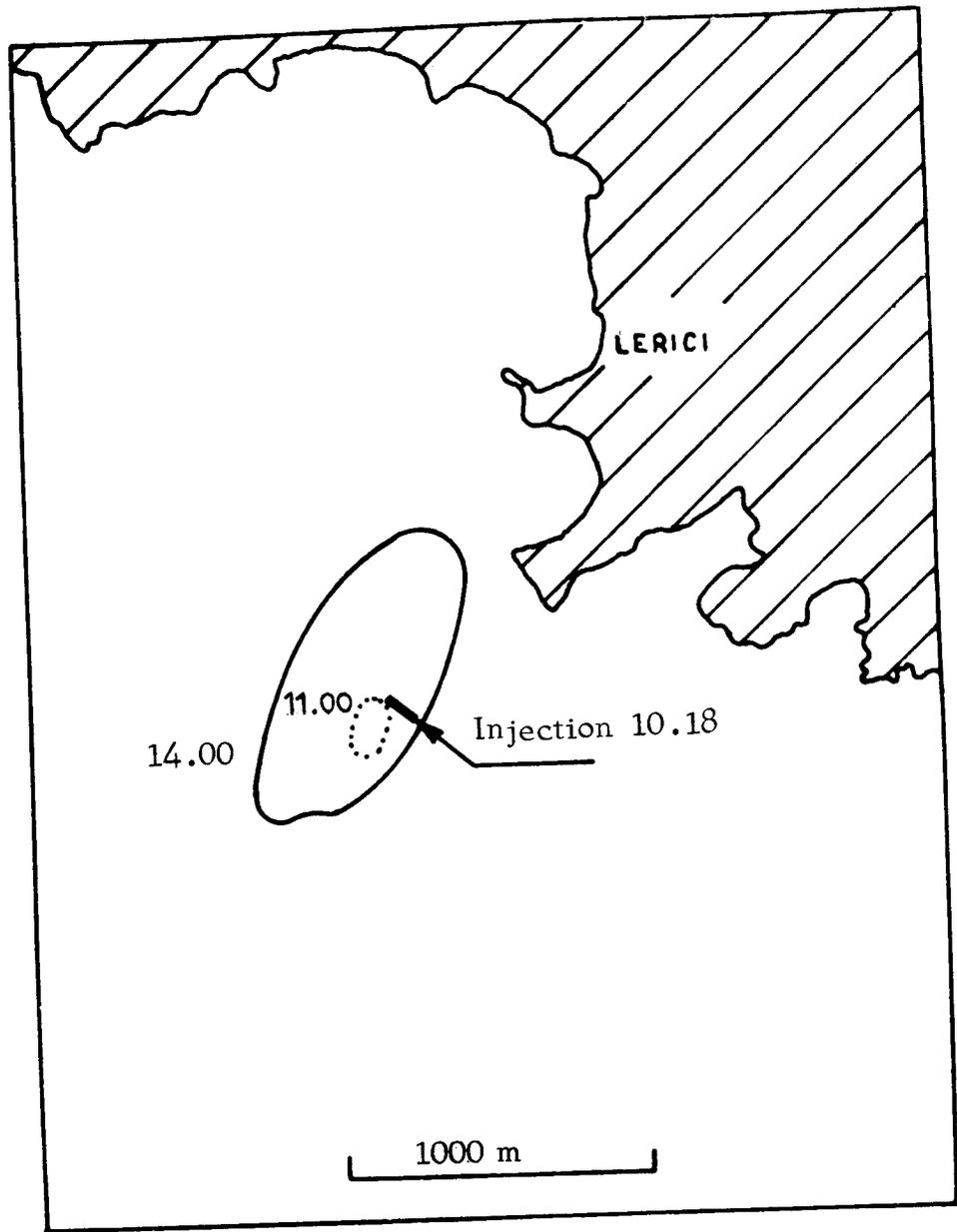


Fig. 8.7. Movement of dye spot in experiment of 4 March 1971

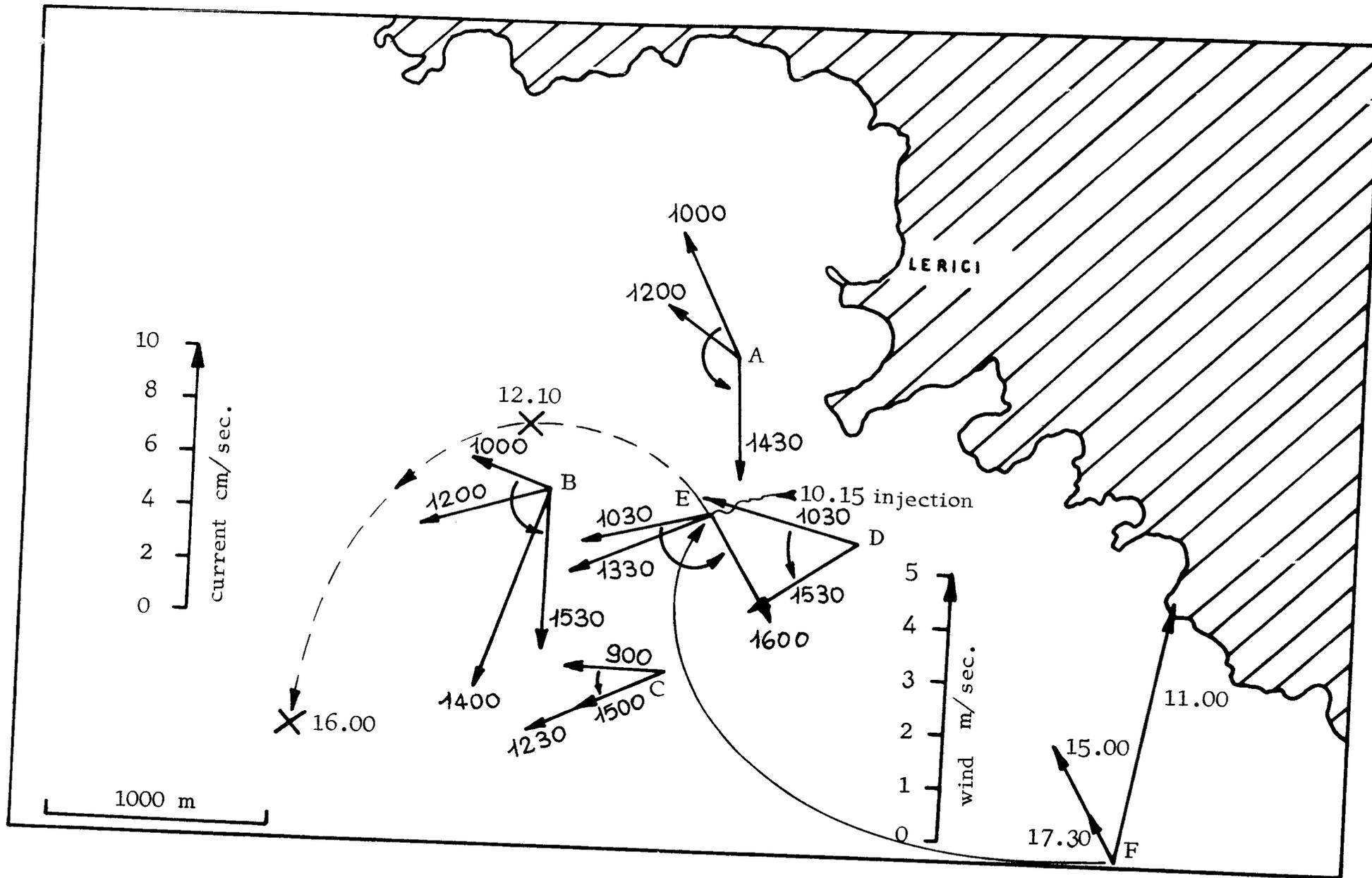


Fig. 8.8. Experiment of 30 March 1971, showing the movement of the spot (x --- x) current data at 4 m depth (ABCDE), velocity and direction of wind (F)

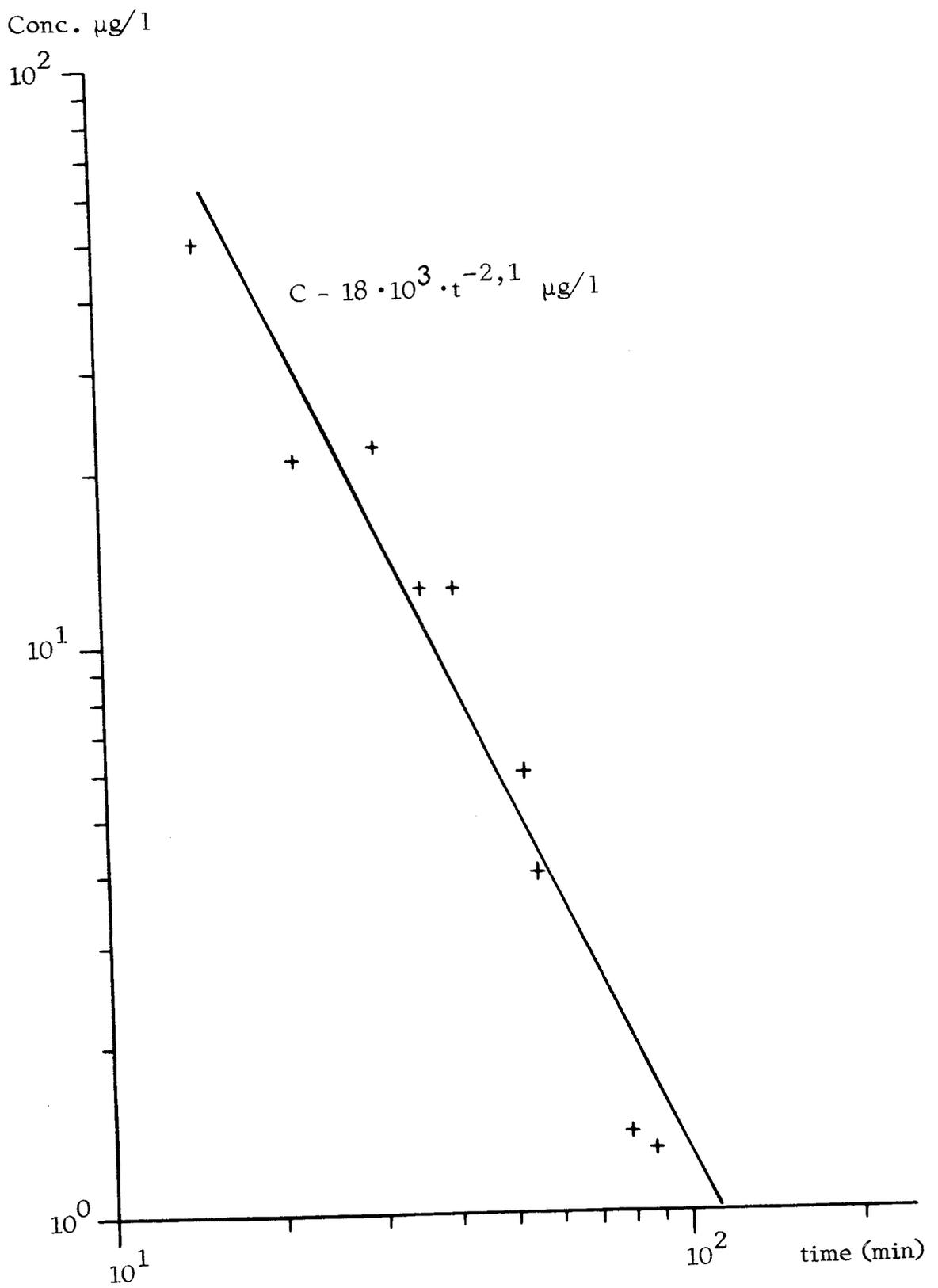


Fig. 8.9. Experiment of 2 March 1971.

Variation of maximum concentration of Rhodamine with time

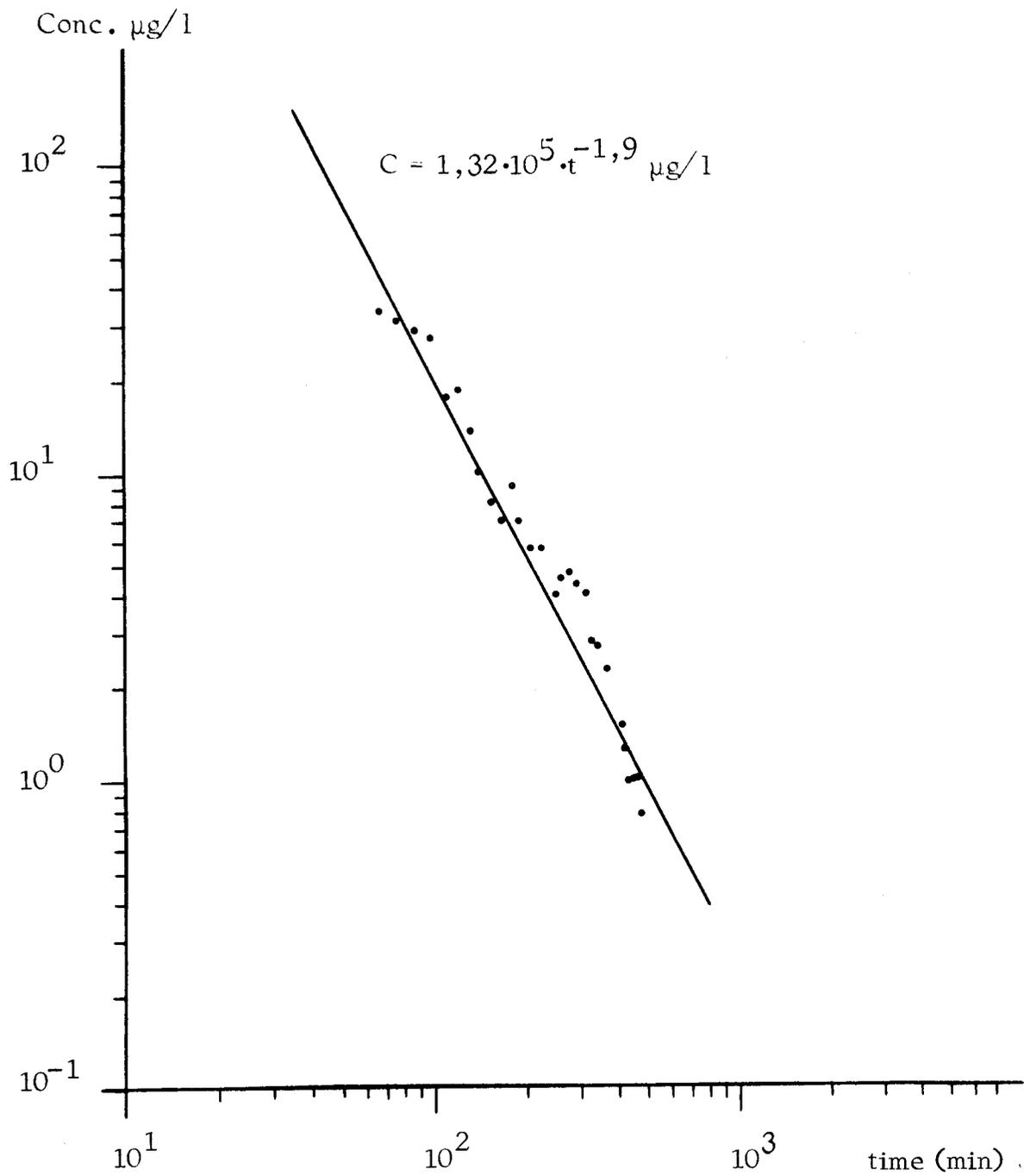


Fig. 8.10. Experiment of 4 March 1971.

Variation of maximum concentration of Rhodamine with time

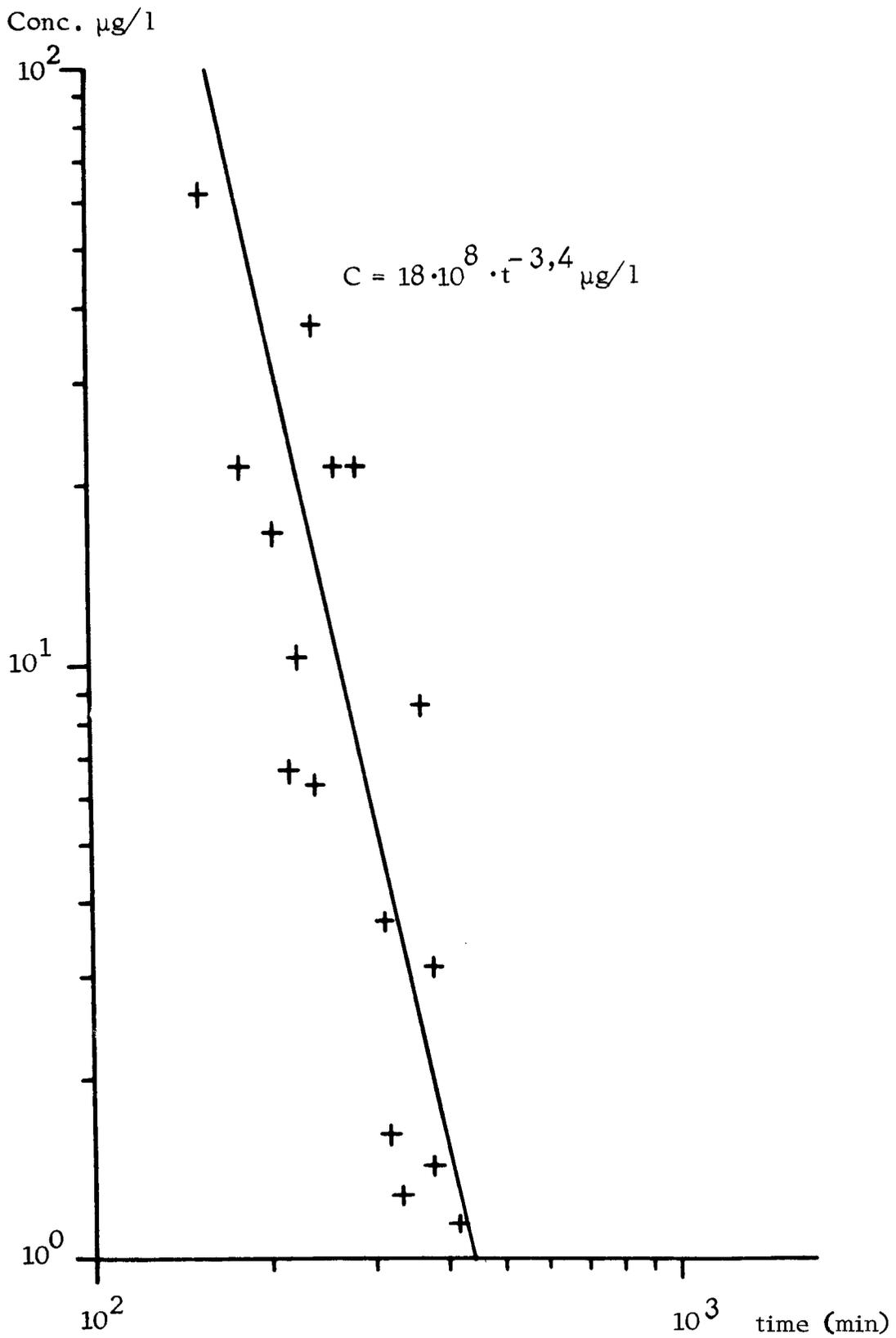


Fig. 8.11. Experiment of 30 March 1971.

Variation of maximum concentration of Rhodamine with time

Diffusion studies with Rhodamine near the planned outlets offshore  
the Trisaia Nuclear Centre

Experiments off the Trisaia Nuclear Centre were carried out during June.

Two experiments were carried out at about 500 m from the coast. Unfortunately it was not possible with the fishing vessel hired for the measurements to come closer to the coast and carry out the measurements at the planned 200 m distance outlet. In the '500 m' experiment only the maximal concentration of the Rhodamine spot was determined. The edges of the spot were identified visually and the distance of these edges from each other estimated with the help of radar.

In the '2000 m' experiments it was possible to make several transacts through the Rhodamine spot. These data were used to produce curves of isoccentration.

Here we will discuss only the three experiments with the slowest dilution, since from a health physics point of view they represent the more conservative data.

Injection near the 200 outlet

At 07 30 hours on 22 June 1971, 1.5 kg Rhodamine B of a density similar to the seawater ( $1.03 \text{ g/cm}^3$ ) were released about 500 m from the coast. At the same location two registering aerometers and two registering current meters (Benedetti et al, 1970) were situated.

Until about 10 00 hours there was very little wind (SW:  $\sim 1 \text{ m/sec}$ )<sup>5)</sup>

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<sup>5)</sup>For better comparison with the current meter data, the wind directions are the directions into which the wind blows, contrary to common usage.

and the sea was calm. The Rhodamine spot diluted very slowly and it divided into two spots.

Then, at about 10 00 hours the wind strengthened to a breeze while changing direction slightly ( $W \sim 4$  m/sec) and the spot of Rhodamine diluted more rapidly and became larger.

At the same time the measurements were started, being continued until 16 00 hours. As can be seen from Fig. 8.12, the movements of the spot followed quite the movement of the wind quite closely. Note that at the end of the experiment the wind had driven one of the Rhodamine spots practically onto the beach. Since the water volume is small here owing to the shallow depth, the concentration determined by water samples was four times that of the Rhodamine in the deeper waters.

The influence of the wind on the dilution of the Rhodamine is well demonstrated in this experiment. Unfortunately the current meter did not function correctly, so we have no data available on direct current measurements.

Plotting the maximal density of the spot against time we obtain the graph in Fig. 8.13.

Interpolation using the least squares method resulted in the following relation between concentration (C) and time (t):

$$C \approx 5 \cdot 10^8 t^{-3.2} \mu\text{g Rhodamine/l} \quad (t \text{ in minutes}) \quad (11)$$

The relationship between the concentration of Rhodamine at greater distance and that near the beach is  $\frac{4 \text{ m depth}}{1 \text{ m depth}} = 4$

#### Injection near the 2000 m outlet

2 kg of Rhodamine are released at 08 00 hours on 23 June 1970 at about 2.2 km from the shore line where the total depth is 12 m. After placing the current meters 4 m above the sea-bed and the anemometer at the released point, the Rhodamine determinations started at about 11 00 hours (Fig. 8.14). During the day the wind varied from south-west to

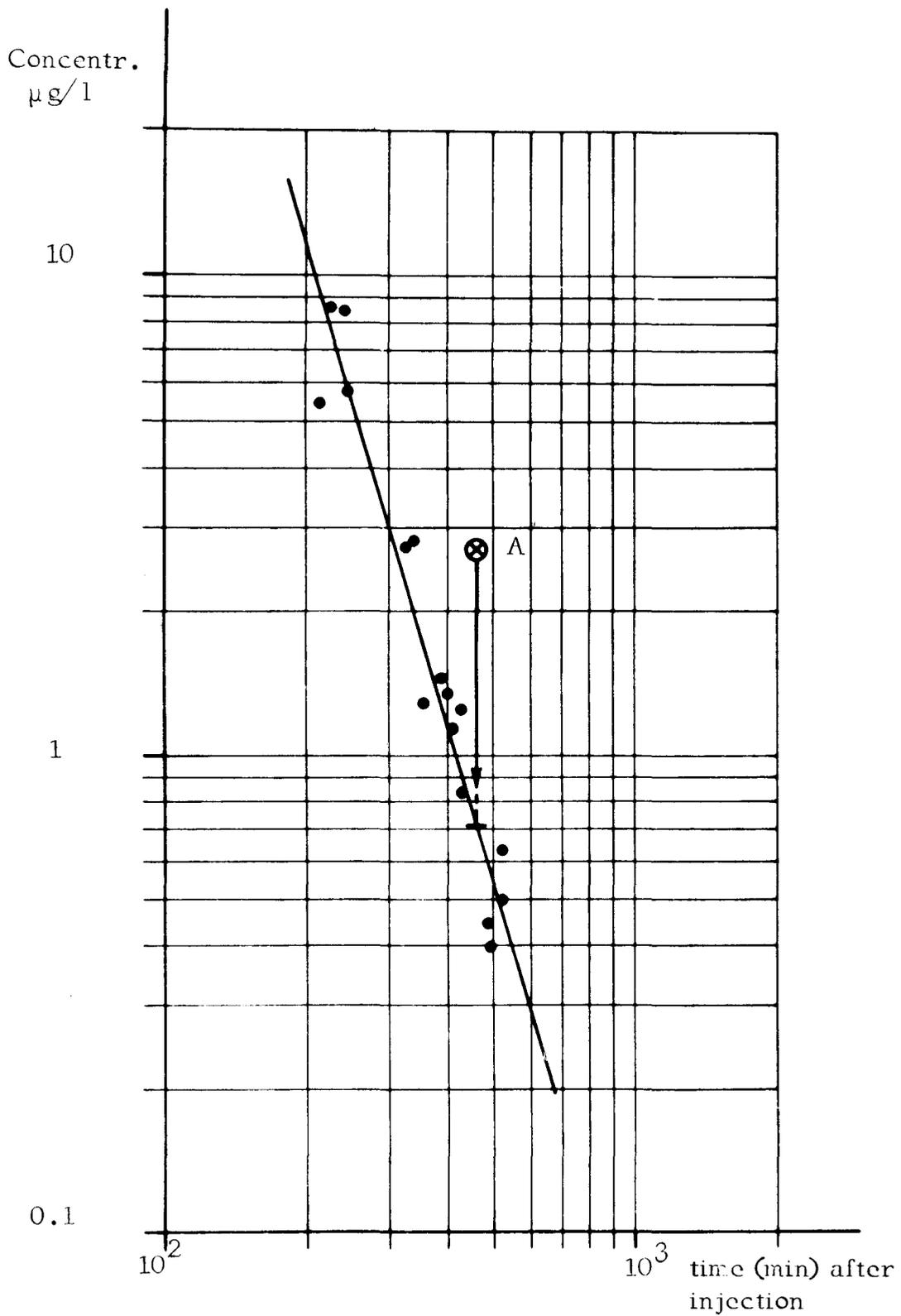


Fig. 8.13. variation of maximum concentration with time for an instantaneous release of 1.5 kg. Rhodamine B (22 June 1971)

A refers to the concentration of the spot 70 m from the coast

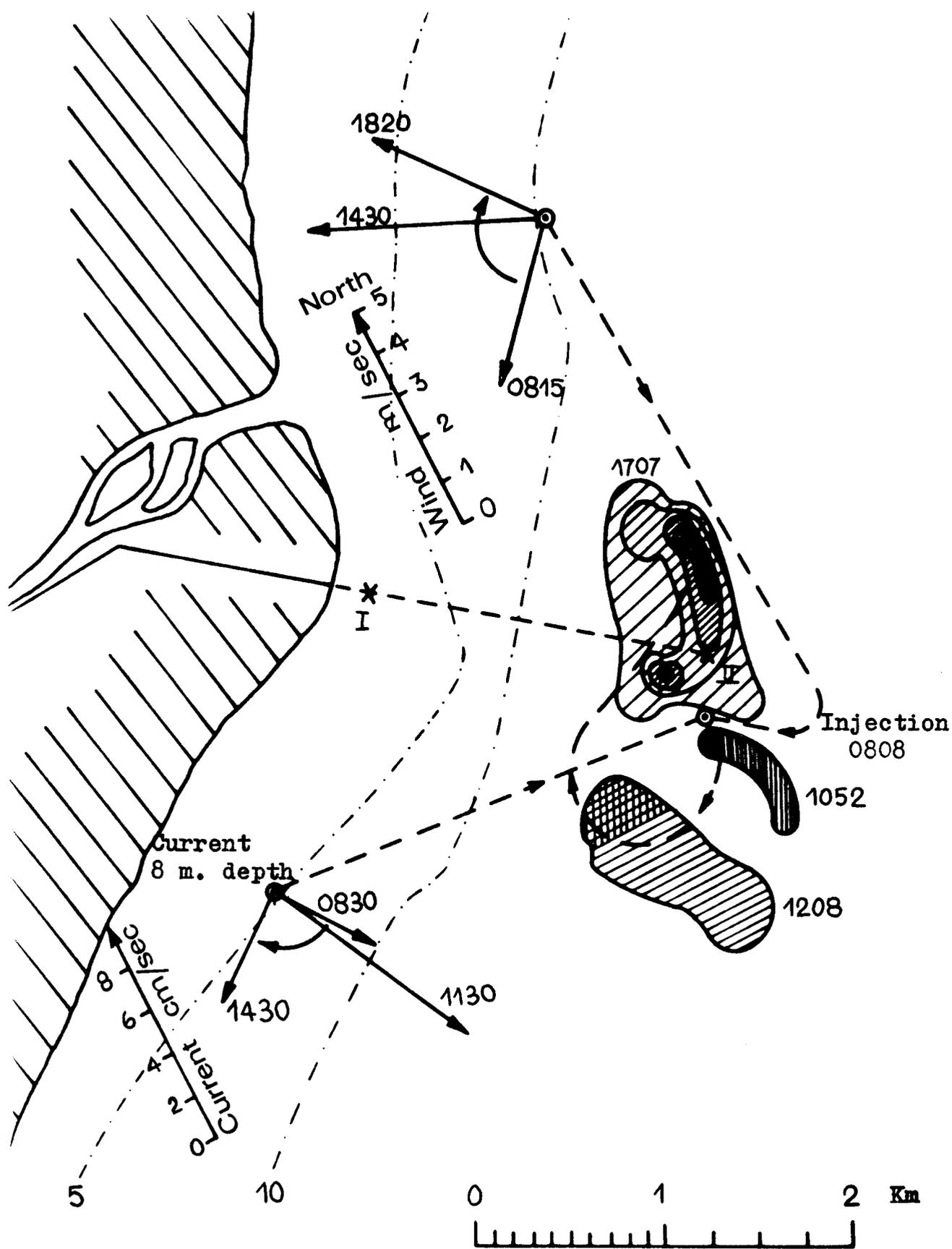


Fig. 8.14. Movement of instantaneous release of Rhodamine B and current and wind directions. Wind directions are shown in direction of air flow (23 June 1971)

north-west, while the current determined with the current meter at the point of release changed direction from SSE to WSW at 14 30 hours following the change of the wind with a certain time lag. In fact the Rhodamine spot moved around the release point. Fig. 8.15 shows the maximum concentration of the spot vs time and the relation between concentration and time was found to be:

$$C = 5 \times 10^8 t^{-3.3} \mu\text{g Rhodamine/l} \quad (t = \text{minutes}) \quad (12)$$

A second experiment at this location was carried out on the following day (24 June 1970) in very similar conditions (see Figs. 8.16 and 8.17), the following results being obtained:

$$C = 1.8 \times 10^7 t^{-3.04} \mu\text{g Rhodamine/l} \quad (13)$$

Two current meters were set out, one 4 m above the sea-bed and one 8 m above sea-bed (total depth 12 m). As can be seen from Fig. 8.16, there was a difference of about  $90^\circ$  between the direction at 4 m and that at 8 m. The difference caused faster diffusion of the Rhodamine due to shearing, as can be easily verified from a three-dimensional model (Fritchards et al, 1966).

With increasing wind velocity the current changes directing towards that of the wind. This change of direction is, however, retarded at greater depths. The shearing explains the faster dilution of the Rhodamine with increasing wind speed. However, at the same time the diffusion is also increased because of stronger turbulence due to the wind action on the water surface.

#### Choice of the diffusion model which best fits the observation

Several authors have compared the two-dimensional diffusion models published (e.g., Smith 1967, Okubo and Pritchard 1969).

Assuming radiallysymmetric diffusion, the concentration (C) changes generally as follows (Talbot 1970):

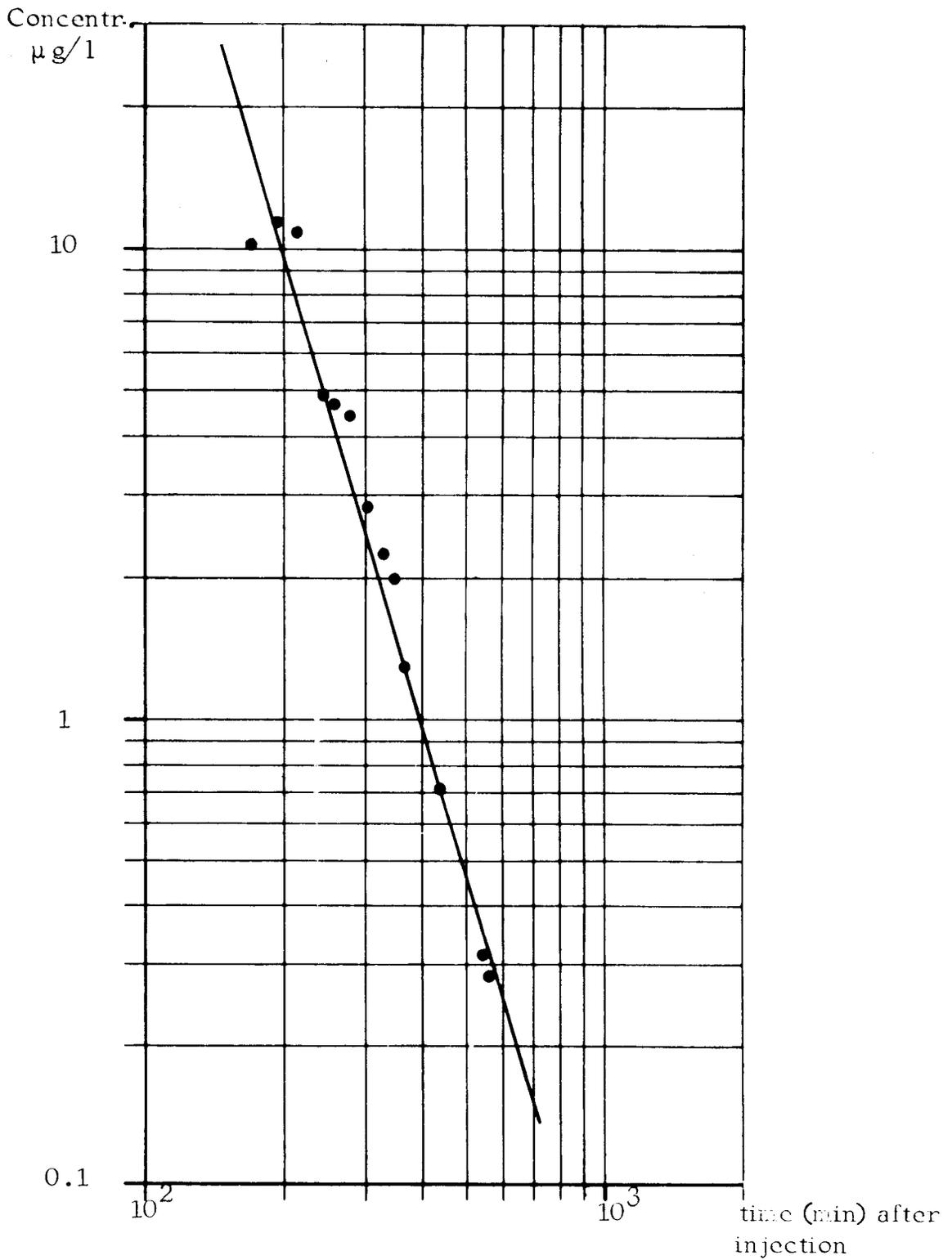


Fig.8.15.Variation in maximum concentration with time for an instantaneous release of 2 kg. Rhodamine B (23 June 1971)

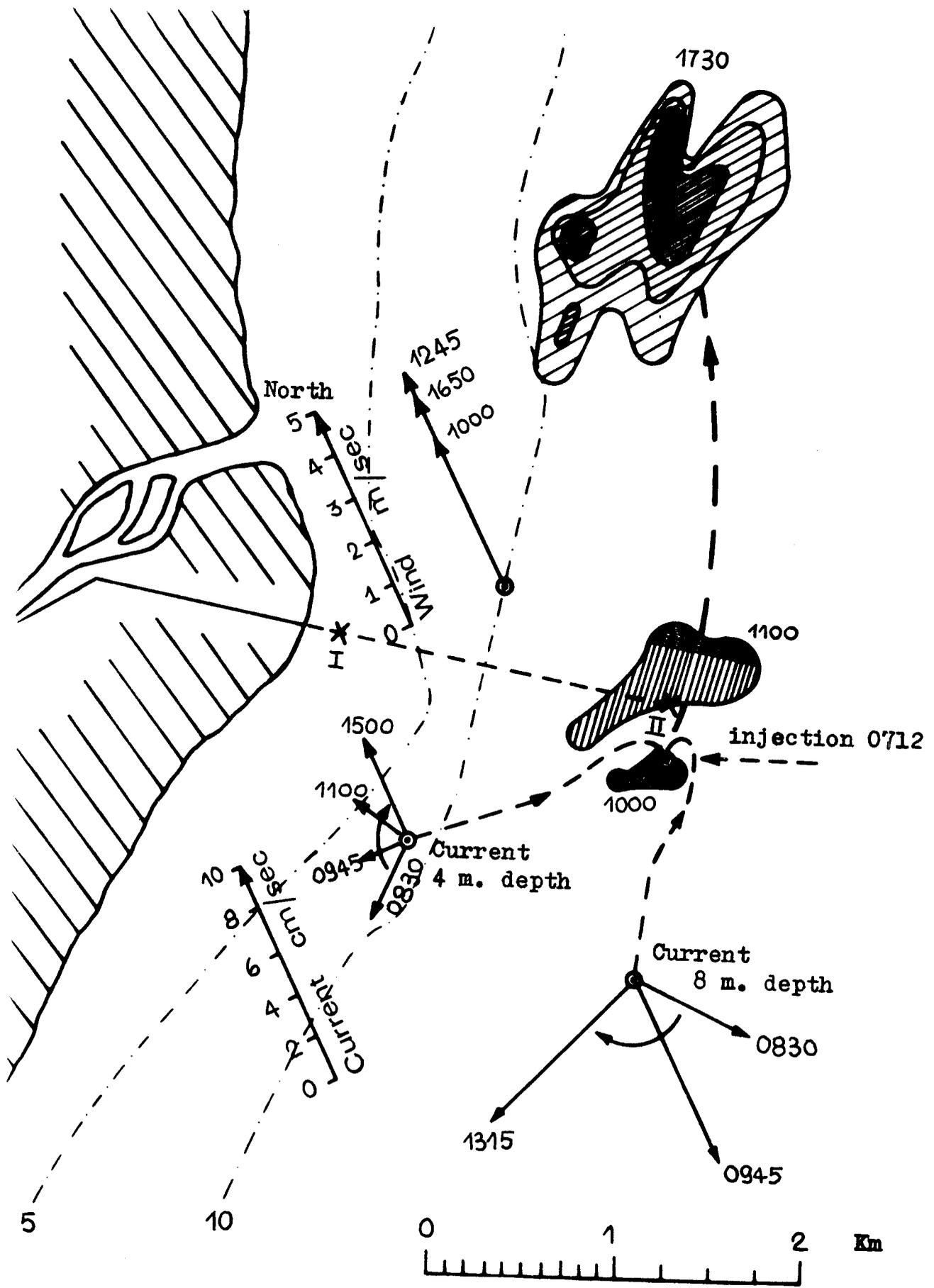


Fig. 8.16. Movement of instantaneous release of Rhodamine B and current and wind directions. Wind directions are shown in direction of air flow (24 June 1971)

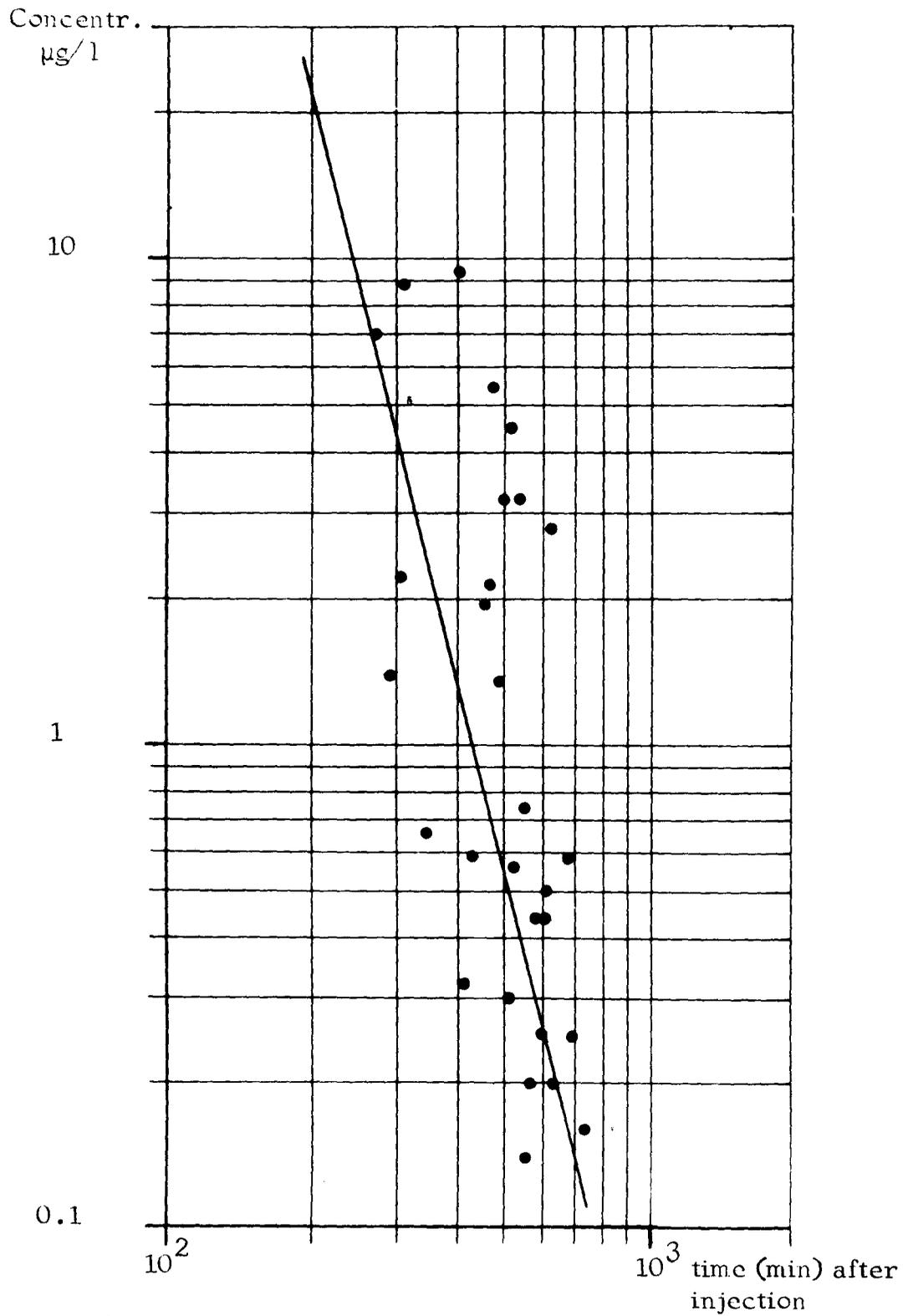


Fig.8.17, Variation maximum concentration with time for a single release of about 2.2 kg. of Rhodamine B (24 June 1971)

$$C(r,t) = C(0,t) \exp[-b(t) r^m] \quad (14)$$

where  $r$  is the distance of the observation point from the centre of the tracer mass,  $b$  is a function of time,  $m$  is an arbitrary constant such that  $0 < m \leq 2$  and the function  $C(C, t)$  describes the behaviour of maximal concentration in time.

The function  $\exp[-b(t) r^m]$  describes the spatial distribution of the dye at a fixed time.

In the models used  $C(C, t) = A t^{-n}$ , where  $n$  assumes values from one to three.

The solution for  $n = 1$  corresponds to the Fickian one. Since, however, this model assumes a constant diffusion coefficient, while the observations suggest an increase in the diffusion coefficient with increasing spot size, the Fickian model is not considered here (Smith, 1967).

For  $n = 2$  two solutions have been suggested:

$$C(r,t) = \frac{M}{2\pi\rho^2 t^2} \exp\left(-\frac{r}{\rho t}\right) \quad (15)$$

(Joseph-Sendner, 1958).

$$C(0,t) = \frac{M}{\pi\omega^2 t^2} \cong \frac{1500g/600cm}{3.14 \cdot 1^2 \cdot 200 \cdot 60^2} \cong 5.5 \mu g Rh/l \quad (16)$$

(Okubo-Pritchard, 1969)

where  $\omega$  ( $\sim 1$  cm/sec) and  $\rho$  ( $\sim 1.5$  cm/sec) are the "diffusion velocities".

$M$  corresponds to  $Q/D$ , where  $Q$  is the quantity of tracer released instantaneously into a water column of a depth  $D$ .

Our observations suggest solutions with  $n = 3$ , which corresponds to the models proposed by Obukhov (1965), Okubo (1962), and Ozmidov (1965).

However, it should be noted that our data were collected after the breeze had accelerated the diffusion. Before the beginning of the breeze the diffusion observed was much slower. Therefore we chose to select a more conservative diffusion model, i.e., a model with  $n = 2$ .

Let us compare the data from measurements with values calculated from models for  $n = 2$ .

In the first release (Fig. 8.12) the Rhodamine (Rh) moved from the point of release at 6 m total depth towards the beach. At the end of the experiment the depth was about 3 m.

Utilising Okubo and Pritchard's model (see equation 16) for the maximum concentration  $C(C, t)$ , with  $\omega = 1$  cm/sec, and  $t = 200$ /min we obtain :

$$C(0, t) = \frac{M}{\pi \omega^2 t^2} \cong \frac{1500 \mu / 600 \text{ cm}}{3.14 \cdot 1^2 \cdot 200 \cdot 600} \cong 5.5 \mu \text{g Rh} / \ell \quad (17)$$

The measurements gave about double the value, i.e., 12  $\mu\text{g Rh}/\ell$ . This higher concentration formed in situ is due to the fact that during the first two hours the diffusion was very slow. After 450 min the spot was situated at about 400 m from the coastline at about 3 m depth. Hence the theoretical concentration is:

$$C(0, t) = \frac{1500 / 400}{3.14 \cdot 1^2 (450 \cdot 60)^2} = 1.6 \mu \text{g Rh} / \ell \quad (18)$$

while the measurements resulted in 0.7  $\mu\text{g Rh}/\ell$ . The part of the spot which came very near to the beach diluted much less since there the depth was only 1 m, the measurement showing 4  $\mu\text{g Rh}/\ell$  against 6.4

calculated.

The second release (Fig. 8.14, 8.15), at 2 100 m from the coast and 12 m depth, gave the following values for  $t = 200$  min:

$$C(0,t) = \frac{2075/1200}{3.14 \cdot 1 \cdot (1200)^2} = 3.8 \mu\text{g Rh/l} \quad (19)$$

against  $9.5 \mu\text{g Rh/l}$  measured. For  $t = 600$  min:

$C(0,t) = 0.42 \mu\text{g Rh/l}$  against  $0.25 \mu\text{g/l}$  measured.

The 'n = 2 - model' gives reasonably good results, despite the fact that the initial concentrations, i.e., those immediately after the release, are undervalued.

Let us now take into consideration the spatial distribution of the dye. Equation (14) can be written as:

$$\ln \frac{C(C,t)}{C(r,t)} = b(t) r^m \quad (20)$$

For a fixed time  $C(C,t)$ ,  $C(r,t)$  and  $r$  can be determined from the curves of equal concentration. These curves will not be circles but, if we smooth out the curve by calculating the radius of the circle which has the same area as that enclosed by a curve of equal concentration, we can calculate the equivalent radius,  $r$ , of such an area. Figs. 8.18 and 8.19 show the results if the data are plotted on logarithmic scales according to equation (20). The slope of the linear graphs corresponds to  $m$ . As can be seen, the observed points result in  $m = 1.07$  and  $0.75$ . The equations of Joseph-Sendner thus best describe our observations. From diffusion measurements carried out over days after the release, Talbot (1970) come to similar conclusions.

#### Application of the Joseph-Sendner model to a continuous release

For a continuous and constant release we obtain for a steady

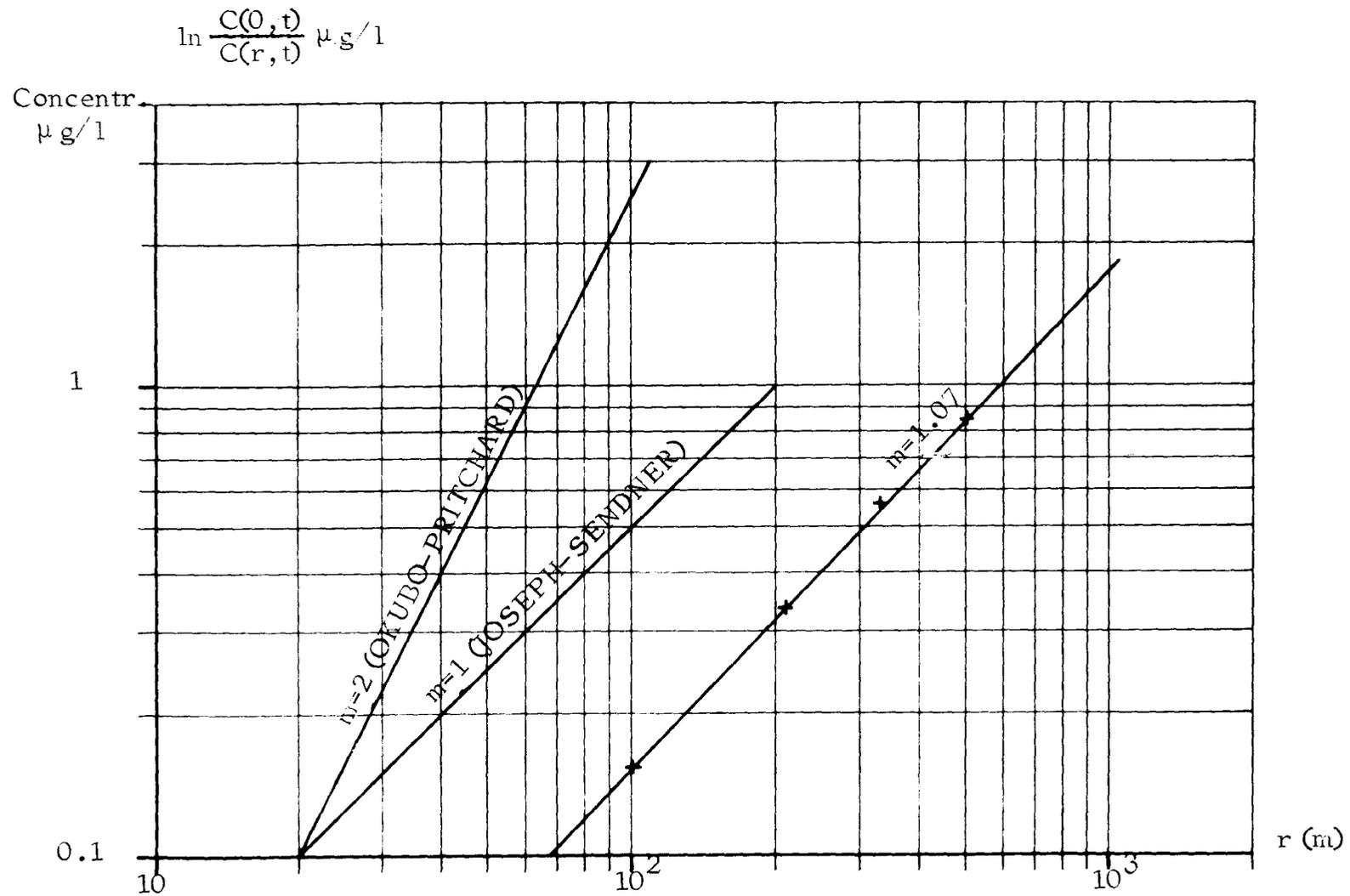


Fig.8.18. Graph illustrating the diffusion behaviour comparing the slope with the Joseph-Sendner and Okubo-Pritchard models (29 June 1971) 9 hours after release

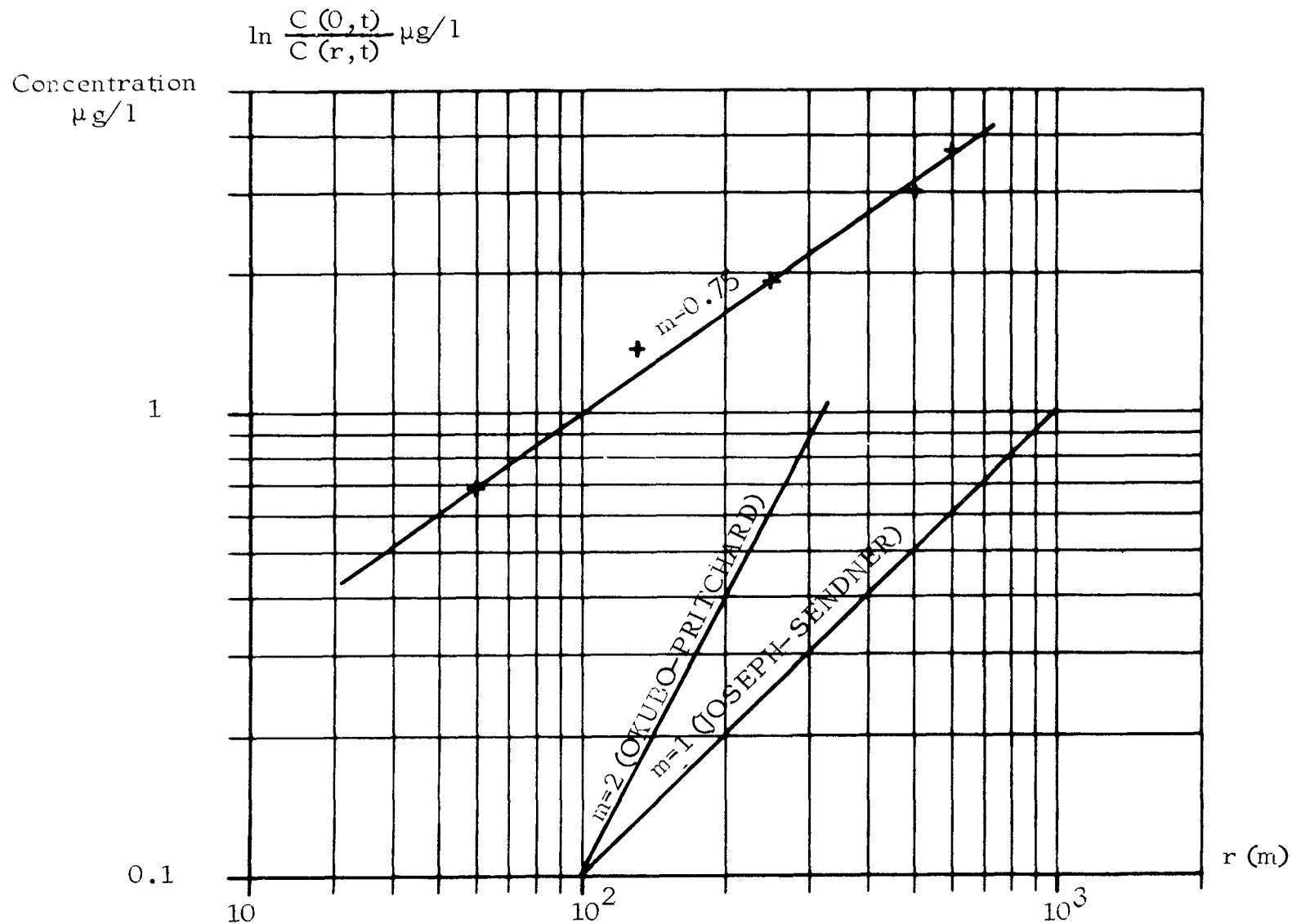


Fig.8.19. Graph illustrating the diffusion behaviour comparing the slope with the Joseph-Sendner and Okubo-Pritchard models (24 June 1971) 10 hours after release

state (Pritchard et al, 1966):

$$C_c(r, t) = \lim \int_0^t Q(t') C_1 [r(t-t')] dt' \quad (21)$$

where  $Q(t')$  is the quantity of activity released per second (Ci/sec) at the time  $t'$  and  $C_1$  the concentration (Ci/m<sup>3</sup>) of the release for an instantaneous release of 1 Ci.

Assuming  $Q(t') = \text{constant}$  and applying equation 15, we obtain:

$$C_c(r, t) = \frac{Q}{D \pi \rho r} \quad (22)$$

In the case of a continuous release at steady state, the maximal concentration at the coast will be

$$C_c(d, t) = \frac{Q}{2 D \pi \rho d} \quad (23)$$

where  $d$  is the distance of the release from the coast.

The influence of the coastline on the diffusion can be simulated by an imaginary symmetrical release at the same distance from the coast as the actual release (Benedetti et al, 1970). This results in a double concentration of the activity at the coast:

$$C_c(d, t) = \frac{Q}{D \pi \rho d} \quad (24)$$

If the location of the release is sufficiently far enough from the coast, the coastline effect can be neglected when the concentration is calculated far away from the coast.

With the help of equation 15 it is possible to calculate a mean

concentration over an area around the release point:

$$\bar{C}_c(r_1, r_2) = \frac{1}{r_2 - r_1} \int_{r_1}^{r_2} C_c(r, t) dr = \frac{Q \ln(r_2/r_1)}{D 2 \pi \rho (r_2 - r_1)} \quad (25)$$

where  $r_1$  is the inner distance from the release point and  $r_2$  the outer distance.

The values are only significant at a certain distance from the release point since mechanical dilution by means of jets etc., will, of course, cause a more rapid dilution near the release point than the diffusion phenomenon can accomplish alone.

By way of illustration we may calculate the mean concentration between 10 and 100 m from the two releases planned, and between 100 and 1000 m for the release farther from the coastline, assuming  $\beta = 1.5$  cm/sec and  $Q$  expressed in Ci/sec:

$$\bar{C}_c(10m - 100m) = \frac{Q}{D 2 \pi \rho} = \frac{2.3}{90m} = \frac{Q}{D} 0.27 \text{ Ci/m}^3 \quad (26)$$

$$C_c(100m - 1000m) = \frac{Q}{D 2 \pi \rho} = \frac{2.3}{900m} = \frac{Q}{D} 0.027 \text{ Ci/m}^3 \quad (27)$$

Summarizing the results for the different zones, we obtain the results shown in Table 8.1 for  $Q = 1$  Ci/year.

Calculations carried out before the data of the dye experiment were available were based (Benedetti et al, 1970) on the Okubo-Pritchard equation for continuous release:

$$C_{\text{coast}} = \frac{Q}{\sqrt{\pi} \omega D r} \quad (28)$$

**Table 8.1** Radionuclide concentration in seawater ( $C_i/m^3$ ) and sorption ( $C_i/m^2 \times 1 \text{ cm}$ ) and deposition ( $C_i/m^2$ ) on sediments

	Max. values near coast (Joseph-Sendner model)		Mean values computed by Joseph-sendner model			
	Conc. $C = \frac{Q}{D 2 \pi r z}$ $C_i/m^3$	Sorpt. 1) in sed. 1) $d = C_i k_d \cdot 10^{-2}$ ( $C_i/m^2$ )	$C(r_1, r_2) = \frac{Q}{D 2 \pi r} \frac{\ln(r_2/r_1)}{(r_2 - r_1)}$			
Continuous release of one radiois. ( $C_i/y$ )	Conc. in SW $C (10, 100)$ ( $C_i/m^3$ )	Sorpt. 1) in sed. 1) $d = C (10, 100) \times 10^{-2} k_d$ ( $C_i/m^2$ )	Conc. in SW $C (100, 1000)$ ( $C_i/m^3$ )	Sorpt. 1) in sed. 1) $d = C (100, 1000) \times 10^{-2} k_d$ ( $C_i/m^2$ )	Conc. in SW $C (100, 1000)$ ( $C_i/m^3$ )	Sorpt. 1) in sed. 1) $d = C (100, 1000) \times 10^{-2} k_d$ ( $C_i/m^2$ )
release at 200 m offshore	( $D = 1 \text{ m}$ ) $C = 3.4 \times 10^{-9}$	$d = 3.4 \times 10^{-11} k_d$	( $D = 3 \text{ m}$ ) $C = 2.9 \times 10^{-9}$	$d = 2.9 \times 10^{-11} \times k_d$	—	—
release at 2000 m offshore	( $D = 6 \text{ m}$ ) $C = 0.56 \times 10^{-10}$	$d = 0.56 \times 10^{-12} \times k_d$	( $D = 12 \text{ m}$ ) $C = 7.1 \times 10^{-10}$	$d = 7.1 \times 10^{-12} \times k_d$	$C(100, 1000) = 7.1 \times 10^{-11}$	$d = 7.1 \times 10^{-13} k_d$

1) Sorption was calculated for  $1 \text{ m}^2$  and  $1 \text{ cm}$  thickness of the sediment

Table 8.1 (contd.)

Mean values computed for the eddy compartment model (10x10km)		
Concentration in SW	Deposition on sediments	Sorption in sediments
$\bar{c} = \frac{K_i}{V(K_7 + \lambda)}$ <p>(Ci/m<sup>3</sup>)</p>	$\bar{d} = \frac{K_6 K_i}{S\lambda(\lambda + K_6 + K_7)}$ <p>(Ci/m<sup>2</sup>)</p>	$\bar{d} = c \cdot 10^{-2} K_d$ <p>(Ci/m<sup>2</sup>)</p>
$\bar{c} = \frac{10^{-9}}{1,5(\lambda+4)}$	$\bar{d} = \frac{10^{-8}}{\lambda \left[ 1 + \left( \frac{\lambda + 4}{0,07 v_d} \right) \right]}$	$\bar{d} = \frac{10^{-11} K_d}{1,5(\lambda+4)}$
$\bar{c} = \frac{10^{-9}}{1,5(\lambda+4)}$	$\bar{d} = \frac{10^{-8}}{\lambda \left[ 1 + \left( \frac{\lambda + 4}{0,07 v_d} \right) \right]}$	$\bar{d} = \frac{10^{-11} K_d}{1,5(\lambda+4)}$

where D is the depth and r the distance of the coast from the release point.

Dividing equation (28) with the one derived from Joseph-Sendner (22) one obtains:

$$\frac{C(\text{OKUBO-PR})}{C(\text{JOSEPH-S})} = \frac{\pi \rho}{\sqrt{\pi} \omega} \cong \sqrt{\pi} \frac{1.3}{1} \sim 2.7 \quad (29)$$

This means that the values calculated with the Okubo-Pritchard model prior to the availability of the experimental data were only three times as high as the values based on the experimental data presented here. Finally, if the concentration calculated with the diffusion model for the area  $r_1 = 100$  m and  $r_2 = 1000$  m are compared with the compartment model, in which the presence of a stationary eddy in front of the Trisaia Centre was assumed, one notes that the compartment model predicts higher concentration than the diffusion model.

However, it should be pointed out that a stationary eddy is a very conservative assumption, since here we assume that the activity released is transported back to the release point, with only small exchange with the remaining waters of the Gulf.

The experiments with Rhodamine have clearly shown that the activity can be transported straight onto the shore by certain wind and currents direction ( Fig. 8.12).

#### Estimation of the "limiting capacity"<sup>6)</sup> of the outfall area

On the basis of the two models (eddy model and Joseph-Sendner model) proposed, the receptivity of the outfall area off the Trisaia Nuclear

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<sup>6)</sup>The limiting capacity of an environment refers to its capacity to receive specified radioisotopes without exceeding the maximum permissible dose to the general public as recommended by the ICRP standards.

Centre has been estimated.

From the information available on the eating habits of certain individuals and groups of persons living in the area, a conservative estimation of the amount of fishery products consumed arrives at a maximum of 1 kg of fish per day. Molluscs are also eaten but not in such large amounts (maximum 50 g/day).

On the basis of these consumption rates the maximum permissible concentration of a single radioisotope in seawater can be calculated using two different methods, one based on the 'Concentration Factor Approach' and another one on the 'Specific Activity Approach'.

The relative merits of both approaches have been discussed elsewhere (Bernhard, 1970).

The estimation of  $\text{Sr}^{90}$  is given here as an example of the two calculations:

$\text{Sr}^{90}$  (bone) MPC<sub>W</sub> 1 p Ci  $\text{Sr}^{90}$ /ml

General public factor  $10^{-2}$

Water intake  $2.2 \times 10^3$  ml/d

ICRP General public max

Daily intake  $1 \times 10^{-2} \times 2.2 \times 10^3 =$

22 p Ci  $\text{Sr}^{90}$ /d

Max consumption rate 1 kg fish/day

Max concentration in 1 kg of fish

22 p Xi  $\text{Sr}^{90}$ /kg

CF =  $\text{Sr}^{90}$  fish/  $\text{Sr}^{90}$  SW = 7

MPC in SW : 22/7

~ 3 p Ci  $\text{Sr}^{90}$ /l

The limiting capacity is taken to mean the capacity on the basis of the appropriate dose limits for man without deliberate safety factors. If this limiting capacity is reduced to a lower capacity while taking into consideration relevant scientific, social, economic and political factors, we arrive at the 'stipulated capacity' (IAEA Panel Principles for limiting the Introduction of Radioactive Waste into the Sea, Vienna, 9-13 November 1970).

MP body burden (bone)	2 000 000 p Ci Sr <sup>90</sup> / 7 000 g FW
General public factor 10 <sup>-2</sup>	
Weight of bone 7 000 g	
MP body burden per g	
$\frac{2\,000\,000 \times 10^{-2}}{7\,000} =$	2.86 p Ci Sr <sup>90</sup> / g FW

Stable Sr conc. in bone:	
0.000015 g Sr/g FW	
Maximal spec. act.	
$\frac{2.86 \text{ p Ci}}{1.5 \times 10^{-5} \text{ g Sr}} =$	$\frac{191\,000 \text{ p Ci Sr}^{90}}{\text{g Sr}}$
Stable Sr conc. in SW	
0.009 g/l	
MPC in SW = 191 000 x 0.009	$\frac{1\,700 \text{ p Ci Sr}^{90}}{\text{l SW}}$

Table 8.2 shows the values of both approaches for a certain number of the most important radioisotopes. With a few exceptions the Specific Activity Approach gives lower MPCs. However, it should be borne in mind that the Specific Activity Approach needs data on the chemical composition of human organs which as such are not yet available for the elements such as Nb, Zr, Ru, Ce, etc. Also, very often the gastrial-intestinal tract is the critical organ and in this case the Specific Activity Approach cannot be applied.

Table 8.3 therefore shows the MPCs in seawater (MPC<sub>SW</sub>) calculated with the Concentration Factor Approach from the MPC for the critical organs of single isotopes. By using the relative frequencies of the radioisotope mixture proposed by the user of the plant (see Table 8.4), one can calculate the irradiation for external exposure due to the concentration of  $\gamma$  emitters in sediments.

The  $\gamma$  dose for single isotopes was calculated according to Slade

Table 8.2. Comparison between the "Concentration Factor Approach" (CFA) and "Specific Activity Approach" (SAA) for the estimation of the maximal permissible concentration (MPC) for single radionuclides in Seawater

isotopes	organs	MPC pCi/ml <sup>w</sup>	CF <sup>2)</sup> fish	body burden pCi	weight of organ <sup>3)</sup> g FW	stable element		MPC <sub>sw</sub> in pCi/l SW		CFA SAA
						e/e FW	g/l SW	CFA	SAA	
H <sup>3</sup>	Total body*	50 000	1	2.10 <sup>9</sup>	70 000	0.1	111	1 100 000	317 100	3.47
Sr <sup>89</sup>	Bone*	100	7	4.10 <sup>6</sup>	7 000	1.5.10 <sup>-5</sup>	0.009	314	3 400	0.09
Sr <sup>90</sup>	Bone*	1	7	2.10 <sup>6</sup>	7 000	1.5.10 <sup>-5</sup>	0.009	3	1 700	0.00176
Y <sup>91</sup>	Bone	300 000	30	5.10 <sup>6</sup>	7 000	<10 <sup>-10</sup>	3.10 <sup>-7</sup>	220 000	>21 420	<10.27
Nb <sup>95</sup>	Total body <sup>1)</sup>	4 000 000	100	4.10 <sup>7</sup>	70 000	7.10 <sup>-7</sup>	~10 <sup>-6</sup>	880 000	0.52	1 692 307
Zr <sup>95</sup>	Total body <sup>1)</sup>	1 000 000	30	2.10 <sup>7</sup>	70 000	<8.5.10 <sup>-8</sup>	~9.10 <sup>-10</sup>	730 000	>3	<243 333
Ru <sup>103</sup>	Kidney	30 000	3	2.10 <sup>7</sup>	300	<10 <sup>-7</sup>	8.10 <sup>-10</sup>	220 000	>530	<415
Ru <sup>106</sup>	Kidney	4 000	3	3.10 <sup>6</sup>	300	<10 <sup>-7</sup>	8.10 <sup>-10</sup>	29 000	>0.8	<36 250
I <sup>131</sup>	Thyroid*	20	20	7.10 <sup>5</sup>	20	3.5.10 <sup>-4</sup>	6.10 <sup>-5</sup>	21.6	60	0.36
Cs <sup>137</sup>	Total body*	200	30	3.10 <sup>7</sup>	70 000	<1.4.10 <sup>-10</sup>	3.10 <sup>-7</sup>	146	>9 200	<0.016
Ce <sup>141</sup>	Liver	3 000 000	30	3.10 <sup>7</sup>	1 700	<1.10 <sup>-12</sup>	5.10 <sup>-9</sup>	2 200 000	>802 000	<2.74
Ce <sup>144</sup>	Bone	80 000	30	5.10 <sup>7</sup>	7 000	<1.10 <sup>-12</sup>	5.10 <sup>-9</sup>	59 000	>357 100	<0.165
Pm <sup>147</sup>	Bone	500 000	100	6.10 <sup>7</sup>	7 000	--	--	110 000	--	--
Zn <sup>65</sup>	Total body*	1 000	8 000	6.10 <sup>7</sup>	70 000	3.3.10 <sup>-5</sup>	10 <sup>-5</sup>	2.75	8,2	0.335
Fe <sup>55</sup>	Spleen*	8 000	5 000	10 <sup>9</sup>	150	3.3.10 <sup>-4</sup>	10 <sup>-5</sup>	35.1	5 128	0.0068
Fe <sup>59</sup>	Spleen	600	5 000	2.10 <sup>7</sup>	150	3.3.10 <sup>-4</sup>	10 <sup>-5</sup>	2.64	102	0.026
Co <sup>60</sup>	Total body	1 000	5 000	10 <sup>7</sup>	70 000	<4.3.10 <sup>-8</sup>	10 <sup>-7</sup>	4.4	3,3	1.33
Mn <sup>54</sup>	Liver	4 000	10 000	2.10 <sup>7</sup>	1 700	1.3.10 <sup>-6</sup>	2.10 <sup>-6</sup>	8.8	305	0.029

\*critical organs

1) the concentrations in seawater for Zr and Nb are estimations

2) CF concentration factor

3) FW fresh weight

Table 8.3.

Calculation of maximal permissible concentration ( $MPC_{SW}$ ) estimated from MPC in drinking water ( $MPC_W$ ) values for critical organs

Elements	critical organ	Concentration factor Fish	$MPC_W$ pCi/ml	$MPC_{SW}$ pCi/l
H <sup>3</sup>	total body	1	50000	1100000
Sr <sup>89</sup>	bone	7	100	314
Sr <sup>90</sup>	bone	7	1	3
Y <sup>91</sup>	G.I.T.	30	300	220
Nb <sup>95</sup>	G.I.T.	100	1000	220
Zr <sup>95</sup>	G.I.T.	30	600	440
Ru <sup>103</sup>	G.I.T.	3	800	5867
Ru <sup>106</sup>	G.I.T.	3	100	733
I <sup>131</sup>	thyroid	20	20	22
Cs <sup>137</sup>	total body	30	200	146
Ce <sup>141</sup>	G.I.T.	30	900	660
Ce <sup>144</sup>	G.I.T.	30	100	73
Pm <sup>147</sup>	G.I.T.	100	2000	440
Zn <sup>65</sup>	total body	8000	1000	2.75
Fe <sup>55</sup>	spleen	5000	8000	35.1
Fe <sup>59</sup>	G.I.T.	5000	600	2.64
Co <sup>60</sup>	G.I.T.	5000	500	2.2
Mn <sup>54</sup>	G.I.T.	10000	1000	2.2

Table 8.4. Discharge formula for the Trisaia Center proposed by Cevolotto et al.1969

Nuclides	Activities discharged per year	fi (fraction of total discharged activity)
H <sup>3</sup>	450 Ci	0.999
Sr <sup>89</sup>	12 mCi	2.7 x 10 <sup>-5</sup>
Sr <sup>90</sup>	4 mCi	8.9 x 10 <sup>-6</sup>
Y <sup>91</sup>	12 mCi	2.7 x 10 <sup>-5</sup>
Nb <sup>95</sup>	5 mCi	1.1 x 10 <sup>-5</sup>
Zr <sup>95</sup>	12 mCi	2.7 x 10 <sup>-5</sup>
Ru <sup>103</sup>	2 mCi	4.4 x 10 <sup>-6</sup>
Ru <sup>106</sup>	2 mCi	4.4 x 10 <sup>-6</sup>
I <sup>131</sup>	6 µCi	1.3 x 10 <sup>-8</sup>
Cs <sup>137</sup>	5 mCi	1.1 x 10 <sup>-5</sup>
Ce <sup>141</sup>	5 mCi	1.1 x 10 <sup>-5</sup>
Ce <sup>144</sup>	20 mCi	4.4 x 10 <sup>-5</sup>
Pm <sup>147</sup>	7 mCi	1.6 x 10 <sup>-5</sup>
Tot 450.1 Ci		

(1968) considering the exposure to the gonads (1 m from sediments) and assuming that the radioisotopes are dispersed on an infinite surface.

The absorption in water is neglected and the build-up factor is considered.

In Table 8.5 the  $\gamma$  dose is computed on the basis of the  $\gamma$  emitter concentration on the beach for the Joseph-Sendner model.

Column (3) in Table 8.5 gives the distribution of  $\gamma$  emitters in sediments evaluated on the basis of distribution coefficient and concentration at the beach ( $3.4 \times 10^{-9}$   $\mu\text{Ci/ml}$ ) for the Joseph-Sendner diffusion model, assuming a release of 1 Ci/y for each isotope (Cagnetti et al, 1971).

Column (4) in Table 8.5 gives the dose from the  $\gamma$  emitters contained in sediments at the shore, a release of 1 Ci/y being assumed for each isotope.

Column (6) gives the dose from the mixture proposed by the users (Table 8.4).

The total dose for 1 000 h/year of exposure for one Ci/y of the mixture is about  $5.7 \times 10^{-7}$  rad/y.

Considering now that the maximum permissible dose rate is 0.05 rem/y (exposure to gonads for general public), the limiting receptivity for external exposure is:

$$Q_T = \frac{0.05}{5.7 \times 10^{-7}} = 8.7 \times 10^4 \text{ Ci/y of the mixture proposed in Table 8.4.}$$

In the same way one can calculate the limiting receptivity for external exposure for the other assumptions (see summary in Table 8.1) of the Joseph-Sendner diffusion model and for eddy model.

The receptivity estimated from the internal exposure was carried out for the different activities of nuclides in the water predicted by the different models already proposed with the formula:

Tab.8.5. Dose from external radiation of activity accumulated in sediments. (Joseph-S. model)

Nuclides	E Mev	$\overset{\infty}{D}\dot{\gamma}$ rad/sec $1\mu\text{Ci}/\text{m}^2$ $\times 10^{-9}$	$\mu\text{Ci}/\text{m}^2$ Joseph-S. model	$\overset{\infty}{D}\dot{\gamma}$ rad/1000h $\times 10^{-3}$	$f_i$ $\times 10^{-6}$	$f_i \overset{\infty}{D}\dot{\gamma}$ rad/1000h $\times 10^{-8}$
	(1)	(2)	(3)	(4)	(5)	(6)
Nb <sup>95</sup>	0.76	3.5	0.18	2.25	7.5	3.35
Zr <sup>95</sup>	0.72	3.4	0.18	2.2	13.5	6
Ru <sup>103</sup>	0.49	8.4	0.6	1.8	2.2	8
Ru <sup>106</sup>	0.51	2.4	0.6	0.505	2.2	2.2
Cs <sup>137</sup>	0.66	3.2	0.28	3.2	5.5	3.52
Ce <sup>141</sup>	0.142	2.6	1.8	17	5.5	18.7
Ce <sup>144</sup>	0.134	0.55	1.8	3.55	22	15.6

---


$$\sum_i f_i \overset{\infty}{D}\dot{\gamma}_i / 1000\text{h} = 5.737 \times 10^{-7}$$

$$Q_T = \frac{1}{\sum_i \frac{f_i C}{MPC_i SW}}$$

where:

$f_i$  is the relative frequency of the single radionuclides

C the concentration in SW given for different models and for release of  
of 1 Ci/y of each isotope

$MPC_i SW$  maximum permissible concentration of the various radionuclides  
estimated from the MPC in critical organs.

The different estimations of the receptivity are shown in Table  
8.6.

The lowest receptivities (about  $8 \times 10^4$  Ci/y) are estimated from  
the Joseph-Sendner model on the basis of the mean concentration over  
an area of 100 m radius and from the concentration at the beach for the  
'200 m' release. If one considers that marine organisms and fishermen  
will not stay in these limited areas but some of them will move to a larger  
area, we can take into consideration a distance of 2 000 m of each side  
of the pipeline. In this case the prediction for different distances are  
the following:

$C_{0m}$	=	$34 \times 10^{-10}$	$\mu\text{Ci/ml}$
$C_{200 m}$	=	$23 \times 10^{-10}$	$\mu\text{Ci/ml}$
$C_{500 m}$	=	$12 \times 10^{-10}$	$\mu\text{Ci/ml}$
$C_{1000 m}$	=	$6.5 \times 10^{-10}$	$\mu\text{Ci/ml}$
$C_{1500 m}$	=	$4.4 \times 10^{-10}$	$\mu\text{Ci/ml}$
$C_{2000 m}$	=	$3.3 \times 10^{-10}$	$\mu\text{Ci/ml}$

The weighted mean value calculated over 0-2 000 m distance  
( $C_{0-2000}$ ) from the maximum concentration at the beach is  $8 \times 10^{-10} \mu\text{Ci/ml}$   
of seawater. To this value ( $C_{0-2000}$ ) corresponds a receptivity, for the

Tab. 8.6. Preliminary evaluation of receptivity of out-fall area in Ci/y of the mixture proposed in Tab. 10

Evaluation from:	Internal exposure	External exposure
<u>Eddy model</u>		
by mean concentration in SW (see tab. 8.1)	$1.37 \times 10^6$	$1.67 \times 10^6$
<u>Joseph-S. model:</u>		
a) Release at 200 m.		
$\bar{c} = 2.9 \times 10^{-9} \mu\text{Ci/ml}$	$2.5 \times 10^5$	$9.8 \times 10^4$
$C_{\text{beach}} = 3.4 \times 10^{-9} \mu\text{Ci/ml}$	$2 \times 10^5$	$8.7 \times 10^4$
$C_{0, 2000} = 8 \times 10^{-10} \mu\text{Ci/ml}$	$9 \times 10^5$	$3.6 \times 10^5$
b) Release at 2000 m.		
$\bar{c}(10, 100) = 7.1 \times 10^{-10} \mu\text{Ci/ml}$	$3.4 \times 10^5$	$4.05 \times 10^5$
$C(100, 1000) = 7.1 \times 10^{-11} \mu\text{Ci/ml}$	$3.4 \times 10^6$	$4.05 \times 10^6$
$C_{\text{beach}} = 0.56 \times 10^{-10} \mu\text{Ci/ml}$	$4.3 \times 10^6$	$4.83 \times 10^6$

proposed mixture, of  $3.6 \times 10^5$  Ci/y for external exposure, and of  $9 \times 10^5$  Ci/y for internal exposure.

The receptivities evaluated for external exposure are higher than that for internal exposure.

Since there are many uncertainties involved in the data used for the calculations, it seems advisable to reduce the capacity of the outfall area by a factor of 100, arriving at a 'stipulated capacity' of  $3.65 \times 10^3$  Ci/year, which means that initially at least the total quantity discharged according to the proposed formula (Table 8.4) can be only  $3650/450 \approx 8$  times higher.

Further data will probably permit the estimation of higher capacity.

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VESSELS

Our laboratory vessel "Odalisca" has made 36 daily cruises into the sampling zone of La Spezia and Gulf of La Spezia.

Between 11 and 22 January 1971 a hydrographic cruise (Taranto VI) was carried out with the R/V "Bannock" to collect data on the general circulation of the Gulf of Taranto.

Between 11 and 24 June 1971 (Taranto VII) the diffusion of Rhodamine B in the Trisaia release zone (Gulf of Taranto) was studied together with current meter measurements using the fishing vessel "Maria Mafalda".

COLLABORATION AND MEETINGS

Collaboration with Prof. B. Schreiber of the Zoological Institute of the University of Parma continued during 1971, as in previous years.

The thirteenth Contact Group Meeting was held in Monaco on 10-11 May 1971 and was attended by:

GERMANY	1	M. Hoppenheit	Biol. Anstalt	Helgoland
ITALY	2	M. Bernhard	CNEN-EURATOM	Fiascherino
	3	A. Nassogne	" "	"
	4	C. Peroni	" "	"
	5	A. Piro	" "	"
	6	B. Schreiber	Ist. Zoologia-Univ. Parma	
	7	A. Zattera	CNEN-EURATOM	Fiascherino
MONACO	8	G. Benayoun	IAEA	Monaco
	9	S. Aston	"	"
	10	E.K. Duursma	"	"
	11	S.W. Fowler	"	"
	12	M. Heyraud	"	"
	13	J. Joseph	"	"
	14	L. Mayheord	"	"
	15	C.N. Murray	"	"
	16	R. Fukai	"	"
	17	L.F. Small	"	"
NETHERLANDS	18	P. Korringa	N.I.F.I.	Ijmuiden
YUGOSLAVIA	19	M. Branica	IRB-CIM	Zagreb
	20	S. Keckes	"	Rovinj

CONTACT-GROUP-MEETING

Monaco, 10 - 11 May 1971

Morning Session

10. 5 - 10 - 12 30 h

- Opening of the Session
- Discussion of the Agenda
- Review: Zooplankton and marine radioactivity, by Prof. Small

Afternoon Session

10. 5 - 14 30 - 18 00 h

- Discussion of Prof. Small's review
- Other papers on this subject

Morning Session

11. 5 - 9 00 - 12 30 h

- Review: Influence of the physico-chemical form of radionuclides on their biogeochemical cycle, by Dr Fukai
- Discussion of this paper
- Other papers on this subject

Afternoon Session

11. 5 - 14 30 - 18 00 h

- Lecture: A classification and systematization of literature on radiation effects in aquatic organisms, by Dr Hoppenheit
- Preliminary discussion on the topics, place and date of the next Contact Group Meeting.

During 1971 the scientific staff participated in the International Symposium on Radioecology in Rome (7-10 September 1971).

Drs Michael Bernhard, Armand Nassogne and Angelo Piro took part the second ENEA Seminar on Marine Radioecology in Hamburg (20-24 September 1971).

Dr Michael Bernhard, participated as observer in the Panel of "Effects of Ionizing Radiation on Aquatic organisms and Ecosystems" in Vienna (15-18 November 1971).

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RADIOECOLOGY RESEARCH IN THE GULF OF TARANTO

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B. SCHREIBER, L. TASSI PELATI and M.G. MEZZADRI

ANNEX I

The Department of Zoology of Parma University performed, together with the CNEN Laboratory of Fiascherino, several oceanographic cruises in the Gulf of Taranto, on which a wide programme of radioecological research has been under way since 1968.

The evaluation of the radioactivity level in the various marine substrata, such as water, plankton, benthic organisms and sediments, is very useful because it will enable us to determine the increase in radioactivity in the environment after contact with the radionuclides stemming from the first radioactive waste discharges from the Trisaia reprocessing plant.

The discharge formula communicated by the Trisaia NRC includes the following radionuclides:  $H^3$ ,  $Sr^{89}$ ,  $Sr^{90}$ ,  $Y^{91}$ ,  $Nb^{95}$ ,  $Ru^{103}$ ,  $I^{131}$ ,  $Cs^{137}$ ,  $Ce^{141}$ ,  $Ce^{144}$ ,  $Pm^{147}$  (1); moreover, as the above mentioned reprocessing plant was built for the uranium-thorium cycle, it is not unlikely that traces of such radionuclides might be present in the radioactive wastes.

Among the substrata taken into consideration for the radioactivity measurement, sea water, plankton and sediments are particularly important.

The collection zone is shown in Fig. 1. We took into account the belt between the coast line (from Metaponto to Trebisacce)

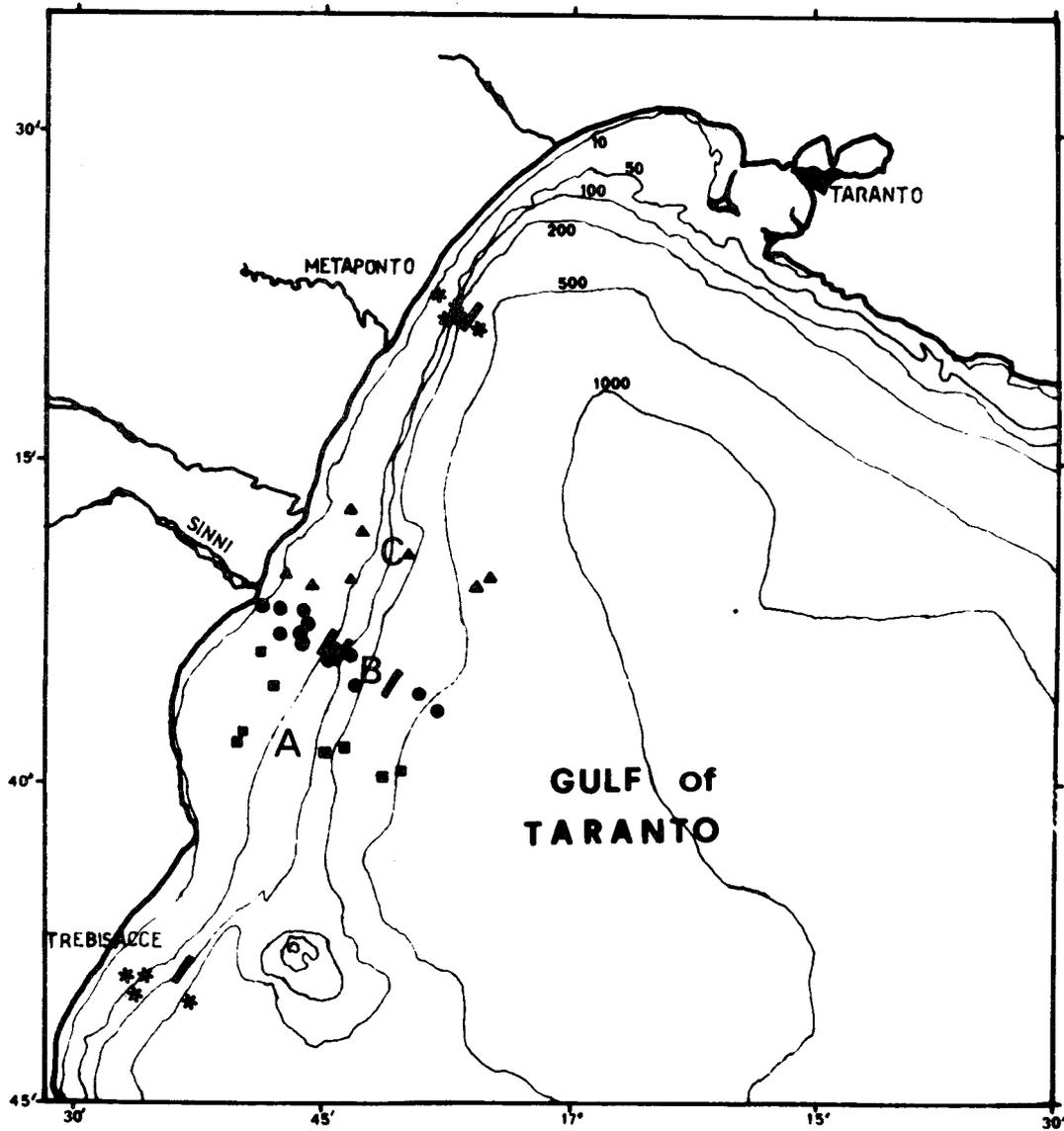


Fig. 1. Zone and stations of sampling (— plankton, ● ▲ ■ \* sediment)

and the isobath of 500 m, which will be the first to be affected by the radioactive discharges.

In January 1971 six plankton samples were collected, the gross beta radioactivity of which was measured as usual.

The gamma spectrometry was not carried out owing to the small size of the samples.

Table 1 shows the results of the plankton radioactivity measurement.

In 1971 we completed the work programme concerning the radioactivity measurement of the sediments collected between 1968 and 1971.

Here we report only the results of the radio-metric measurements and the  $K^{40}$  content. The results of the radiochemical analyses carried out in collaboration with C. Triulzi (CISE, Milan) were reported at the XVII Congress of the AIFSPR, held at Monteporzio Catone <sup>2</sup>.

For a preliminary study of the radioactivity in the superficial layer of the sea-bottom we carried out 65 collections with the mudsnapper.

Forty cores were collected for the study of the radioactivity stratification in the first 20-30 cm of the sea-bottom.

Each sample taken with the mudsnapper was subdivided into two fractions by means of a copper sieve designed to retain the particles smaller than 150  $\mu$ .

The gross fraction ( $>150 \mu$ ) comprises the sand, while the finer fraction ( $\geq 150 \mu$ ) includes the fine sand, silt and clay. As the artificial radionuclides chiefly bind to the silt-clay of the fine fraction, we measured the radioactivity only on a fraction of which the  $K^{40}$  was deter-

Table 1

Gross beta radioactivity data of plankton samples collected on 18-19 January 1971

symbol of sample	sampling station	collection depth (m)	settling ml	dry/settling (g/100 ml)	450°C ash/dry %	cpm/g ash 15 days after collection	R
MP 3 a	40°21'40"N	10	80	1.5	37.5	53	3.5
MP 3 b	16°53'15"E	20	50	2.1	33.3	28	2
TP11 a	40°05'36"N	10	80	1.6	23.1	25	1.7
TP11 b	16°46'15"E	20	70	1.5	28.6	67	3.3
TrP 3a	39°49'45"N	10	70	1.4	25.0	44	2.3
TrP 3b	16°33'30"E	20	50	1.5	26.7	41	2.4

mined also.

Table 2 summarizes the results of the radioactivity study of the superficial layer of the sea-bottom.

The cores were cut into fractions 0.5 cm thick; the separation between gross and fine fraction was not carried out on them, but the radioactivity was measured on an aliquot of the total fraction.

$K^{40}$  was determined by means of flame spectrophotometry.

The gross beta radioactivity measurement was repeatedly carried out at regular intervals, both on samples collected with the mudsnapper and on the fractions of some particularly interesting cores.

Gamma spectrometry was performed on those samples showing the highest values of gross beta radioactivity.

The description of the technical details has been already reported in some works published on the same subject (3, 4).

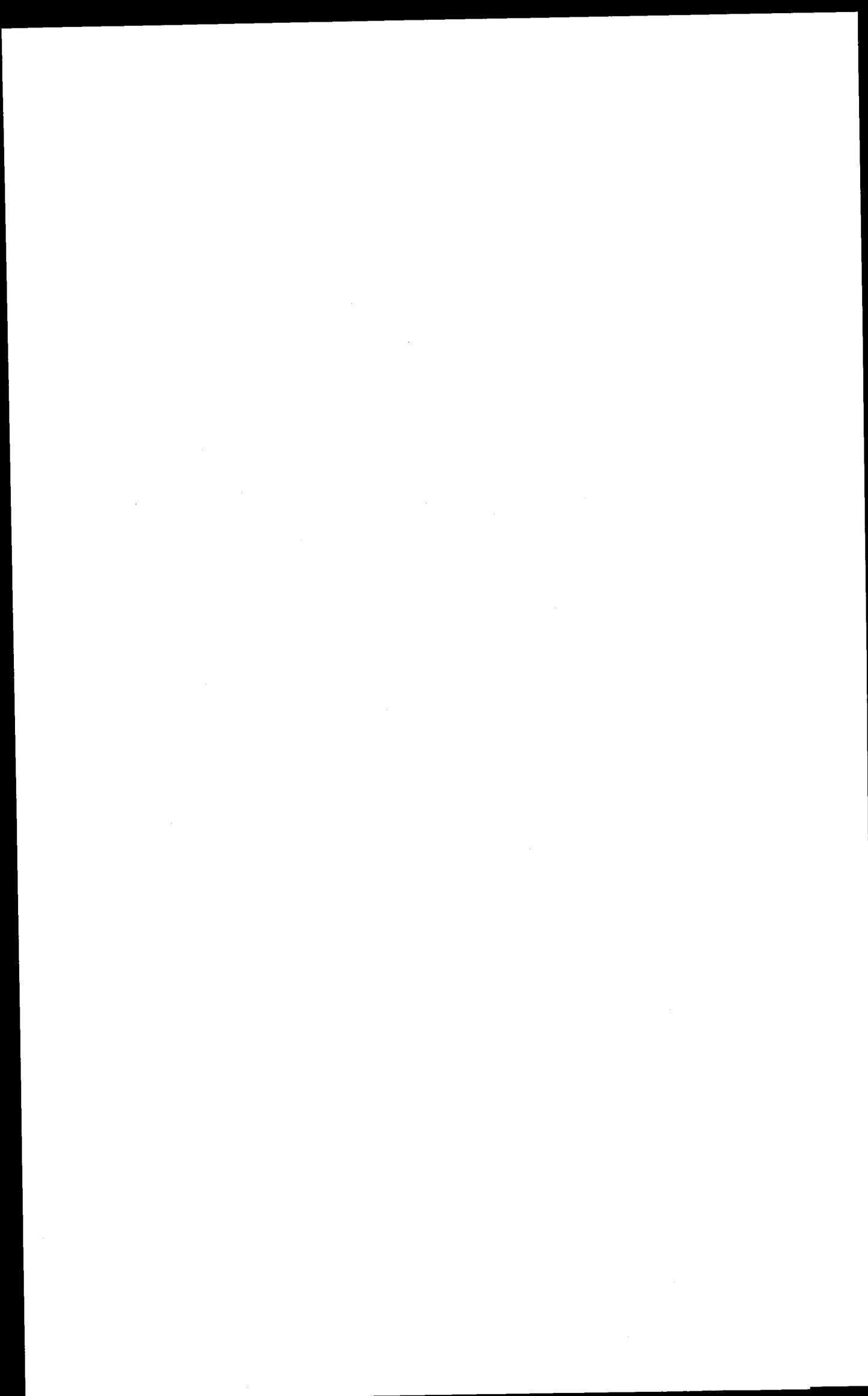
The results of the gross beta radioactivity measurements have been represented, as usual, with the so-called "stratigraphic curves", some of which are drawn in Fig. 2. Table 3 gives the gross beta radioactivity values only of the first cm of each core. Such a table shows also the percentage of fine fraction determined on samples collected with the mudsnapper in the same stations. The influence of the sediment composition on the radioactivity may be evaluated in this way.

#### General remarks

The gross beta radioactivity measurement and the gamma spectrometry of plankton enabled us to observe even

lected in the

			METAPONTO			
C						
depth (m)	pCi/g dry	% fine sediment fraction	symbol of core	depth (m)	pCi/g dry	% fine sediment fraction
11	19	96				
16	19	84				
20	18	81				
30	19	75	MC 1	25	19	95
47	18	87	MC 5	40	19	100
220	23	100	MC 2	180	22	100
235	21	100	MC 4	192	20	92
510	25	100	MC 3	350	22	100
530	21	97				



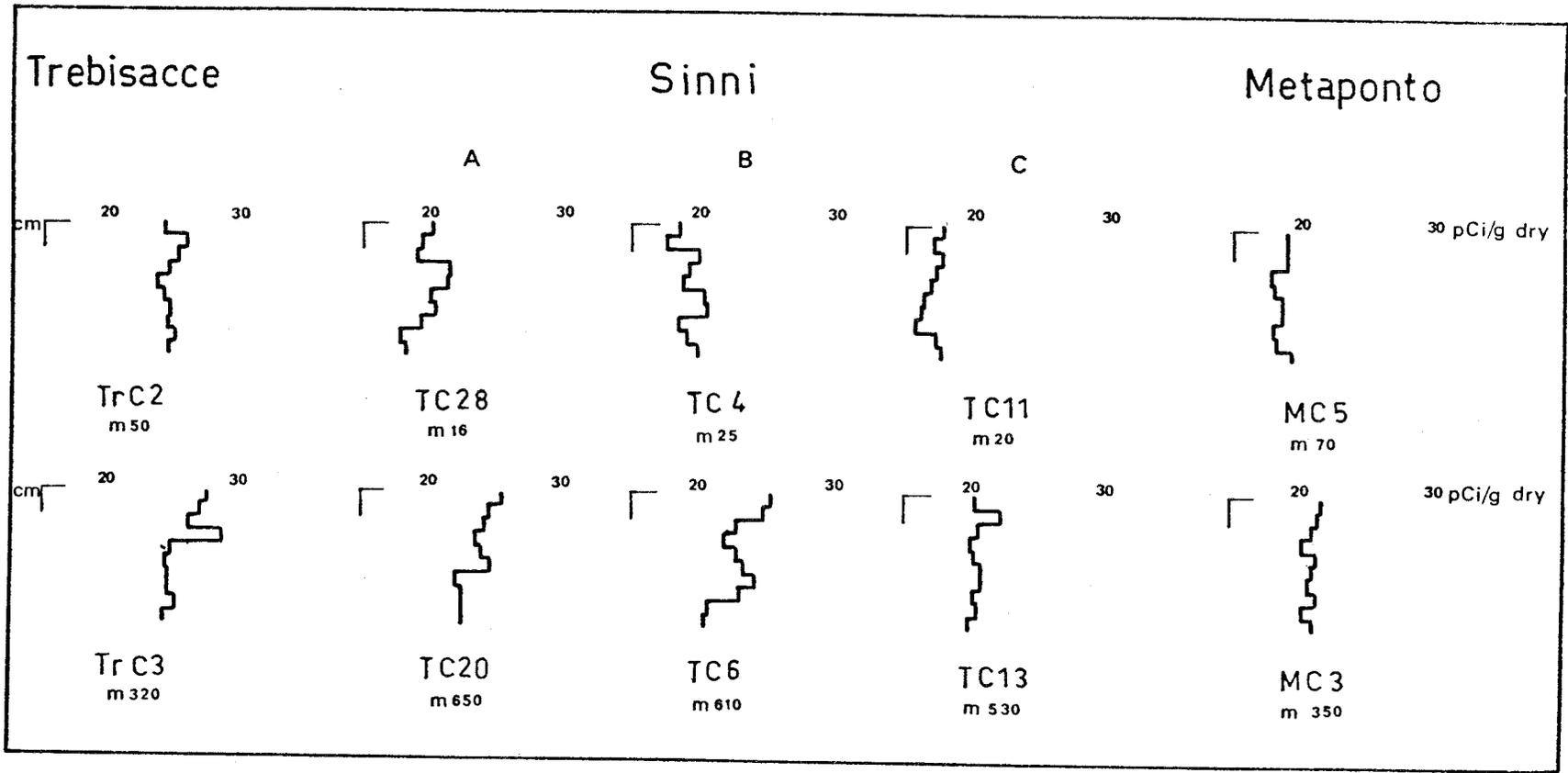


Fig. 2. Gross beta radioactivity trend in some cores

Table 3

Mean level of radioactivity (pCi/g dry) in sediment of the Gulf of Taranto

Depth (m)	Zone	Sinni			Metaponto
	Trebisacce	A	B	C	
10 - 50	24.0	20.2	18.4	18.6	19.0
50 - 500	26.5	25.5	24.3	22.5	21.3

small variations in the radioactive contamination in the sea due to fallout (5). Plankton is therefore the best substratum for monitoring purposes.

The measurements for 1971 point to a certain decrease in the radioactive contamination of marine environment compared with 1969-70. The value of "R" obtained from the ratio between the activity measured 15 days after collection and that measured 200 days after collection shows a certain diversity in the composition of the mixture of radionuclides present in the plankton. We previously remarked that where R is  $> 2$  we have a fresh fallout with many short-lived radionuclides; where R is  $< 2$  there are long-lived radionuclides, both artificial and natural.

We would reiterate our observation that the sedimentary material captures the radionuclides dispersed or dissolved in the surrounding water, retaining them more or less firmly (6). Consequently the radioactive rare earths disappear with a certain speed from the sea water, whereas radiostrontium and radiocaesium remain in solution.

The deposition rate of the various radionuclides on the sea-bottom is thus a useful parameter for the evaluation of the environmental receptivity (7, 8).

We therefore think that the measurement of the sediment radioactivity before and during the radioactive discharges from the Trisaia reprocessing plant could in fact supply these data.

From the gross beta measurement of the marine sediment collected in the above-mentioned zone, with a higher frequency in the zone facing the Sinni River, we can state that no variation in the radioactivity took place between 1968 and 1971.

By means of the chemical analysis of K and gamma spectrometry, we have been able to indicate the magnitude of the natural radioactivity. Only by means of the radiochemical analysis of big samples it was possible to find and determine the amount of some artificial radionuclides (2). The data in Table 2 reveal a certain discrepancy between values relevant to the sediment beyond the 50 m isobath and those within such an isobath.

Moreover it seems to be possible to subdivide the zone facing the Sinni River into three sectors, A, B and C, on the grounds of a variation in the radioactivity with decreases from C to A. The analysis of the variance in the values in Table 2 with regard to the three sectors shows a difference significant for 97.5 %; the difference is significant for 99.9 % if we compare the radioactivity values within the 50 m isobath with those beyond such an isobath.

The different values of the sea-bottom radioactivity depending on the depth and place of the various sectors are also shown in Table 3. The data reported there were obtained by averaging those in Table 2.

We therefore consider that part of the radioecological study of the Gulf of Taranto is nearly complete as we know the value of the radioactivity due to beta and gamma emitter radionuclides in the chief marine substrata before the beginning of the radioactive waste discharges.

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ANNEX II

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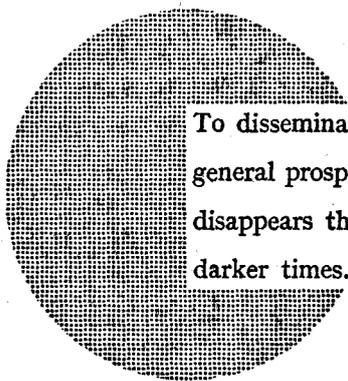




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