MEDITERRANEAN ACTION PLAN

MED POL

UNITED NATIONS ENVIRONMENT PROGRAMME

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

PROBLEMS OF COASTAL TRANSPORT OF POLLUTANTS (MED POL VI)

PROBLEMES DU TRANSFERT DES POLLUANTS LE LONG DES COTES (MED POL VI)

FINAL REPORTS OF PRINCIPAL INVESTIGATORS
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This volume is the sixth issue of the Mediterranean Action Plan Technical Reports Series.

This Series will collect and disseminate selected scientific reports obtained through the implementation of the various MAP components: Pollution Monitoring and Research Programme (MED POL), Blue Plan, Priority Actions Programme, Specially Protected Areas and Regional Oil Combating Centre.

Ce volume constitue le sixième numéro de la série des Rapports techniques du Plan d'action pour la Méditerranée.

Cette série permettra de rassembler et de diffuser certains des rapports scientifiques établis dans le cadre de la mise en oeuvre des diverses composantes du PAM: Programme de surveillance continue et de recherche en matière de pollution (MED POL), Plan Bleu, Programme d'actions prioritaires, Aires spécialement protégées et Centre régional de lutte contre la pollution par les hydrocarbures.

INTRODUCTION

The United Nations Environment Programme (UNEP), in co-operation with the relevant specialized United Nations Agencies (FAO, WHO, WMO, IOC) , presented to the Intergovernmental Meeting of Mediterranean countries (Barcelona, 1975) a proposal for a Co-ordinated Mediterranean Pollution Monitoring and Research Programme (MED POL).

MED POL was approved and UNEP was requested to implement the Programme, consisting of seven pilot projects, in close collaboration with the relevant specialized United Nations Agencies.

Its pilot phase (MED POL-Phase I) was designed as the precursor of a long-term programme for pollution monitoring and research in the Mediterranean (MED POL-Phase II) to be carried out according to the provisions of the legal component of the Mediterranean Action Plan.

The pilot projects approved at the 1975 Barcelona Meeting as parts of MED POL-Phase I were:

- MED POL I: Baseline Studies and Monitoring of Oil and Petroleum Hydrocarbons in Marine Waters
- MED POL II: Baseline Studies and Monitoring of Metals, particularly Mercury and Cadmium, in Marine Organisms
- MED POL III: Baseline Studies and Monitoring of DDT, PCBs and Other Chlorinated Hydrocarbons in Marine Organisms
- MED POL IV: Research on the Effects of Pollutants on Marine Organisms and their Populations
- MED POL V: Research on the Effects of Pollutants on Marine Communities and Ecosystems
- MED POL VI: Problems of Coastal Transport of Pollutants
- MED POL VII: Coastal Water Quality Control

Subsequent to the 1975 Barcelona Meeting, several other projects were added or considered as collaterals to MED POL to broaden the scope of the programme and to provide the necessary support to it. They were:

- MED POL VIII: Biogeochemical Studies of Selected Pollutants in the Open Waters of the Mediterranean
- MED POL IX: Role of Sedimentation in the Pollution of the Mediterranean Sea
- MED POL X: Pollutants from Land-Based Sources in the Mediterranean

MED POL XI: Intercalibration of Analytical Techniques and Common Maintenance Services

MED POL XII: Input of Pollutants into the Mediterranean Sea through the Atmosphere

MED POL XIII: Modelling of Marine Systems

Participants in the pilot projects were national research centres designated by the States participating in the Mediterranean Action Plan.

The co-ordination of the MED POL-Phase I (1975-1981) was carried out by UNEP as a part of the Mediterranean Action Plan (MAP).

The following United Nations Co-operating Agencies were responsible for the technical implementation of various pilot projects :

- The Food and Agriculture Organization of the United Nations (FAO) through the General Fisheries Council for the Mediterranean (GFCM) (MED POL II, III, IV and V),
- The United Nations Educational, Scientific and Cultural Organization (UNESCO) (MED POL IX and XIII),
- The World Health Organization (WHO) (MED POL VII and X),
- The World Meteorological Organization (WMO) (MED POL XII),
- The International Atomic Energy Agency (IAEA) (MED POL VIII and XI) and
- The Intergovernmental Oceanographic Commission (IOC) of UNESCO (MED POL I and VI)

This volume of the MAP Technical Reports Series is the collection of final reports of the Principal investigators who participated in the pilot project : "Problems of Coastal Transport of Pollutants (MED POL VI)".

INTRODUCTION

Le Programme des Nations Unies pour l'environnement (PNUE), en coopération avec les organismes spécialisés compétents des Nations Unies (FAO, OMS, OMM, COI), a présenté à la Réunion intergouvernementale des pays méditerranéens (Barcelone, 1975), une proposition de Programme coordonné de surveillance continue et de recherche en matière de pollution dans la Méditerranée (MED POL).

Le MED POL a été approuvé, et il a été demandé au PNUE de mettre en oeuvre le programme qui se compose de sept projets pilotes, en étroite collaboration avec les organismes spécialisés compétents des Nations Unies.

Sa phase pilote (MED POL - Phase I) a été conçue comme le prélude d'un programme à long terme de surveillance continue et de recherche en matière de pollution dans la Méditerranée (MED POL - Phase II) à mettre en oeuvre conformément aux dispositions de l'élément juridique du Plan d'action pour la Méditerranée.

Les projets pilotes approuvés à la Réunion intergouvernementale de Barcelone, en 1975, dans le cadre de la Phase I du MED POL, comprenaient:

MED POL I: Etudes de base et surveillance continue du pétrole et des hydrocarbures contenus dans les eaux de la mer

MED POL II: Etudes de base et surveillance continue des métaux, notamment du mercure et du cadmium, dans les organismes marins

MED POL III: Etudes de base et surveillance continue du DDT, des PCB et des autres hydrocarbures chlorés contenus dans les organismes marins

MED POL IV: Recherche sur les effets des polluants sur les organismes marins et leurs peuplements

MED POL V: Recherche sur les effets des polluants sur les communautés et écosystèmes marins

MED POL VI: Problèmes du transfert des polluants le long des côtes

MED POL VII: Contrôle de la qualité des eaux côtières

A la suite de la Réunion de Barcelone de 1975, plusieurs autres projets ont été adjoints ou considérés comme subsidiaires au MED POL en vue d'étendre la portée du programme et de lui assurer l'appui indispensable. Ce sont:

MED POL VIII: Etudes biogéochimiques de certains polluants au large de la Méditerranée

MED POL IX: Rôle de la sédimentation dans la pollution de la mer Méditerranée

MED POL X: Polluants d'origine tellurique dans la Méditerranée

MED POL XI: Inter-étalonnage des techniques d'analyse et services communs d'entretien

MED POL XII: Polluants d'origine tellurique dans la Méditerranée

MED POL XIII: Modélisation des systèmes marins

Les participants aux projets pilotes étaient des centres nationaux de recherche désignés par les Etats prenant part au Plan d'action pour la Méditerranée.

La coordination de MED POL - Phase I (1975-1981) a été assumée par le PNUE dans le cadre du Plan d'action pour la Méditerranée.

Les organismes coopérants des Nations Unies qui étaient chargés de l'exécution technique des divers projets pilotes sont les suivants:

- Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO) par l'entremise du Conseil général des pêches pour la Méditerranée (CGPM) (MED POL II, III, IV et V).

- Organisation des Nations Unies pour l'éducation, la science et la culture (UNESCO) (MED POL IX et XIII).

- Organisation mondiale de la santé (OMS) (MED POL VII et X).

- Organisation météorologique mondiale (OMM) (MED POL XII).

- Agence internationale de l'énergie atomique (AIEA) (MED POL VIII et XI), et

- Commission océanographique intergouvernementale (COI) de l'UNESCO (MED POL I et VI).

Ce volume de la série des Rapports techniques du PAM rassemble les rapports finaux des chercheurs responsables qui ont participé au projet pilote intitulé: "Problèmes du transfert des polluants le long des côtes (MED POL VI)".

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Research Centre: Fisheries Department, Ministry of Agriculture and Natural Resources, Nicosia, Cyprus

Principal Investigator: A. DEMETROPOULOS - L. ATHANASSIADOU

INTRODUCTION:

The report has been updated to include results obtained up to March 1980. The Department has been active in studies related to the coastal transport of pollutants as part of a survey carried out in Morphou Bay to investigate the extent of pollution and the transportation of materials that were being discharged untreated directly into the sea from mining of copper and iron pyrites in the area.

The study of coastal currents by the use of Woodhead sea-bed drifters has been continued also during 1979. Furthermore, recording Aanderaa current meters have been deployed in Akrotiri Bay. Measurements of various environmental parameters have been made. These include dissolved oxygen, salinity, suspended solids, water temperature, transparency and sediments. For two of the stations, data on nitrite and nitrate are available from two cruises. Also, data on some selected meteorological parameters are available.

AREA(S) STUDIED:

Limassol Bay faces south with Cape Gata in the west sheltering it from the westerly winds. On the Bay is Limassol, a town of about 65,000 inhabitants and light industries which include mainly wine and spirit and soft drink factories. The total amount of waste water entering the Bay was 194,000 tons in 1976, and 210,000 in 1977. Pollution load from industries, measured as BOD_5, was estimated at 238 tons in 1976 and 271 tons in 1977. Sources of inflow of fresh water are very limited coming mainly from the run-off rivers. The continental shelf of the Bay has a gentle slope becoming steeper near Cape Gata. The sea bed is sand with shingle near the beach, becoming sandy further offshore. The marine life of the area is characterized by soft-bottom communities with a fair variety of species and relatively low abundance. Episkopi Bay on the other hand has been studied for purposes of comparison. It lies west of the Akrotiri peninsula and is a relatively unpolluted area free from direct effluent discharges. There is no habitation close to the sea. The bottom morphology and the marine life of the area are similar to those of Limassol Bay. A map showing the area is given in figure 1.

MATERIAL AND METHODS:

Currents were measured with locally made drogues in Akrotiri (Limassol) Bay (figure 1). Two series of experiments were conducted: the first during a cruise from 25 to 28 November 1977, and the second on 24 January 1979. For the first cruise, three sections were chosen: one near Amathus Beach Hotel (stations 1, 2 and 3); one near the new port of Limassol (stations 4, 5, 6 and 7); and the third at Cape Gata (stations 8, 9 and 10). Releases were made at 5, 15 and 25 fathoms depth (a fathom is six feet or just under 2 m), and on the harbour section drifters were also released at a depth of 50 fathoms. For the second experiment the drifters were released in Akrotiri Bay at 9 somewhat different stations from those used earlier. The new stations were at three sections crossing the depth contours of 5, 10 and 15 fathoms and between the cement factory and Limassol (figure 1). A self-addressed card was attached to the drifter, printed in Greek and English requesting the finder to complete pertinent information and return the card with the drifter to the Department. Cards and drifters were serially numbered for identification. The first Aanderaa recording current meter was moored in April 1979 in Akrotiri Bay and the second in January 1980. Thereafter, it will be moored again in the same place continuously for at least one year. Meteorological observations were kindly provided by the Meteorological Service of the Ministry of Agriculture and Natural Resources.

RESULTS AND THEIR INTERPRETATION:

Table I shows the currents measured by drogues between 26 June 1975 and 11 October 1976. The observed speeds were generally greater farthest from the shore. There was some tendency for the deeper drogues to move at a lower speed than those released at or near the sea surface. Table II shows the releases of 360 sea-bed drifters between 25 and 28 November 1977, and the recoveries. Of the 360 sea-bed drifters released only 29 were recovered; 8.1 per cent. Station 1 had the most recoveries: 23 or 25.6 per cent of those released at that station. The drift was approximately 3.4 nautical miles eastward, but one drifter travelled eastward approximately 11 nautical miles, reaching the Zygi area. Of the 270 drifters released in the second experiment only 52 were recovered; 19.3 per cent. The greatest number of recoveries (16 drifters or 5.9 per cent) was of those released at station 1, which is positioned at the 5 fathom contour. Owing to the short distance travelled by those drifters and the fact that the recovery area was not always adequately described, no firm conclusions were drawn from this experiment (see also table III). Three tapes with data have been obtained from the recording current meters. As the preliminary treatment of these data is not yet concluded, the results will be reported later.

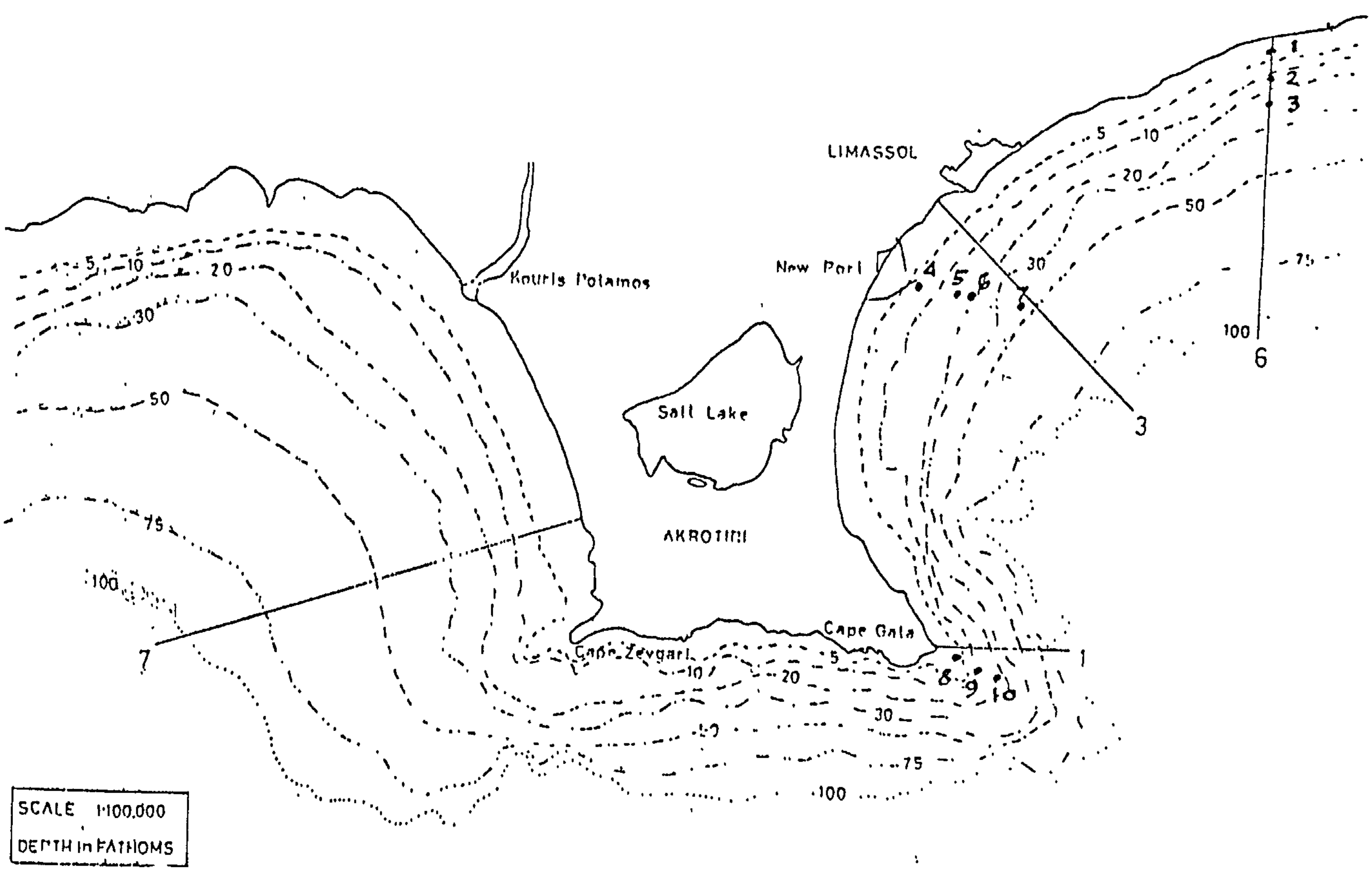


Fig. 1. Map showing the area studied. Four section (1, 3, 6 and 7) for hydrographic sampling are shown, as well as the ten sea-bed drifter-release stations on 25-28 November 1977

Table I : Currents estimated by drogues in 1975 and 1976

Station number	Date	Drifter number	Drifter depth of release-ft.	Current Velocity direction	Current Velocity speed cm/sec	Wind Direction	Wave height ft.
1	26/6/75	1	0	SW	14.7	N	1/2
		2	10	NW	1.6		
		3	20	SW	14.8		
		4	30	SW	12.0		
2	1/7/75	1	0	NW	7.8	SW	1
		2	10	W	2.8		
		3	20	SW	4.6		
		4	30	SW	5.8		
3	17/10/75	1	0	SW	50.2	SW	Calm
		2	10	NW	10.5		
		3	20	SW	3.8		
		4	30	NW	8.2		
4	18/11/75	1	0	NW	7.4	-	Calm
		2	10	NW	5.9		
		3	20	NW	4.2		
		4	30	NW	2.3		
5	2/12/75	1	0	N	3.0	S	
		2	10	NW	6.7		
		3	20	N	1.9		
		4	30	NE	1.8		
6	4/8/76	1	0	NW	39.4	SW	Calm
		2	10	NW	32.5		
		3	20	NW	28.4		
		4	30	NW	25.8		
7	5/8/76	1	0	SE	31.2	SW	1
		2	10	NE	9.1		
		3	20	SE	35.5		
		4	30	SE	20.0		

Table I : Currents estimated by drogues in 1975 and 1976 (cont'd/..2)

Station number	Date	Drifter number	Drifter depth of release-ft.	Current Velocity direction	Current Velocity speed cm/sec	Wind Direction	Wave height ft.
8	13/8/76	1	0	W	7.6	-	Calm
		2	10	W	6.8		
		3	20	W	2.7		
		4	30	SW	1.9		
9	27/8/76	1	0	NE	14.2	-	
		2	10	NE	10.0		
		3	20	N	8.1		
		4	30	NE	5.6		
10	11/10/76	1	0	SW	24.0	S	-
		2	10	SW	22.6		
		3	20	SW	22.6		
		4	30	SW	20.5		

Table II : Data obtained from the release of Woodhead sea-bed drifters during Cruise No. 1, 25 - 28 November 1977

Station data	Drifter No.	Recovery Date	Recovery Area	Days adrift	Remarks
St.1 Drifters Nos 1-90 released at a depth of 5 fm. on 25 Nov. 1977	1	1 Dec.77	Moni Station	7	
	6	6 Dec.77	Cement Factory	9	
	6	6 Dec.77	Moni	9	
	10	11 Dec.77	Moni	17	
	12	11 Dec.77	Moni	17	
	17	11 Dec.77	Moni	17	
	31	11 Dec.77	Moni	17	
	35	6 Dec.77	Cement Factory	9	
	36	11 Dec.77	Moni	17	
	49	11 Dec.77	Moni	17	
	54	7 Dec.77	Moni	10	
	57	6 Dec.77	Cement Factory	9	
	58		E Cement Factory		
	62	6 Dec.77	Cement Factory	9	
	66	6 Dec.77	Cement Factory	9	
	70	17 Dec.77	W Cement Factory	23	
	72		E Cement Factory		
	75		E Cement Factory		
	79	11 Dec.77	Ayia Barbara Limassol	17	
	84	2 Apr.78	500m E of Zygi	128	
	87	6 Dec.77	Cement Factory	9	

Table II : Data obtained from the release of Woodhead sea-bed drifters during Cruise No. 1, 25 - 28 November 1977 (cont'd/..2)

Station data	Drifter No.	Recovery Date	Recovery Area	Days adrift	Remarks
	89	22 Jan.78	Zygi	58	
	90	6 Dec.77	Cement Factory	9	
St.2 Drifters Nos. 301-330	315	5 Dec.77	Amathus 36 fm	8	Fished out (Trawler)
St.3 Drifters Nos. 331-330	332	5 Dec.77	Amathus 36 fm	8	Fished out (Trawler)
25 fm 28 No.77	350	5 Dec.77	Limassol harbour 35 fm	8	Fished out (Trawler)
St.4 Drifters Nos. 91-120			NO RETURNS		
St.5 Drifters Nos. 15 fm 25 Nov.77	146	29 Nov.77	Limassol harbour	4	Fished out (Fishing boat)
	149	20 Dec.77	Cement factory	26	Fished out (Trawler)
St.6 Drifters Nos. 151-180			NO RETURNS		
St.7 Drifters Nos. 181-210 50 fm 25 Nov.77			NO RETURNS		
St.8 Drifters Nos. 211-240 5 fm 25 Nov.77	237	8 Dec.77	Cape Gate	14	Fished out (Fishing boat)
St.9 Drifters Nos. 241-270 15 fm 25 Nov.77			NO RETURNS		
St.10 Drifters Nos. 271-300 25 fm 25 Nov.77			NO RETURNS		

Table III : Data obtained from the release of Woodhead sea-bed drifters during Cruise No. 2, 24 January 1979

Station Data	Drifter No.	Recovery Date	Recovery Area	Days Adrift	Remarks
St. No.1 Drifters Nos.	361		Cement Factory		Fished out at 15 fm
361-390 fm	362	10 Feb.79	E Cement Factory	18	
	365	10 Feb.79	Moni	18	
	367	10 Feb.79	Moni	18	
	368	10 Feb.79	Moni	18	
	372	10 Feb.79	Moni	18	
	373	18 Feb.80	Cement Factory	391	
	374	10 Feb.79	Moni	18	
	375	10 Feb.79	Moni	18	
	377	10 Feb.79	Moni	18	
	378	10 Feb.79	Moni	18	
	379	10 Feb.79	Moni	18	
	380	10 Feb.79	Moni	18	
	382	8 Mar.79	Cement Factory	16	
	383	10 Feb.79	Moni	18	
	385	26 Feb.79	Moni	34	
	387	10 Feb.79	E Cement Factory	18	
	390		Cement Factory		Fished out at 12 fm
St. No.2 Drifters Nos. 391-420 10 fm			NO RETURNS		
St. No.3 Drifters Nos. 241-450 15 fm			NO RETURNS		

Table III : Data obtained from the release of Woodhead sea-bed drifters during Cruise No. 2, 24 January 1979 (cont'd/..2)

Station Data	Drifter No.	Recovery Date	Recovery Area	Days Adrift	Remarks
St. No.4 Drifters Nos.	453	9 Feb.79	Old Limassol Area	17	
451-480 5 fm	454	9 Feb.79	Old Limassol Area	17	
	455	12 Feb.79	Old Limassol Area	20	
	462	25 Feb.79	Agia Barbara L/ssol	33	
	466	15 Jan.80	Moni	357	
	480	9 Feb.79	Old Limassol Area	17	
St. No.5 Drifters Nos.	493	3 Feb.79	Cement Factory		Fished out at 30 fm
481-510 10 fm	504	29 Jan.79	Amathus Cement Factory		Fished out at 13 fm
St. No.6 Drifters Nos.	511	2 Feb.79	Limassol-Cement Factory		Fished out at 35 fm
511-540 15 fm	514	2 Feb.79	Limassol-Cement Factory		Fished out at 35 fm
	515	2 Feb.79	Limassol-Cement Factory		Fished out
	517		Zygi		Fished out
	519	2 Feb.79	Limassol-Cement Factory		Fished out
	524	2 Feb.79	Limassol-Cement Factory		Fished out
	526	3 Feb.79	Cement Factory		Fished out
	530	2 Feb.79	Limassol-Cement		Fished out
	536	3 Feb.79	Cement Factory		Fished out

Table III : Data obtained from the release of Woodhead sea-bed drifters during Cruise No. 2, 24 January 1979 (cont'd/..3)

Station Data	Drifter No.	Recovery Date	Recovery Area	Days Adrift	Remarks
St. No.7 Drifters Nos.	542	1 Apr.79	High Chaparal Rest Area	68	
541-570 5 fm	546	17 Nov.79	Ladies Mile?	298	
	547	11 Feb.79	High Chaparal	19	
	548	5 Dec.79	Amathus-Posidonia Ht.	316	
	549	9 Nov.79	Amathus-Posidonia Ht.	290	Fished out at 9 fm
	550	11 Feb.79	High Chaparal	19	
	554	10 Feb.79	High Chaparal	18	
	558	9 Nov.79	Amathus	290	Fished out at 9 fm
	562	23 Feb.79	High Chaparal	31	
	563	11 Feb.79	High Chaparal	19	
	566	11 Feb.79	High Chaparal	19	
	569	21 Feb.79	High Chaparal	29	
St. No.8 Drifters Nos. 571-600 10 fm			NO RETURNS		
St. No.9 drifters Nos.	611	3 Feb.79	Cement Factory		Fished out by trawler
601-630 15.fm	619	3 Feb.79	Cement Factory		Fished out by trawler
	621		Zygi		Fished out by trawler
	629	15 Feb.79	Moni		Fished out by trawler

Research Centre: Institute of Oceanography and Fisheries
Mediterranean Branch
ALEXANDRIA
Egypt

Principal Investigator: M. A. Gerges

INTRODUCTION:

The report has been updated to the end of March 1980. The Mediterranean Branch of the Institute of Oceanography and Fisheries at Alexandria has been participating in the MED POL VI pilot project since mid-1976. However, the regular investigation, relevant to the problems of coastal transport, actually started in January 1977. These investigations consisted of two major components: direct current measurements and hydrographic surveys have been carried out monthly in the investigated area. Only the direct current measurements are discussed here. For 1977 and part of 1978, data for some selected meteorological parameters are also available.

AREA(S) STUDIED:

The area selected for MED POL VI investigations extends for about 70 kilometres along the coast and for a distance of about 35 kilometres seaward (to a water depth of about 100 m). This covers the area from El-Max, west of Alexandria to Rashid near Rosetta at the mouth of the River Nile. This area receives almost all of the pollutants in this part of the Egyptian Mediterranean coast.

The four main sources of pollutants in the areas are:

Area	Source of pollution
El-Max	Western harbour, fishing boats, oil from harbour and more expected from the oil pipe lines.
Alexandria	Eastern harbour, fishing boats, sewage.
Abu Qir	Industrial wastes, discharges from Lake Idku (agricultural drainage), fishing boats.
Rashid	Nile river discharge.

Figure 1 shows the area studied, including the current-meter mooring sites and the hydrographic stations.

The release stations for the drifter experiments are not indicated on this Figure since they are numerous and scattered all over the coast, in and outside the investigated area.

MATERIAL AND METHODS:

Monthly releases of Woodhead plastic surface drifters, carrying driftcards were made from May 1976 to November 1977, except in September and October 1976. The releases were made at 55 stations along the Egyptian Mediterranean coast, where 2,650 drifters were released.

The procedure is described in the paper: "Drift methods for studying surface currents and some preliminary results of Egyptian experiments in the Mediterranean", by M. A. Gerges, and included in the document IOC-UNEP/DRIFTEX - ad hoc - 1/3 (1976). The data have been analysed using a computer programmme developed at the Instituto de Investigationes Pesqueras in Barcelona by A. Cruzado and J. Salat.

In June 1978, three experiments were made to measure sub-surface currents in Abu Qir Bay at three stations A, B and C (Fig. 1) using moorings with Aanderaa recording current meters. Two current meters were deployed. The upper one was mounted at about 5 m below the sea surface to measure the near-surface currents. The lower one was fixed about 3 m above the bottom to measure the near-bottom currents. The processed data are not yet available for interpretation.

At a later stage the current meters were deployed at two sites near Port-Said about 25 km off the coast and in about 20 m of water. Altough these sites are located outside the MED POL VI investigation area, they do present some interest regarding the question of transport of pollutants from that region near the Suez Canal to other parts of the Egyptian coast. Simultaneous observations of wind and hydrographic parameters were made for correlation with the current measurements.

Four parallel hydrographic stations were taken in a NW direction normal to the coast. On each of these sections four hydrographic stations were occupied; measurements were made at depths of about 15, 25, 50, and 100 meters.

Salinity and temperature were measured at these standard depths. The depth to the bottom was recorded, and the surface wind speed and direction were obtained using a hand anemometer. Salinity determinations were made using a Beckman induction salinometer.

The following information was also collected at each station during the hydrographic surveys: air temperature, air pressure, cloudiness, sea state and wave height (visual); transparency (Secchi disc reading and water colour), and dissolved oxygen at selected depths and stations.

The four cruises were timed to give seasonal coverage: winter (January); spring (May); summer (July); and autumn (October-November).

RESULTS AND THEIR INTERPRETATION:

I. MEASUREMENTS OF SURFACE CURRENTS USING DRIFTERS.

The following table gives the number of drifters released during each monthly experiment from November 1976 to March 1977, the number of cards received and the percentage recovery for each month for the whole period.

Month	No. of Drifters released	No. of cards received	Percentage recovery
November 1976	194	42	21.6
December 1976	190	11	5.7
January 1977	85	17	20.0
February 1977	140	31	22.1
March 1977	99	30	30.0
Total	708	131	18.5

Rough computations of both speed and direction of surface currents in the investigated area were made. These estimated velocities were tabulated and the drift routes were plotted on maps.

Taking the later data (a further 1842 drifters released) the percentage recovery over-all was about 20 per cent.

Some drifters, which were released away from the coast, travelled long distances to the east, obviously under the influence of the main eastward flow of the general cyclonic circulation in the eastern Mediterranean. Others drifted towards the coast and became stranded on beaches within a short period of time, ranging from a few hours to a few days, indicating a strong onshore component of the surface drift. The results also revealed great monthly variabilities in speed and direction of the surface currents. These variabilities could be correlated with the prevailing meteorological conditions. They were, in most cases, attributed to corresponding changes in the speed and direction of the wind over the investigated area.

The data have been processed using the computer programme mentioned earlier. This programme actually provides real and theoretical trajectories according to certain programme criteria, including those based on prevailing meteorological conditions.

The main results from the 1977 measurements, giving the general features of the surface circulation, could be summarized as follows:

(i) Winter (November to February)

The transport in the offshore area (20-25 kms from coast) is directed mainly toward the east at an average velocity of 13 cm/ sec, apparently under the influence of the main eastward flow circulating the Eastern Mediterranean as a part of the general circulation in this basin. The transport closer to the coast indicates the existence of a westward current of an average velocity ranging from 3 to 8 cm/sec.

(ii) Early spring (March and April)

An eastward surface current exists in the region between Abu Qir Head and Rosetta with the velocities ranging between 2 cm/sec. and 20 cm/sec., with an average of 4 cm/sec. In the meantime, to the west of Abu Qir Head, there is a westward current with a velocity between 3 and 19 cm/sec and average velocity of 9 cm/sec.

(iii) The transitional month of May

An obvious reversal in the direction of the surface transport relative to the preceeding month is clearly indicated. Westward and southward currents exist almost everywhere in the area with an average velocity of about 10 cm/sec.

(iv) Summer (June to August)

Apparently, the westward current continues during the summer time in the area between Rosetta and Alexandria. However, there was an indication that a strong onshore component of the surface drift exists and influences the transport in the area to the west of Abu Qir Head.

(v) Autumn (September and October)

Generally weak eastward currents start to appear in the area, and a transport in this direction at an average velocity of 3 cm/sec was indicated particularly in the near-shore region. However, there was usually clear evidence of a strong onshore component of the coastal currents with a small south-eastward or south-westward drift; occasionally there are westward currents to the west of Abu Qir.

II. MEASUREMENTS OF SUBSURFACE CURRENTS USING FIXED CURRENT METERS

As mentioned above, the data from the measurements in the Abu Qir Bay are not yet available for discussion.

Preliminary analysis of the current measurements in the Port-Said area indicated that mean currents near the surface were fluctuating in the range 2-17 cm/sec, and current directions varied from north-easterly to south-easterly over the period of observation. Near-bottom currents were generally weaker and fluctuating within a smaller amplitude. (2-12 cm/sec). As the velocities and directions of the near-surface and near-bottom currents, respectively, showed co-variation only during some periods, the effects of water stratification on the currents is being studied.

Publications based, totally or partly, on the work covered by this report:

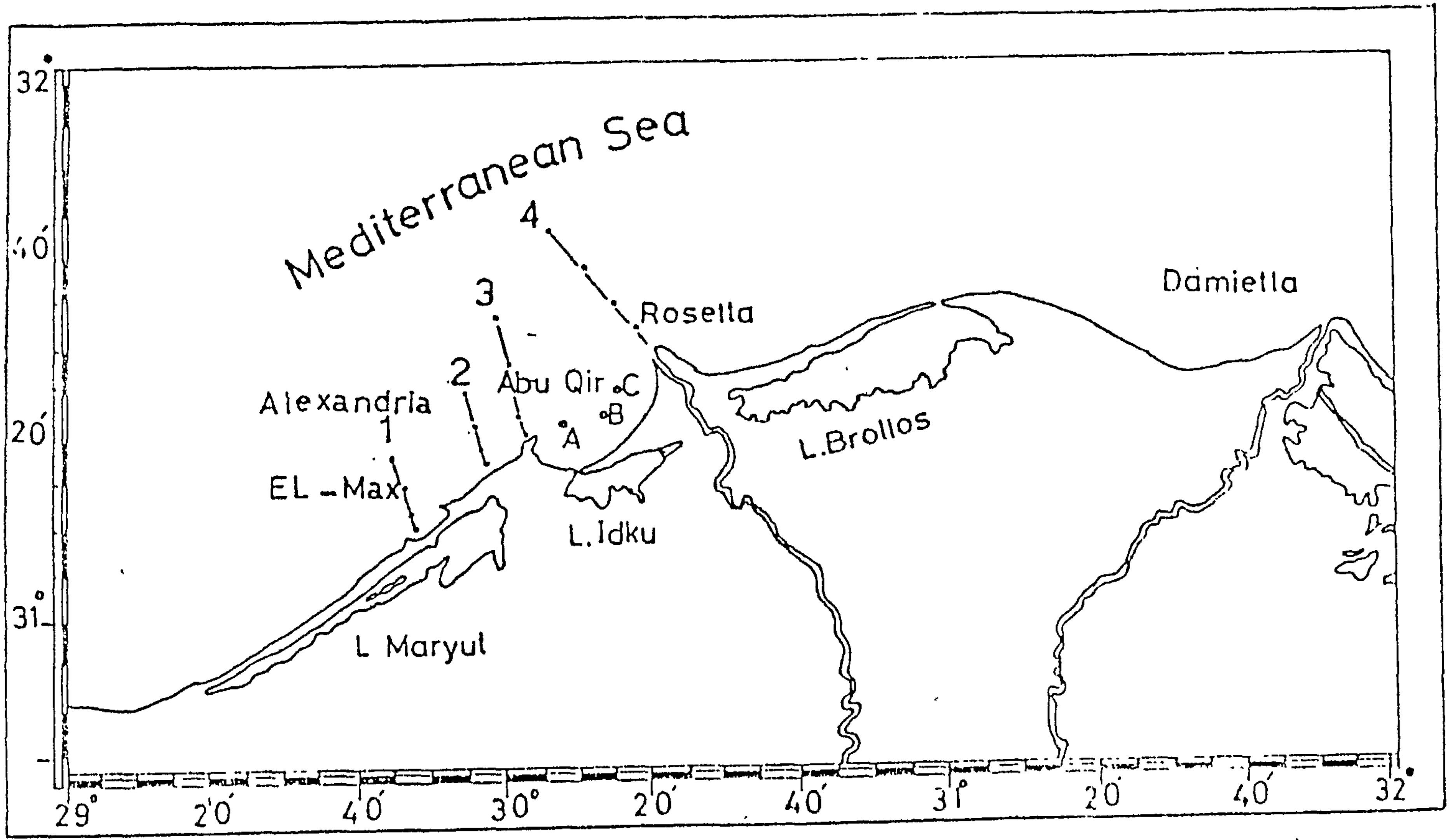
GERGES, M. A. Thermal structure of the continental shelf waters off the Egyptian Mediterranean coast. Proc. of the 5th. Ocean Thermal Energy Conversion Conference, Miami, U.S.A., February (1978).

GERGES, M. A. Trajectories and speeds of surface currents near the Egyptian Mediterranean coast, as deduced from the movement of surface drifters. Proc. of the 26th Congress and Plenary Assembly of ICSEM, Workshop on Marine pollution of the Mediterranean, Antalya, Turkey, (1978).

SAID, M. A. Effect of Oceanographic and Meteorological factors on the transport of pollutants in Abu Qir Bay. M.Sc. Thesis, Alexandria University, 95 p. (1979).

GERGES, M. A. and SAID, M. A. Marine pollution in the Egyptian Mediterranean waters off Alexandria: Sources and Effects. Unpublished (1980).

GERGES, M. A. Recent observations of currents from mooring in the Egyptian Mediterranean waters off the Sinai coast. 17th General Assembly of the International Union of Geodesy and Geophysics (IUGG), International Association for the Physical Sciences of the Ocean (IAPSO), Canberra, (1979). (In press).



• Hydrographic stations • Mooring Sites for current measurements

Fig. 1. Area of investigations and sampling stations

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Principal Investigator: J. GANOULIS

INTRODUCTION:

The very high level of the pollution in the Bay of Thessaloniki, which is readily seen from the colour and the odour of the water, makes the execution of the MED POL VI pilot project in this area very urgent. The results of this study, and especially the analysis of water circulation patterns, will be very useful in calculating the dilution of the wastes, and in deciding the most efficient way to dispose of the sewage. In fact, a recent sewage disposal plan is under study by the Greek Ministry of Public Works.

The Department of Hydraulics of the Aristotle University of Thessaloniki had previous experience in applied mathematical modelling before starting the programme, but the in situ measurements started practically upon the signature of the agreement (February 1979). The measurement of the currents was made using drogues floating at the surface and at different depths; at the same time, the water is sampled for the determination of the salinity and the density. Two Aanderaa current meters were supplied (in August 1979) under the pilot project, and the auxiliary equipment (deck unit, hydrophone, etc.) ordered by the University is in delivery; it is expected that it will be brought into service during the next few months. Concerning the training of our scientific staff, the stay of Dr. D. Tolikas for four weeks in the O.G.S. Institute of Trieste (June 1979), was especially useful, while Dr. C. Koutitas has gained valuable experience in mathematical modelling of coastal circulation during his two years' leave as a Research Fellow, in Simon Eng. Laboratories, Manchester, England.

AREA(S) STUDIED:

The general map in Figure 1 shows the location of the coastal area studied; more details are given in Figure 2. Thessaloniki Bay is a semi-enclosed basin opening southwards to the Aegean Sea. It is naturally divided into three parts: the inner and the central bay having a mean depth of about 20 m., and the outer bay into which flow two major rivers of northern Greece, the Axios and the Aliakmon.

Chemical and biological characteristics of the bay are seriously affected by industrial wastes coming from an ESSO refinery, steel industry, paper mills and some other industries located in the industrial areas west of the city (Fig. 2). The domestic sewage is actually discharged directly along the coast near the city. The recent sewage disposal plan provides a main collector which will take all the domestic and industrial wastes and discharge them after treatment to the outer bay through the Axios river (Fig. 2.).

MATERIAL AND METHODS:

For the direct measurement of currents in this first phase of the programme, we decided to use drogues, for two principal reasons: (i) to explore better the surface current field, since it is not feasible to measure it by current meters; and (ii) to determine the most characteristic positions for the installation of the current meters in the second phase of the programme.

Figure 3 shows the form and the dimensions of the drogues used. Some of these drogues have been used at a depth of 6 m, but generally they have proved very efficient when used at the sea surface. [1]

Currents are actually measured in the inner and central bay, which are greatly polluted by the domestic and industrial wastes, but the outer bay, or Thermaikos Gulf area, is included in the numerical simulation model (see below).

In situ methods - To determine the position of the drogues on the map at different times, two different methods have been used. The first is a direct optical method and the second is based on the use of a radar system. The latter method appeared more precise and convenient and it will be adopted for the future cruises.

The optical method is based on the measurement of three horizontal angles between the boat and two different points fixed along the coast. This method is not very precise, owing to the deviations of the compass, and its application is dependent on good visibility.

Even if visibility is poor, it is possible to fix the position of the boat by measuring the distance from three known points on the coast, using a radar system. The application of this method for our purpose led to a small error, because the distances in the Thessaloniki Bay are relatively small ($<$10 km).

The current velocity can be computed if we know the successive positions of the drogues at different times. The presentation and the analysis of the data can be made using a normalized tabular form. During a day on a cruise, 4 or 5 drogues were dropped into the sea and their displacements were recorded throughout the day.

Temperature of the water samples was measured in situ, and salinity was determined in the hydraulics laboratory using a conductivity meter. The water density was then calculated using standard tables.

The water samples were taken at different locations and several depths, but not in a systematic way, since the water in the bay is nearly homogeneous.

Fluctuation of the mean water level in the bay is continuously measured by the port authorities in the port installations near the town (Fig. 2). To analyze the influence of the tides on the water currents in the bay, some special numerical codes are composed for spectral analysis of stochastic time series. These codes have been successfully tested for the analysis of the flow rate of the river Axios [2] and they will be very useful for the analysis of the data from current meters.

Meteorological data, especially wind speed and direction, have been taken by the National Meteorological Service at Mikra Airport, Thessaloniki (see Figure 2). These data have been compared with the direct measurements of the winds over the boat [1].

Mathematical modelling:

If u(x, y, z, t) and v(x, y, z, t) are the horizontal components of the velocity vector, ζ (x, y, t) the surface elevation, h(x, y) the water depth, q the mass inflow ($m^3/s/m^2$) and $v_T(x, y, z)$ the eddy viscosity coefficient, the following equations express the conservation of the momentum and the mass:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} - fv = - g \frac{\partial \zeta}{\partial x} + \frac{\partial}{\partial z} (v_T \frac{\partial u}{\partial z}) \qquad (a)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + fu = - g \frac{\partial \zeta}{\partial y} + \frac{\partial}{\partial z} (v_T \frac{\partial v}{\partial z}) \qquad (b)$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial}{\partial x} \int_0^h udz + \frac{\partial}{\partial y} \int_0^h vdz = 0 \qquad (c)$$

where $f = 2\omega\sin\varphi$ is the Coriolis coefficient.

This hydrodynamic model, together with the appropriate boundary conditions ([3], [4]), can describe the unsteady flow pattern in the three-dimensional flow field, which is developed by the combined action of the wind and the tides. Dr. C. Koutitas has constructed a very efficient numerical algorithm to integrate the equations (a), (b) and (c) on the computer. Figure 4 shows the two-dimensional grid covering the bay in the horizontal plan, in which finite differences are used. Along the vertical direction, one-dimensional finite elements are used, and the Galerkin procedure permitted us to overcome the difficulties caused by the application of the boundary conditions over the irregular bottom of the bay. More details concerning the integration scheme and the simulation of the eddy-viscosity variation can be found in reference [4].

RESULTS AND THEIR INTERPRETATION:

Drogues - The data are summarized in Tables I and III, for the first and second cruises, respectively. The wind data for each cruise are given in Tables II and IV, likewise.

Hydrodynamic model - Actually the numerical stimulation of the hydrodynamics of Thessaloniki Bay is operational, and computation of the water circulation for various boundary conditions (winds, tides, river discharge, etc.) is possible on the UNIVAC 1106 computer at the Aristotle University of Thessaloniki. Figure 5 gives an example of the flow pattern at the surface for a north wind (W = 20 m/sec). Calibration of the mathematical model so as to find the eddy viscosity distribution, which gives more satisfactory results for the surface elevation and the water currents, is nearing completion.

Taking into account the special conditions in Thessaloniki Bay, the principal objective of this programme is to answer the following questions:

(i) As the tide intensity is relatively small, what is the correlation between the winds and the currents in respect of speed and direction?

(ii) What is the influence of the other factors (tides, density variation near the mouth of the river Axios, etc.) over the water circulation in the Bay?

(iii) What is the importance of the mass exchange between the inner and the central bay, and between the central and the outer (Thermaikos) bay for different seasonal conditions?

The answers to these questions will require the data to be provided by the current meters. But using the preliminary results from the drogues, and using the simulation model, we can draw the following conclusions:

The water circulation in the inner bay seems to have a systematic anticyclonic rotation (clockwise), as indicated by the observations on 10, 14 and 15 February 1979, for variable winds from S-E to S-W. For these cases, the mass exchange between the inner and the central bay seems to be limited to near Cape Emvolon.

No reversal of currents is observed until the 6 m depth.

According to the observations made during the second cruise, there is a correlation in the central bay between the direction of the wind and the direction of the currents, which have a predominantly easterly direction. Along the separation line between the central bay and the outer bay (Thermaikos), there is an important outward mass transfer at the surface, at least for a N-W wind (21/6/79).

For wind velocities smaller than 10 m/s, the current speed does not exceed 30 cm/s.

Salinity and density distributions measured in the inner bay show that the mass of the water in this area is nearly homogeneous.

The following publications have been based wholly or partly on the work carried out under MED POL VI:

[1] GANOULIS, J. Research programme on physical oceanography of coastal areas in Northern Greece. First progress report submitted to Greek Ministry of Co-ordination, October 1979 (in Greek).

[2] TOLIKAS, D., and GANOULIS, J. Spectral Analysis of Hydrological Data. Proc. II Hydr. Sem., Greek Min. of Coordination, February 1980 (in Greek).

[3] KOUTITAS, C. Numerical solution of the complete equations for nearly horizontal flows. Adv. in Water Res., Vol 1., No. 4, pp. 213-217 (1978).

[4] KOUTITAS, C. and O'CONNOR, B.A. Modelling three-dimensional wind-induced flows. J. of the Waterways and Harbors Division, ASCE. (1980).

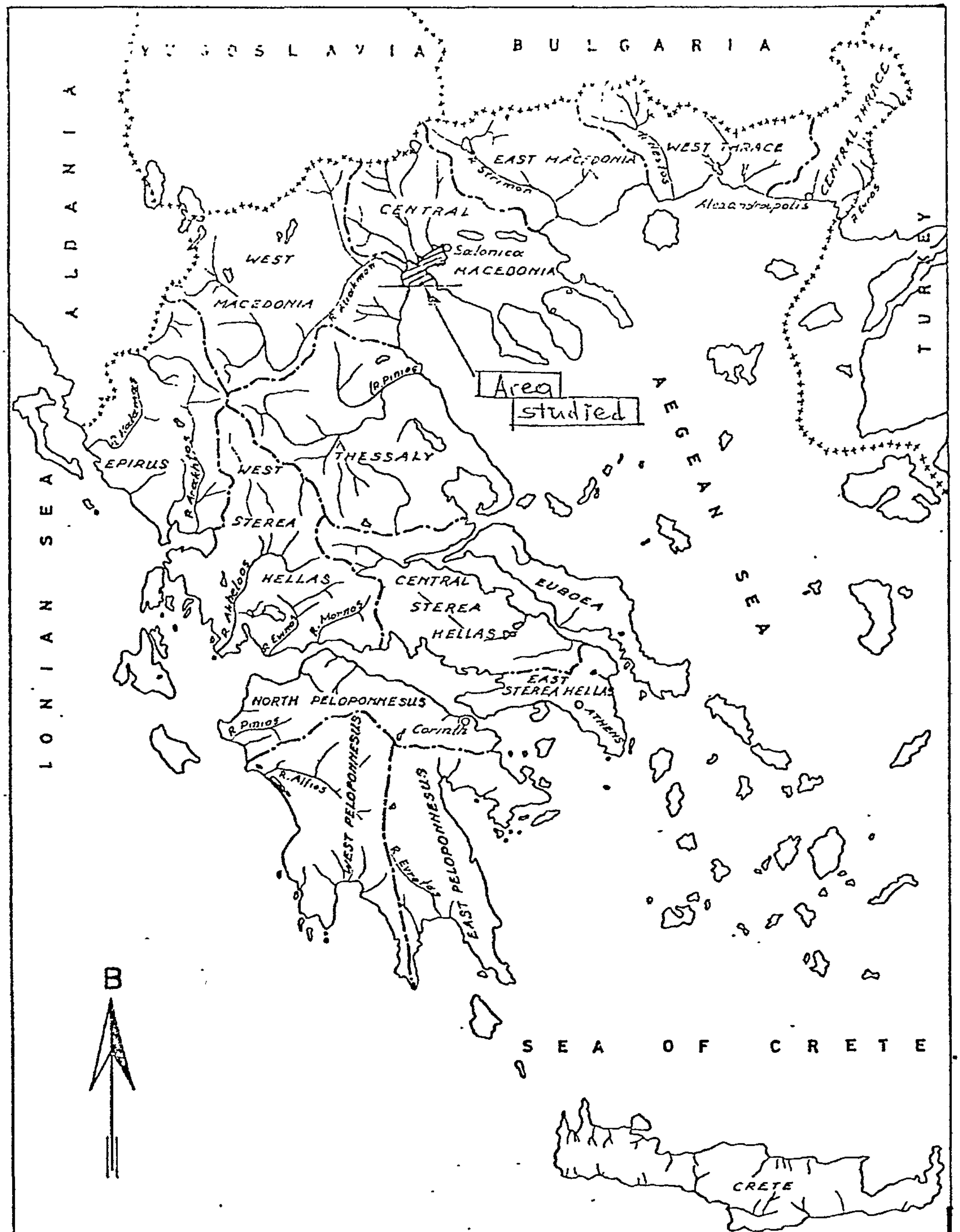

Fig. 1. Location of the area studied

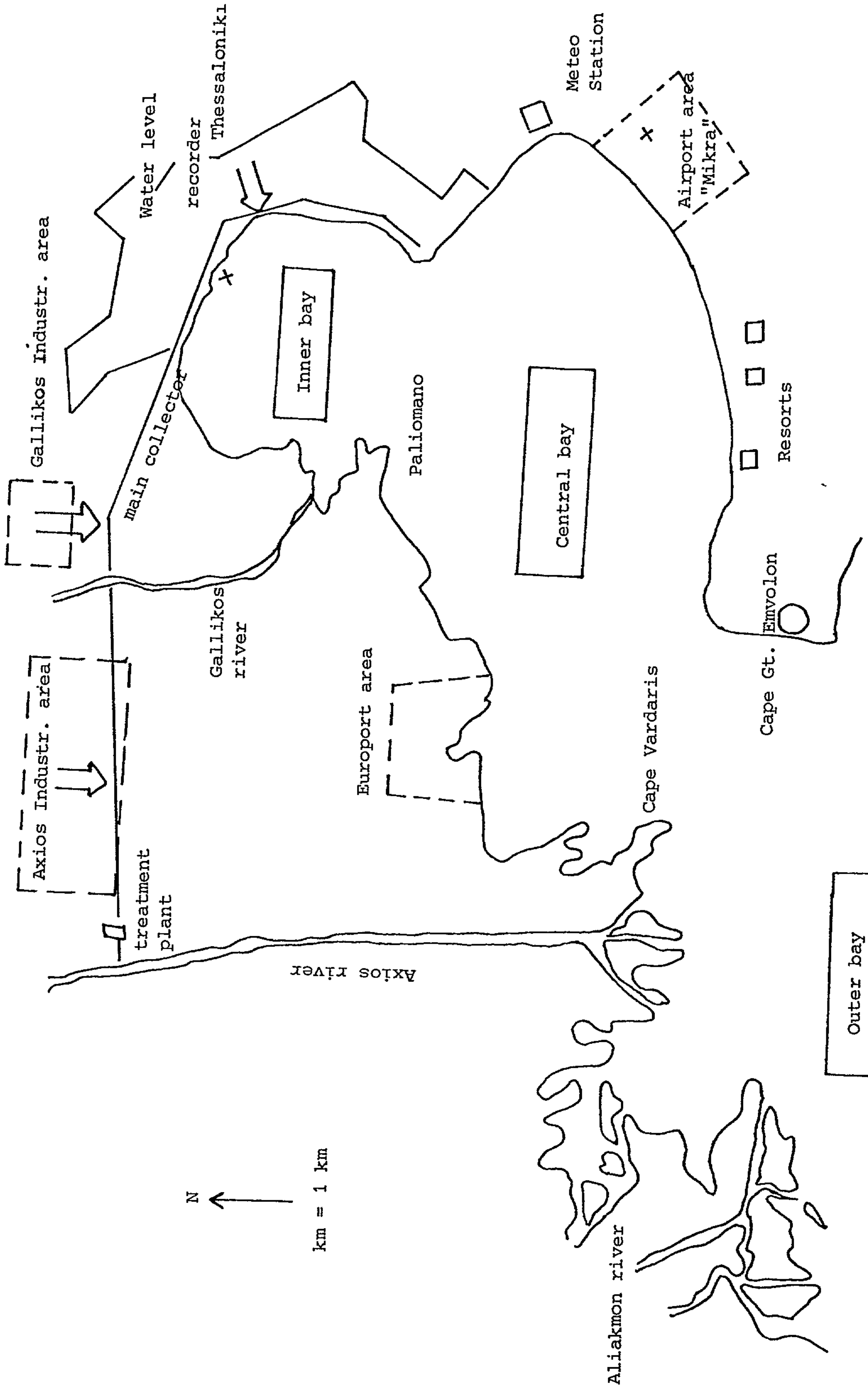

Fig. 2. Details of the Thessaloniki bay area

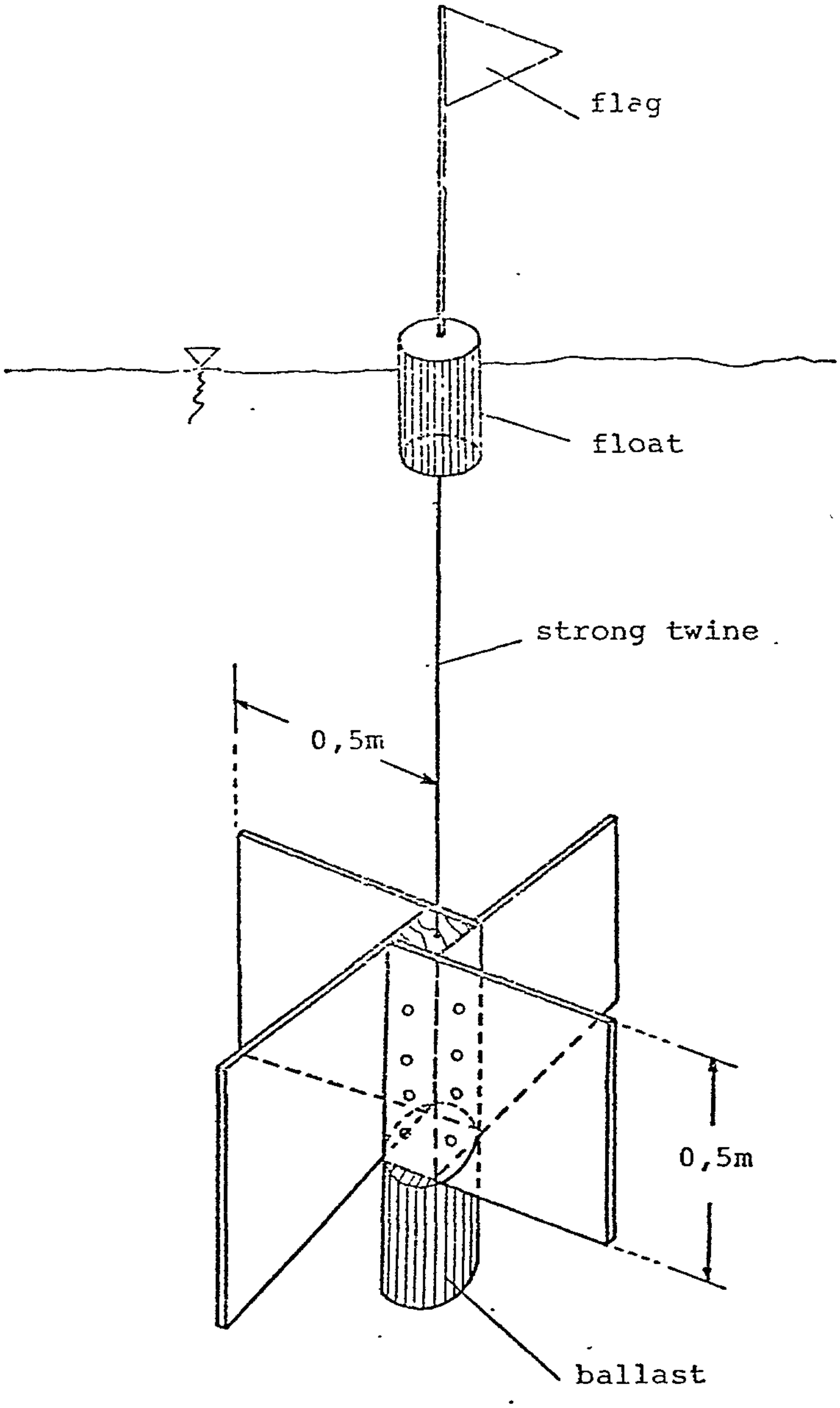

Fig. 3. Details of drogues used

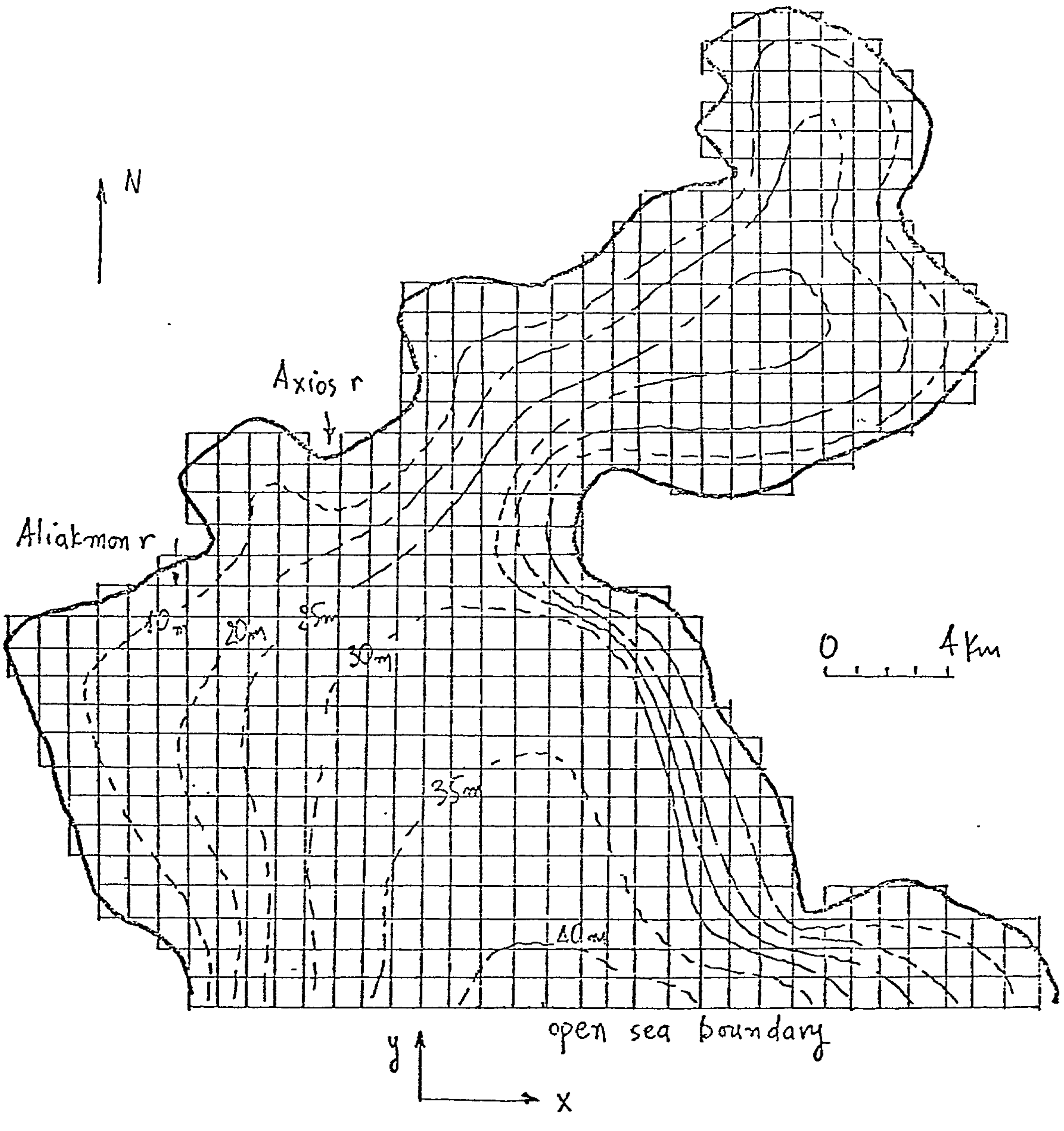

Fig. 4. Discretization of the coastal area for numerical simulation

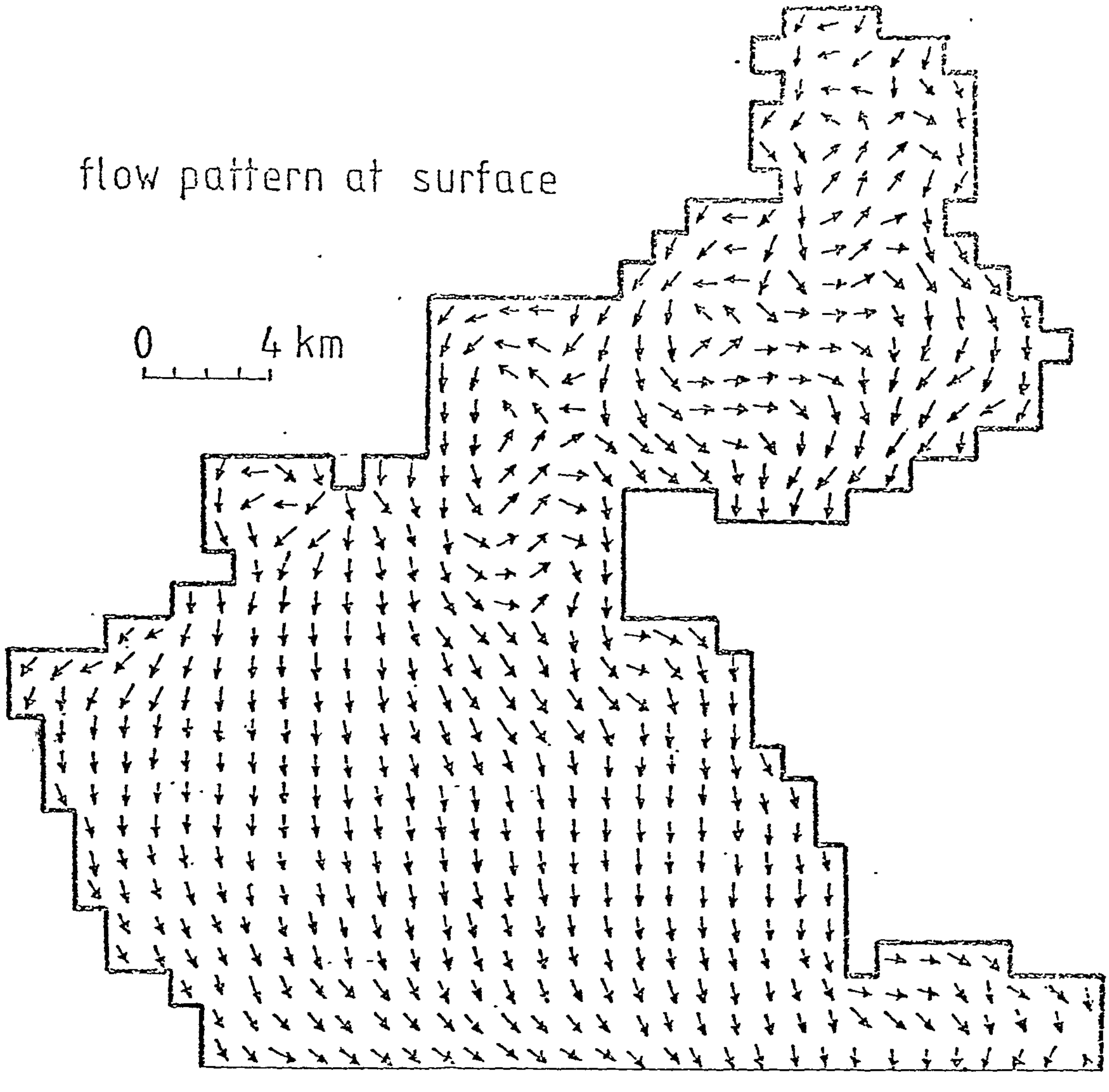

Fig. 5. Results of computation of currents (Northern wind; W = 20 m/s)

Table I. Summary of drogue observations in the first cruise (10 - 21 February 1979).

10.2.79				14.2.79			
Drogue No. Obs.	Time	Speed m/min	Direction	Drogue No. Obs.	Time	Speed m/min	Direction
1.1	10.45	8.13	S	7.1	9.50	24.72	NNW
1.2	11.25	7.18	S	7.2	11.20	28.00	NNE
1.3	13.13	8.83	SSW	7.3	11.45	6.82	N
1.4	16.00			7.4	12.40	23.46	N
				7.5	13.45	6.88	E
2.1*	10.45	8.13	S	7.6	14.25	4.38	E
2.2	11.25	3.00	SW	7.7	15.30	6.55	W
2.3	13.05	2.30	S	7.8	16.25		
2.4	16.10						
				8.1*	9.50	6.67	NW
3.1	11.05	10.45	S	8.2	11.35		
3.2	12.00	8.08	SSW				
3.3	14.10	8.95	SW	9.1*	11.05		
3.4	15.45			9.2	12.00	8.18	N
				9.3	14.10	6.54	N
4.1*	11.05	6.25	S	9.4	15.40	4.17	NNE
4.2	12.05	3.98	WSW	9.5	16.15	16.00	SW
4.3	13.33	3.54	SW				
4.4	15.40			10.1	10.30	18.48	NNW
				10.2	12.15	8.25	NW
5.1	12.40	6.75	SE	10.3	13.55		
5.2	14.40	9.38	SSE				
5.3	15.20			11.1	14.50	1.20	NE
				11.2	16.55		
6.1*	12.40	3.09	SE				
6.2	14.30	2.00	SE				
6.3	15.15						

* Drogues started at points 2.1, 4.1, 6.1, 8.1, and 9.1 were released at 6 m depth; the rest at the sea's surface.

Table I. Summary of drogue observations in the first cruise (10 - 21 February 1979) (cont'd/...2)

15.2.79

Drogue No. Obs.	Time	Speed m/min	Direction
12.1	9.35	7.86	WNW
12.2	11.20	6.50	NNE
12.3	13.50		
13.1	9.50	6.48	NW
13.2	11.55	11.15	N
13.3	14.05		
14.1	10.20	10.23	NE
14.2	12.10	6.35	N
14.3	14.20		
15.1	10.35	4.55	SE
15.2	12.25	3.73	NNE
15.3	14.35		
16.1	10.50	3.80	SSW
16.2	12.37	4.57	N
16.3	14.45		
17.1	9.25	5.00	SSW
17.2	11.10	3.81	WNW
17.3	12.55	10.74	NW
17.4	15.17		
18.1	9.45	12.89	NW
18.2	11.20		
19.1	12.15	9.55	ENE
19.2	14.18	15.80	SE
19.3	15.45		
20.1	10.30	7.24	NE
20.2	13.40	8.13	NE
20.3	15.18		

21.2.79

Drogue No. Obs.	Time	Speed m/min	Direction
18.1	9.45	12.89	NW
18.2	11.20		
19.1	12.15	9.55	ENE
19.2	14.18	15.80	SE
19.3	15.45		
20.1	10.30	7.24	NE
20.2	13.40	8.13	NE
20.3	15.18		

Table II. *Wind data obtained on board ship during the first cruise*

8.2.79			10.2.79			14.2.79		
Time	Direction	Speed m/s	Time	Direction	Speed m/s	Time	Direction	Speed m/s
9.15	120°	3.6	9.15	-	-	9.15	110°	5.1
10.15	130°	3.1	10.15	270°	2.6	10.15	130°	6.2
11.15	110°	4.1	11.15	-	-	11.15	130°	4.1
12.15	120°	2.1	12.15	-	-	12.15	170°	5.1
13.15	120°	4.1	13.15	270°	3.1	13.15	130°	3.1
14.15	330°	0.3	14.15	-	-	14.15	150°	5.1
15.15	-	-	15.15	-	-	15.15	90°	1.5
16.15	-	-	16.15	-	-	16.15	140°	4.1
Average	150°	2.9 m/s	Average	270°	2.9 m/s	Average	131°	4.3 m/s

15.2.79			21.2.79		
Time	Direction	Speed m/s	Time	Direction	Speed m/s
9.15	90°	1.5	9.15	140°	2.6
10.15	130°	1.5	10.15	320°	0.2
11.15	300°	2.6	11.15	270°	4.1
12.15	-	-	12.15	270°	4.1
13.15	300°	3.1	13.15	270°	3.1
14.15	240°	2.1	14.15	310°	5.1
15.15	320°	2.6	15.15	310°	3.1
16.15	240°	2.6	16.15	290°	2.1
Average	231°	2.3 m/s	Average	272°	3.05 m/s

Table III. Summary of drogue observations in the Second Cruise (19-22 June 1979)

19.6.79				20.6.79			
Drogue No. Obs.	Time	Speed m/min	Direction	Drogue No. Obs.	Time	Speed m/min	Direction
1.1	9.50			5.1	9.10	10.0	SSW
1.2	10.46	8.67	E	5.2	10.05	8.9	SSE
1.3	11.35	4.50	SE	5.3	11.00	4.47	SSE
1.4	12.25	9.01	ESE	5.4	12.25	6.98	SSE
1.5	13.26	3.01	E	5.5	13.28	3.97	SE
1.6	14.24			5.6	14.40	3.15	SE
				5.7	16.10		
2.1	10.00	11.50	ESE				
2.2	10.40	7.79	ESE	6.1	9.22	12.92	SSW
2.3	11.39	6.25	SSE	6.2	10.15	3.24	SSE
2.4	12.15	4.46	SE	6.3	11.12	3.08	SSE
2.5	13.20	11.44	ESE	6.4	12.35	4.77	SSE
2.6	14.19	9.28	SSE	6.5	13.40	2.63	E
2.7	15.15			6.6	14.50	1.95	ENE
				6.7	16.22		
3.1	10.10	6.2	SE				
3.2	11.00	8.76	SE	7.1	9.30	11.8	SSW
3.3	12.05	9.76	ESE	7.2	10.23	3.07	S
3.4	13.10	12.5	SE	7.3	11.20	4.00	S
3.5	14.02	12.32	SSE	7.4	12.45	3.51	SSE
3.6	15.00			7.5	13.52	3.68	ESE
				7.6	15.00	3.00	ESE
				7.7	16.35		

Table III. Summary of drogue observations in the Second Cruise (19-22 June 1979) (cont'd/..2)

21.6.79				22.6.79			
Drogue No. Obs.	Time	Speed m/min	Direction	Drogue No. Obs.	Time	Speed m/min	Direction
8.1	9.45	6.8	SSW	14.1	9.20	8.87	E
8.2	10.35	3.86	SSW	14.2	10.35	10.3	E
8.3	11.32	6.37	SSW	14.3	11.10	10.7	ENE
8.4	12.58	3.21	W	14.4	14.25		
8.5	14.09	3.90	N				
8.6	15.26	4.61	WSW	15.1	9.45	6.67	E
8.7	16.55			15.2	11.45	7.22	ESE
				15.3	14.45		
9.1	10.35	19.75	SW				
9.2	12.10	8.61	WSW	16.1	10.00	8.24	NNE
9.3	13.40	2.92	SSW	16.2	11.25	7.98	ENE
9.4	15.47			16.3	14.55		
10.1	11.00	8.82	WSW				
10.2	12.25	9.76	SW				
10.3	13.50	4.51	SSE				
10.4	15.02						
11.1	11.12	7.61	SW				
11.2	12.42	7.47	SW				
11.3	14.07	5.37	SE				
11.4	15.15						
12.1	11.25	6.87	SE				
12.2	13.20	9.74	SE				
12.3	14.37	17.9	ESE?				
12.4	15.42						
13.1	9.10	7.29	SSE				
13.2	10.46	5.20	E				
13.3	14.35						

Table IV. Wind data obtained on board during the second cruise.

19.6.79			20.6.79		
Time	Direction	Speed m/s	Time	Direction	Speed m/s
9.00	20°	2.57	9.00	290°	4.11
10.00	120°	2.57	10.00	310°	5.10
11.00	320°	7.19	11.00	290°	4.11
12.00	320°	6.17	12.00	270°	7.71
13.00	340°	7.19	13.00	300°	7.19
14.00	320°	8.22	14.00	300°	8.22
15.00	320°	7.19	15.00	310°	7.19
16.00	290°	5.10	16.00	270°	6.17
17.00	290°	4.11	17.00	180°	7.19
Average	260°	5.6 m/s	Average	280°	6.3 m/s
21.6.79			22.6.79		
Time	Direction	Speed m/s	Time	Direction	Speed m/s
9.00	320°	6.17	9.00	320°	7.19
10.00	320°	5.10	10.00	300°	7.19
11.00	320°	6.17	11.00	290°	6.17
12.00	320°	5.10	12.00	290°	7.19
13.00	300°	6.17	13.00	300°	6.17
14.00	310°	5.10	14.00	310°	3.08
15.00	290°	11.31	15.00	290°	7.71
16.00	310°	2.57	16.00	270°	5.10
Average	309°	6.1 m/s	Average	296°	5.7 m/s

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INTRODUCTION:

Oceanographic studies of the Saronikos Gulf were initiated in 1972 as part of a major "Environmental Pollution Control Project". Many cruises were undertaken and a great number of stations were established to investigate the physical, chemical, geological, and biological characteristics of the Gulf. Current measurements started in 1975.

The inner Saronikos Gulf has been selected for current measurements. This region is of primary interest because:

(i) it is a pathway from Pireaus harbour which contributes to the pollutant load, especially with petroleum products;

(ii) it is the area where the main sewage outfall of metropolitan Athens is located;

(iii) this area is densely populated, the eastern coast being preferred for recreation.

The results of these studies will be used to establish suitable locations for sewage outlets so that the fisheries resources and recreational potential of this area will be least affected.

AREA(S) STUDIED:

Saronikos Gulf is a semi-enclosed marine area, bounded on the west by the Argolis peninsula, and on the north and east by Attica. It occupies an area of 2,900 km^2. Islands running north-south tend to divide the Saronikos Gulf into eastern and western sections (Figure 1).

MATERIALS AND METHODS:

Current measurements were carried out at three stations arranged to form a triangle. The location of these current-meter mooring stations is shown in figure 2. Station R1 can be considered as a long-term mooring station with several breaks. Two Aanderaa recording current meters with extra sensors for temperature, conductivity and depth were used at each station. One of the meters was near the sea bed and the second one approximately 17 m below the sea surface to avoid accidents from passing ships, as well as the effects of waves.

Information on the exact position of the stations, the periods during which the measurements took place and the depths of the instruments are given in Tables I to III.

The raw data were decoded using the manufacturer's calibrations for conversion to physical units, tested for their validity and stored on a 7-track magnetic tape. Fortran programs were prepared to plot the continuous data (speed, direction) and compute the E-W and N-S components, the hourly mean values, histograms and progressive vector diagrams (PVD). These are constructed by graphical vector addition of successive horizontal components of the velocity field at a fixed point. They do not indicate the path of drifting particles but they give an estimate of the variations of the current vectors in time.

All these contours have been closely inspected and compared in an attempt to identify existing permanent features, variations and correlations between the flows at the three stations.

A lot of difficulties arose with the safety of the instruments because of the extensive fishing activities and the anchoring of commercial ships near the area of investigation. Up to now, four recording current meters and one acoustic release have been lost.

On Atalanti, a small uninhabited island in the northern Saronikos Gulf, a recording anenometer has been installed. Additional meteorological data are obtained from the meteorological stations at Piraeus port and Hellinikon airport.

RESULTS AND THEIR INTERPRETATION:

The most frequently observed velocities are within the range of 3-7 cm/sec. Although the maximum observed velocity was 27 cm/sec., several times there are short periods of one or two hours during which the currents are so slow that they cannot be detected.

All measurements show a high predominance of two modal directions. Very often they differ by nearly 180 degrees which is evidence of the presence of tidal periodicities. The principal mode at station R1 is about 260 degrees most of the time. At station R2 and R3, the principal mode varies considerably.

The graphical representations of the cartesian components are characterized by fluctuations in which there are several interfering periodicities. The inner Saronikos Gulf is charactarized by a weak field of motion, and the presence of different periodicities makes the study of tidal currents extremely difficult and uncertain. Spectral analysis is envisaged to give more information about the contribution of each periodicity.

One of the more important types of current information relates to their persistance; i.e., how long the water flows in one direction. A convenient graphical view of the mean flow is given by PVD.

The majority of the records show flow patterns that are constant for several days and even weeks. At station R1, PVDs demonstrate a flow that is reversible towards WSW-ENE for the upper layer and a steady flow towards WSW for the near-bottom layer. At station R2 the near-bottom flow is variable towards SW, W, NW, while the near-surface flow is steady towards NE and N.

At station R3 there is a reversible flow towards NNW and SSE near the surface, and a variable flow towards W, E, N, near the sea-bed.

Bearing in mind the south-easterly orientation of Saronikos Gulf, we observe that the predominant flow at station R1 is parallel to the east coast of Salamis, while at station R3, it is parallel to the west coast of Attica.

It is very important to note that the general circulation observed in this way is, for long periods, either clockwise or counter-clockwise.

The Saronikos Gulf appears to be replenished by a western boundary current from the North Aegean Sea, flowing south-wards along the continental slope on the eastern side of Attika peninsula and into the Gulf.

The inner Saronikos Gulf is characterized by a weak field of velocities. There are no significant tidal forces and the evaluation of tidal components becomes rather difficult and of minor importance.

Baroclinic conditions are developed only during summer (April-October).

The evidence of clockwise and counter-clockwise circulation, as well as the fact that the predominant winds are northerly and southerly, give an indication of wind-driven circulation.

Additional computations are planned with wind records measured at Atalanti station to determine whether southern winds develop an anticyclonic circulation, and northern winds a cyclonic circulation.

TABLE I.

Summary of Aanderaa current-meter data obtained at Station R_1 *

CURRENT METER SERIAL No	PERIOD	POSITITION		INSTRUMENT DEPTH	VELOCITY		DIRECTION MODE	
		LAT	LONG		MAX cm/sec	MODE cm/sec	PRINCIPAL	SECONDARY
1209/2	29/12/75-4/1/76	37°54.58"	23°35.53"	-8 **	5.5	3.0	27°	110°
1210/2	29/12/75-2/3/76	37°54.58"	23°35.53′	35	23.0	5.0	260°	80°
1209/3	6/4/76-18/4/76	37°54.45′	23°34.20′	-7	12.5	6.5	240°	
1210/3	6/4/76-1/6/76	37°54.45′	23°34.20′	17	24.0	6.5	260°	80°
1209/4	17/6/76-2/8/76	37°54.30′	23°34.10′	-7	15.0	5.0	260°	90°
1210/4	17/6/76-22/7/76	37°54.30′	23°34.10′	17	23.0	5.0	260°	70°
1209/5	2/8/76-21/9/76	37°54.30′	23°34.10′	-7	15.0	4.0	260°	80°
1210/5	2/8/76-20/8/76	37°54.30′	23°34.10′	17	9.5	4.0	260°	70°
1209/6	4/10/76-28/11/76	37°54.30′	23°34.10′	-7	18.5	3.0	270°	90°
1210/6	4/10/76-25/10/76	37°54.30′	23°34.10′	16	13.5	5.0	250°	60

* Station depth is approximately 90 metres

** Minus sign at instrument depth means distance above the sea bottom; otherwise actual depth is given

NOTE: The last four columns have been derived from histograms

TABLE II.

Summary of Aanderaa current-meter data obtained at Station R_2

CURRENT METER SERIAL No	PERIOD	POSITITION		INSTRUMENT DEPTH	VELOCITY		DIRECTION MODE	
		LAT	LONG		MAX cm/sec	MODE cm/sec	PRINCIPAL	SECONDARY
2112/7	7/7/77-28/7/77	$37^{o}53.0'$	$23^{o}32.5'$	16	23.0	5.5	50^{o}	270^{0}
2114/7	7/7/77-19/7/77	$37^{o}53.0'$	$23^{o}32.5'$	88	18.0	4.5	315^{o}	45^{o}
2115/10	3/9/77-26/9/77	$37^{o}53.0'$	$23^{o}32.5'$	88	15.0	4.5	240^{o}	50^{o}

TABLE III

Summary of Aanderaa current-meter data obtained at Station R_3

CURRENT METER SERIAL No	PERIOD	POSITITION		INSTRUMENT DEPTH	VELOCITY		DIRECTION MODE	
		LAT	LONG		MAX cm/sec	MODE cm/sec	PRINCIPAL	SECONDARY
2091/1	13/3/76-17/4/76	$37^{o}53.05$	$23^{o}40.12$	16	22.0	4.5	160^{o}	350^{0}
2112/1	13/3/76-20/4/76	$37^{o}53.05$	$23^{o}40.12$	58	16.0	4.5	340^{0}	90^{o}
2091/2	29/4/76-16/6/76	$37^{o}53.05$	$23^{o}40.12$	18	14.0	5.0	310^{o}	120^{o}
2093/7	8/7/77-29/7/77	$37^{o}53.00$	$23^{o}40.00$	59	14.0	4.5	360^{o}	180^{o}
2090/8	5/9/77-26/9/77	$37^{o}53.00$	$23^{o}40.00$	7	27.0	7.5	330^{o}	130^{o}

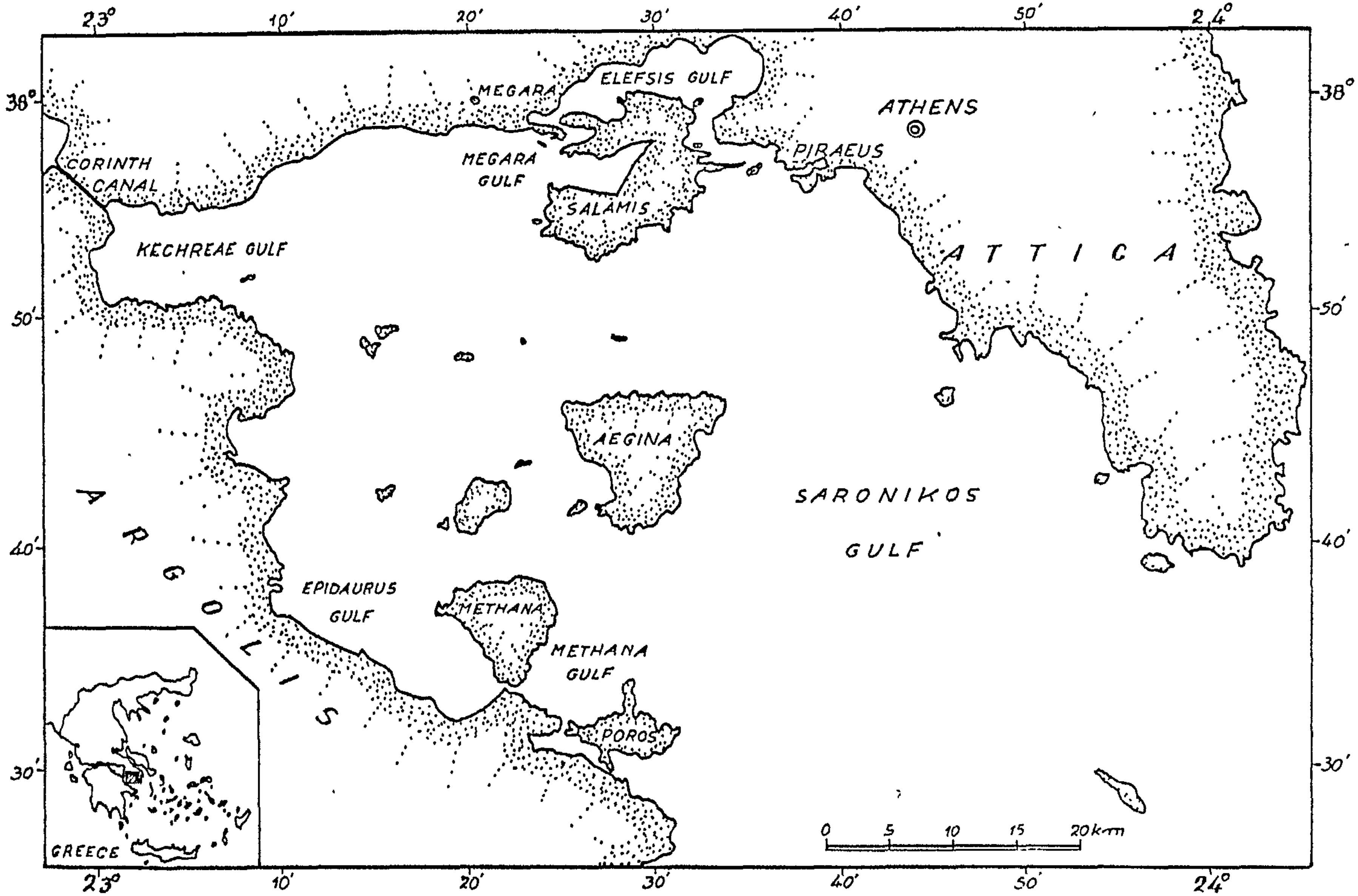

Fig. 1. The Saronikos gulf

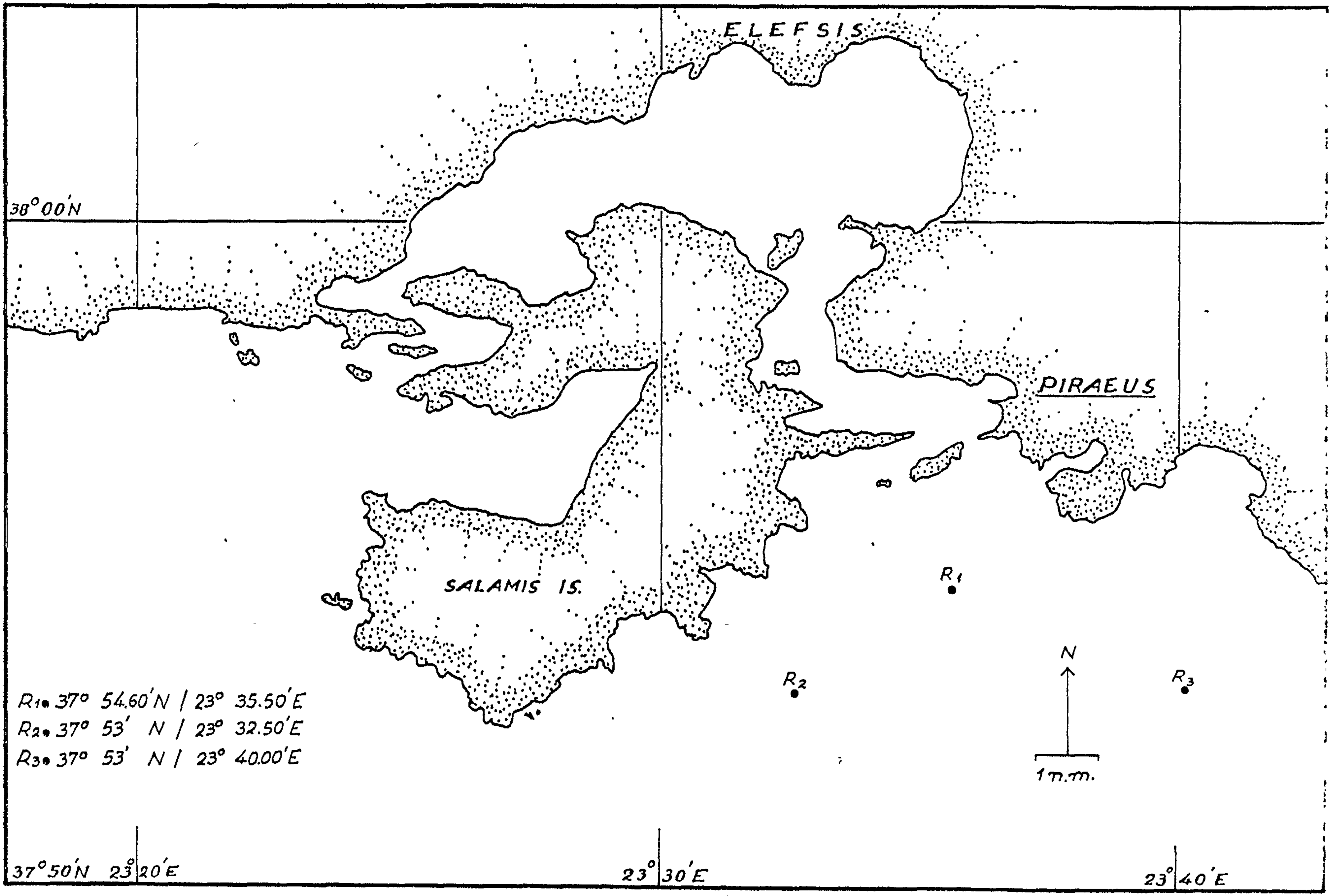

Fig. 2. Current-meter mooring stations

Participating Research Centre: Water Research Institute - CNR
ROME
Italy

Principal Investigator: M. BENEDINI

INTRODUCTION:

The work carried out by the Water Research Institute has been carried out in the period between 1971-1980 and consists of the verification of the most advanced methods based especially on systems analysis applications, for the optimum management of water resources in a hydrographic basin. This work is therefore a methodological experiment within the research programme of the Institute, but it is independent of decisions on measures for the protection of water quality; these are in the mandate of governmental institutions, with which the Water Research Institute has several contacts.

It should be stressed that the methods that are the subject of this work are not strictly related to the specific case of the Tiber River and its coastal waters; the main object of this research is to assess the general features of the problems and the applicability of the results to the broadest possible set of similar situations. As for the control of water quality in coastal areas, the aims of such a study would be principally sanitary reclamation, wild-life protection in shallow water, and prevention of eutrophication, and would be achieved through the assessment of the optimum utilization criteria for inland waters in the whole river basin.

AREA STUDIED:

The area studied is the estuary of the River Tiber and the nearshore sea in the vicinity thereof. (Fig. 1).

MATERIAL AND METHODS:

The measurements and observations taken for present purposes are: current meter records; periodical drogue studies; periodical measurements of salinity, temperature and dissolved oxygen; sampling and analysis of water and sediments for content of metals, nutrients and other specific pollutants; velocity and flow rate in the branches of the river mouth; remote-sensing by satellites and aircraft, and related numerical and analog image-processing; waves and meteorological data.

The above-mentioned data are collected mainly with the aim of proving their significance and representativeness, testing the effectiveness of instruments and techniques, and showing the possibilities for using such information as management tools for making decisions on the optimum use of inland waters. Mathematical models are among the most important tools.

RESULTS AND THEIR INTERPRETATION:

Fixed current meter - The velocity roses of current at two stations (B and E) are shown in figures 2 and 3.

Drogues - The tracks of three drogues released on each of two days (27 and 28 September 1977) are shown in figure 4. The inshore displacements on both days were similar, but were in quite opposite directions offshore.

Hydrography - The freshwater plumes are indicated by the salinity (figure 5). The flow from the southern (Fiumara Grande) channel is approximately four times as big as that from the northern (Fiumicino) channel (fig. 6). The maximum thickness of these plumes is 2 to 3 metres. They follow the predominant alongshore currents.

Remote sensing - The data show that upwelling phenomena occur in the area of the study.

Other measurements - Wave amplitude and period are recorded since waves are considered to be a possible factor in breaking up the freshwater plumes. More data are needed to establish such effects, as well as data on the role of sediments, winds and inland hydrological activities.

The following publications were based wholly or partly on the work done in this pilot project:

BENEDINI, M., CICIONI, G., GIULIANO, C. and SPAZIANI, F.M. Un esperimento metodologico di pianificazione e gestione delle risorse iddriche in un grande bacino idrografico: un modello per lo studio dell'ossidazione biochimica nelle acque di un fiume. Quad. Ist. Ric. Acque, 40 (in press.).

BENEDINI, M., CICIONI, G., GIULIANELLI, M., GIULIANO, G. and SPAZIANI, F.M. Un esperimento metodologico di pianificazio ne e gestione delle risorse idriche in un grande bacino idro grafico: Un modello do ottimizzazione a variabili economiche (MARK 3). Quad. Ist. Ric. Acque, 52 (in press).

BENEDINI, M. A Tiber basin model. Symposium on Trends in Mathematical Modelling, Venice, Italy, 13-18 December 1971.

BENEDINI, M. and GIULIANO, G. System approach to water management problems of river basins in Italy: The Tiber study. The Use of Computer Techniques and Automation for Water Resources Systems, Washington D.C. USA, 26 March to 4 April 1974.

GIULIANO, G. and SPAZIANI, F.M. The Tiber project: a case study in a systems approach to water resources management. International School on a Systems Approach to Management and Control of Water Resources, Dubrovnik, Yugoslavia, 5 to 16 August 1974.

BENEDINI, M., CICIONI, G., GIULIANO, G. and SPAZIANI, F.M. The Tiber basin study: a methodological system approach to problems of water management. International Institute for Applied Systems Analysis, Symposium on Energy and Water Systems, Zlatni Piasatci, Bulgaria, 22 to 24 October 1975.

BENEDINI, M., PASSINO, R. and LA NOCE, T. Inquinamento da corsi d'acqua e da insediamenti costieri: Aspetti scientifici dell'inquinamento dei mari italiani. Accademia Nazionale dei Lincei, Rome, Italy, 19 to 21 January 1976.

ISTITUTO DI RICERCA SULLE ACQUE. A case study for water management problems: the Tiber research. U.N. Water Conference, Mar del Plata, Argentina, 14-25 March 1977.

PASSINO, R., BENEDINI, M. and PAGNOTTA, R. Research and experimental data necessary for implementing pollution control programmes. 2nd International Marine Pollution Symposium, UNEP, Dubrovnik, Yugoslavia, 10 to 13 October 1977.

GIULIANELLI, M., LECHI, G. and TODISCO, A. Multispectral analysis of fluvial discharges: a methodological approach. XVI Convegno di Idraulica e Costruzioni Idrauliche, Turin, Italy, 25 to 27 September 1978.

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BENEDINI, M. Une expérience de gestion des ressources en eau d'un grand bassin Italien. Rev. Tech. Int. Eau, 7 (1975).

ISTITUTO DI RICERCA SULLE ACQUE. Atti del Seminario: Un esperimento metodologico di pianificazione e gestione delle risorse idriche in un grande bacino idrografico, Rome, Italy, 26 to 27 June 1974. Quad Ist. Ric. Acque, 30 (1976).

ISTITUTO DI RICERCA SULLE ACQUE. Indagini sull'inquinamento del fiume Tevere. Quad. Ist. Ric. Acque, 27 (1978).

COLANTONIO-VENTURELLI, R., ROVAGNA, R., BELLACICCO, A., MED, F. and WOLSKI, J. Problemi di pianificazione del territorio connessi con la gestione delle risorse idriche in un grande bacino idrografico. Quad. Ist. Ric. Acque, 37 (1978).

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TODISCO, A., ZANDONELLA, A. Correlation between Secchi depth transparency and radiance values of Landsat satellite: an example from the Tiber mouth. II Congresso Nazionale sul Telerilevamento delle Risorse Terrestri. Varenna (Como), Italy, 24 to 26 September 1979.

LECHI, G. M. and TODISCO, A. Analisi multitemporale di rilievi da satellite sullo scarico del fiume Tevere con controllo di verità al suolo e interpretazione fisica dei fenomeni idraulici. Congresso AICA, Bar, Italy, 10 to 13 October 1979.

LECHI, G. M. and TODISCO, A. Remote-sensing techniques in evaluating upwelling velocity in the zone of entrainment: The river Tiber northern plume as a case study. II Congress of the Asian and Pacific Regional Division of IAHR, Taiwan (Formosa), 12 to 14 May 1980.

BENEDINI, M. L'applicazione del Telerilevamento al Monitoraggion dell'Inquinamento di Acque Costiere. XXIV Congresso per l'Eletronica, Rome, Italy, 28 to 30 March 1977.

ISTITUTO DI RECERCA SULLE ACQUE. Indagini sull'Immissione del Fiume Tevere nel Mar Tirreno. Quad. Ist. Ric. Acque, 62 (1983)

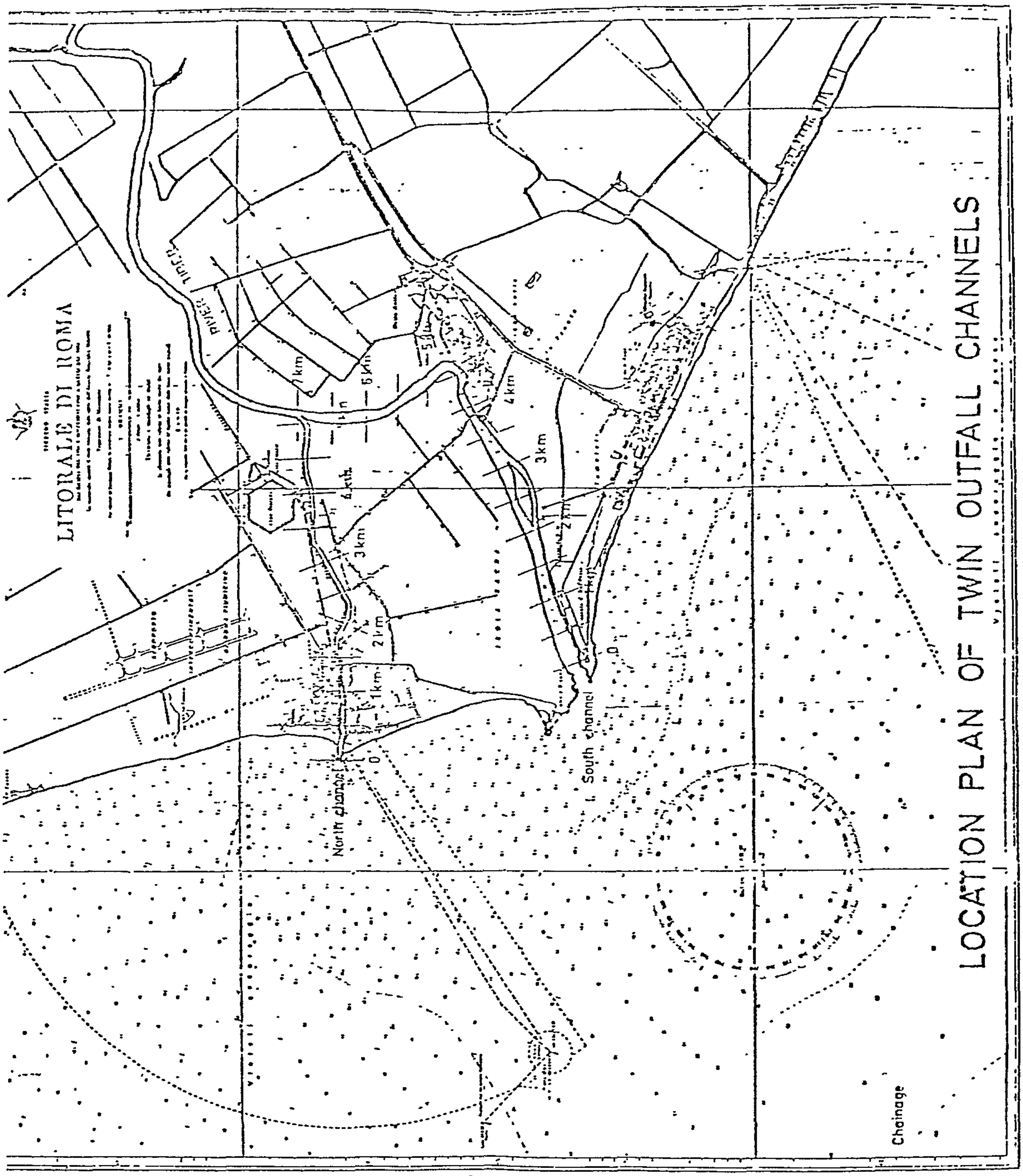
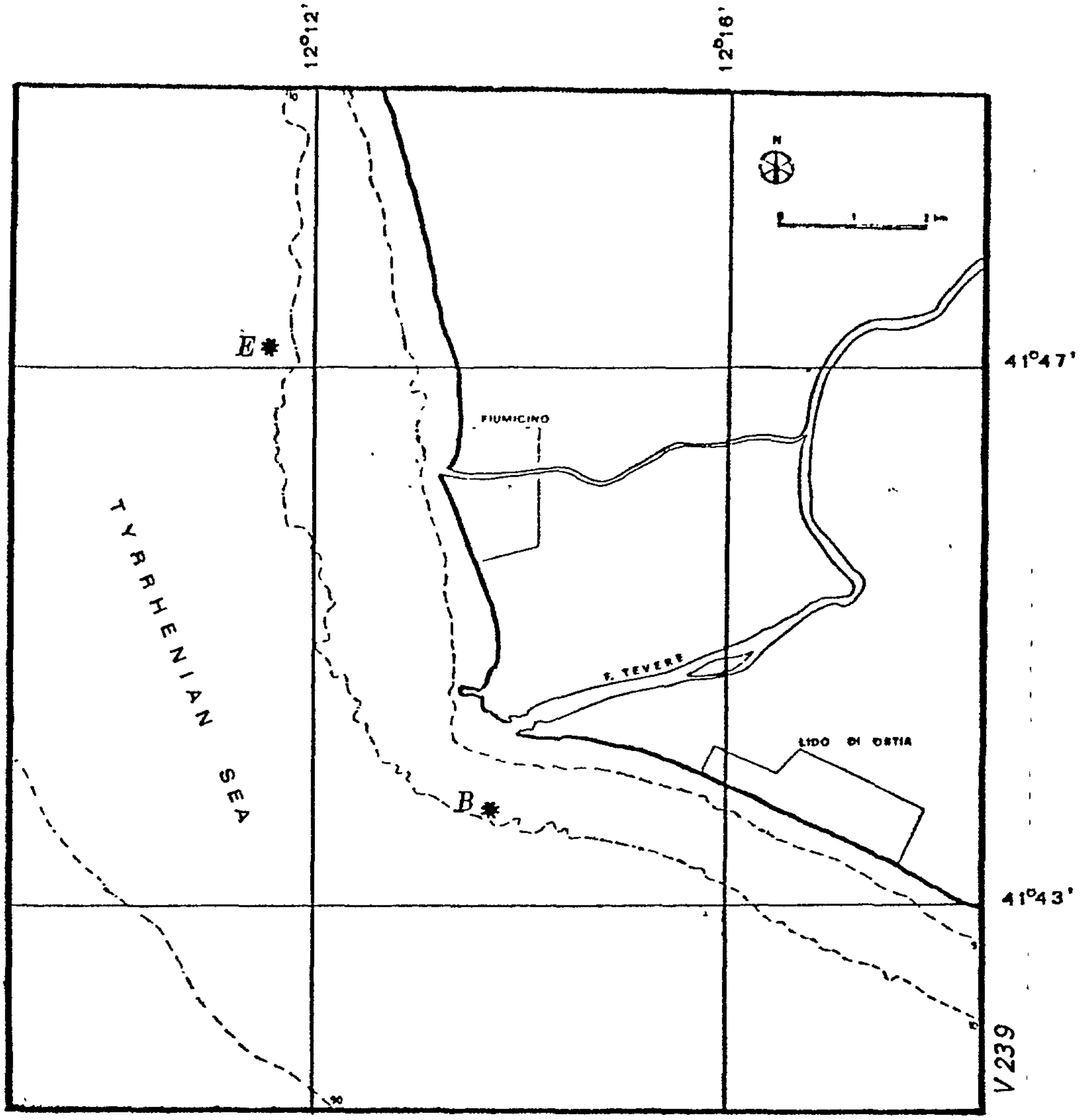


Fig. 1. Area of study



Stations' Coordinates

E { 41° 47' 52"
12° 11' 35"

B { 41° 43' 53"
12° 13' 52"

Fig. 2. Position of stations B and E for current velocity

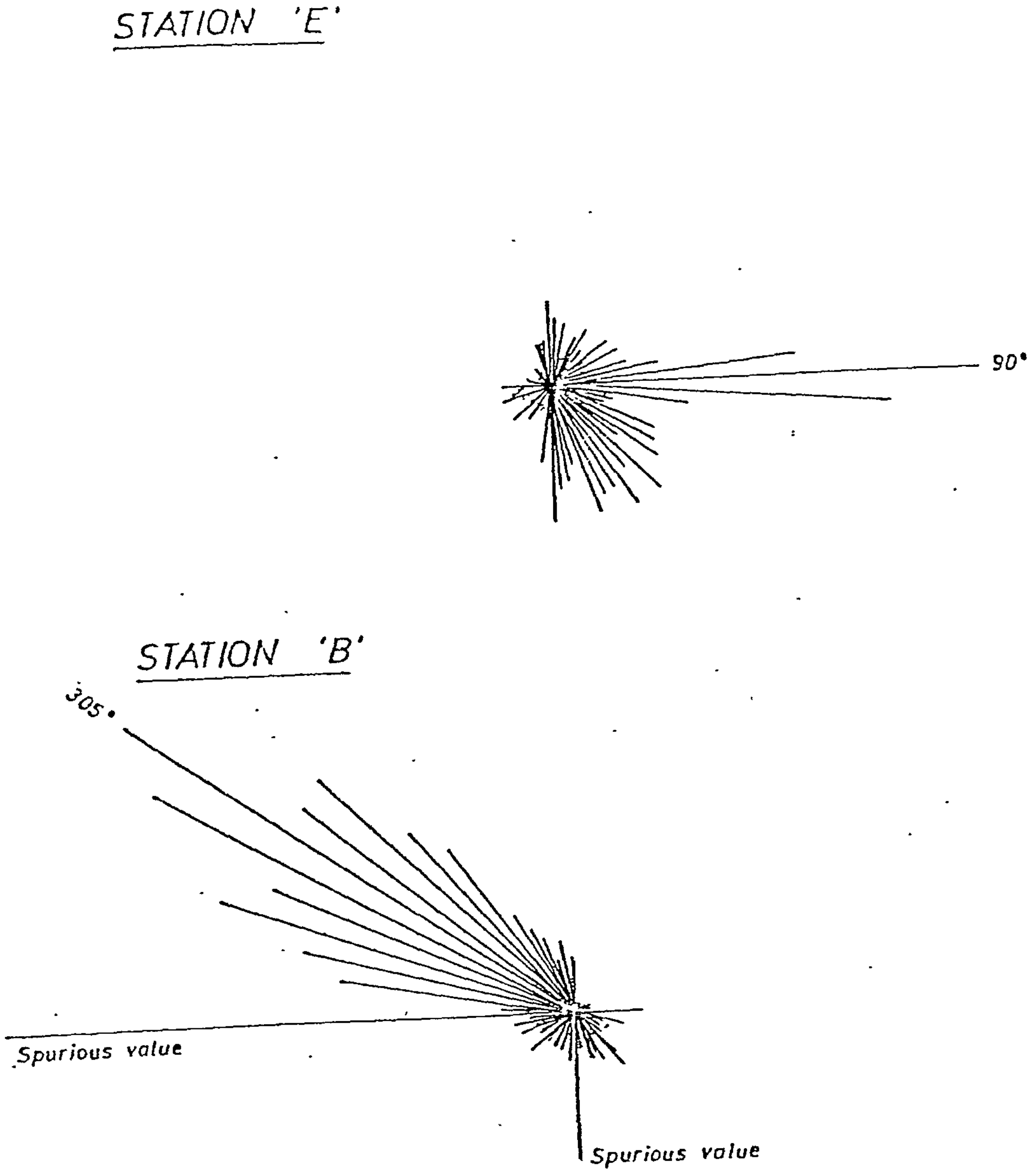


Fig. 3. Frequency distribution of longshore current direction 22-27 September 1976

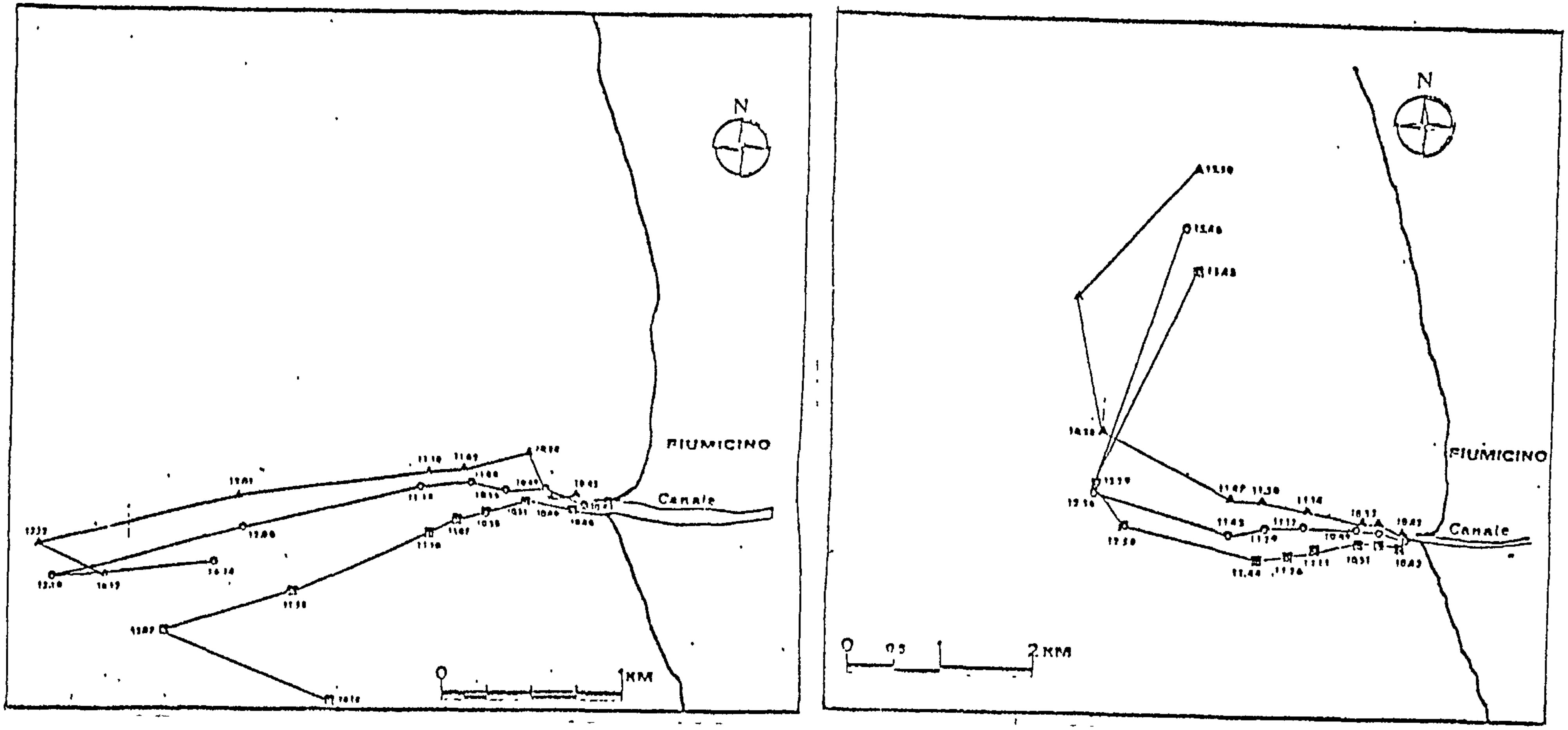


Fig. 4. Drogue paths from a release point at the northern (Fiumicino Canal), on 27 and 28 September 1977, with check times indicated

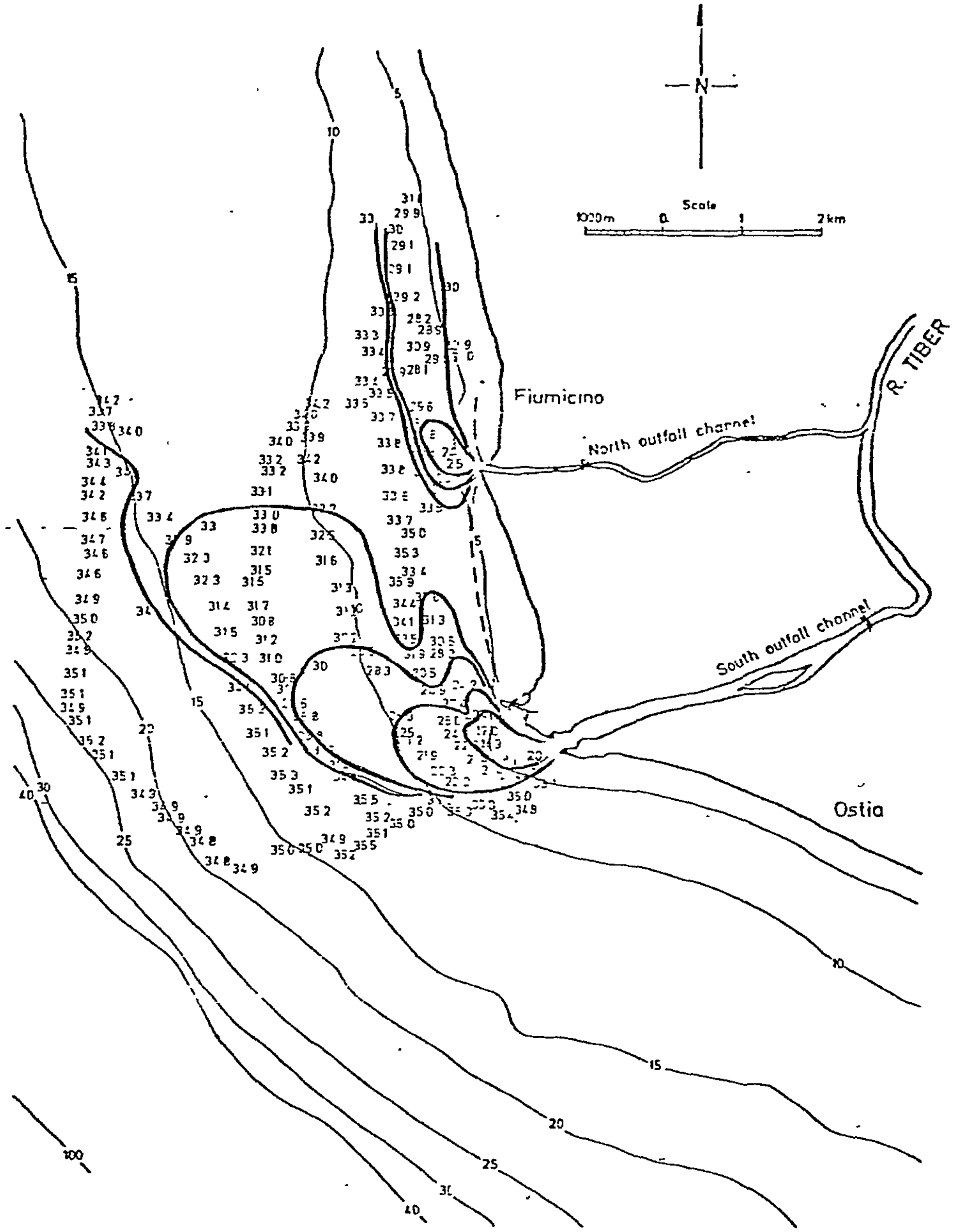


Fig. 5. Surface salinity distribution in the Tiber River plumes on 27 September 1976. Salinity - kg/m^3; depth contours - m.

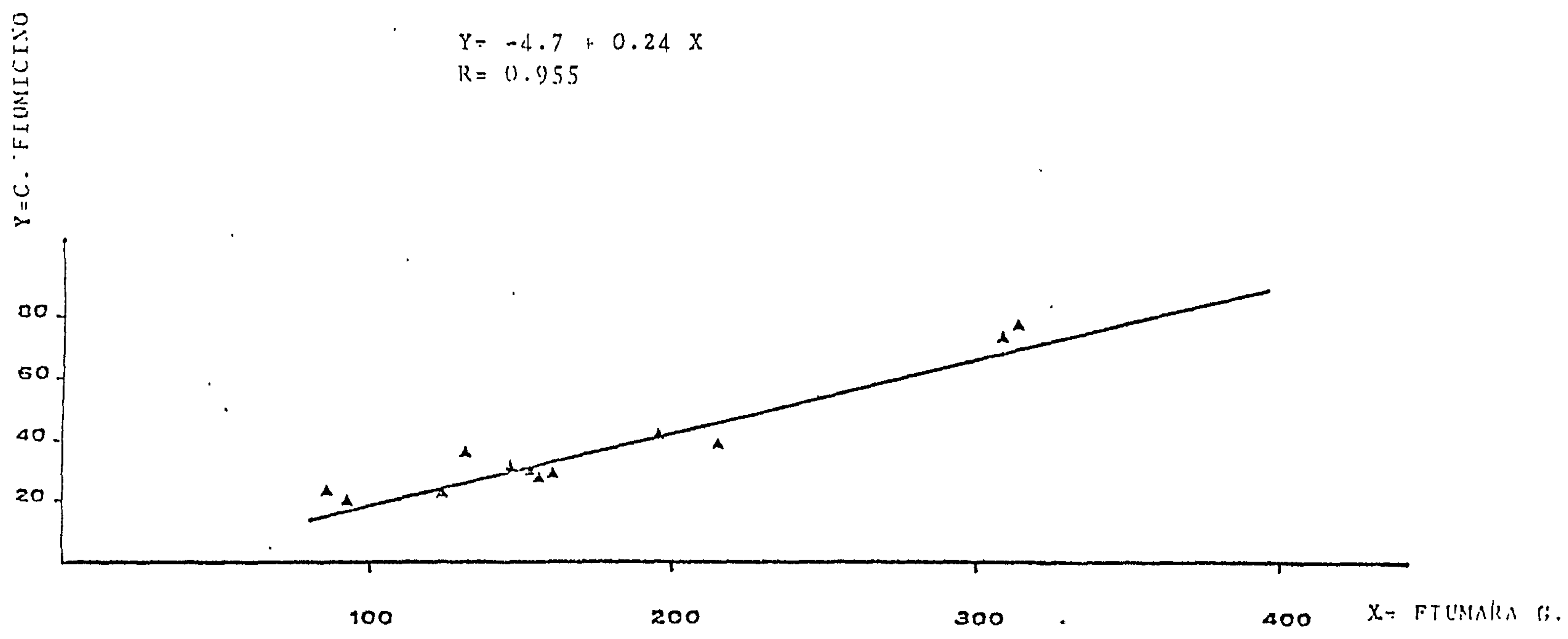


Fig. 6. Regression of the flow of the northern (Fiumicino) channel on that of the southern (Fiumara Grande) channel

Research Centre: Group for Oceanographic Research - Genova
Institute of Hydrobiology and Fish Culture,
University of Genova
GENOVA
Italy

Principal Investigator: I. DAGNINO

INTRODUCTION:

Previous activities relevant to MED POL VI in coastal waters have been carried out since 1952, particularly during the International Geophysical Year (1958). Some research on water-mass movement along the coast has been carried out in recent years, but still prior to MED POL.

AREA STUDIED:

The Ligurian Sea

Two hydrographical transects, one from Genova to Corsica and the other from Corsica to Imperia, were made on three cruises in October 1978 (6-8, 14-15 and 22-23). At each station the mean temperature (Tm) of the water column down to 400 m., and the geodynamic height (ΔH) were calculated.

MATERIAL AND METHODS:

In view of the difficulty of anchoring current meters in deep water, and since a sufficient quantity of them was not, in any case, available, the off-shore circulation was studied using data on hydrographical and meteorological parameters.

RESULTS AND THEIR INTERPRETATION:

The transects are shown in figures 1, 2 and 3 with plots of the mean temperature and the geodynamic height at each station. The central part of the Corsica-Imperia transect was clearly affected by the cyclonic vortex which is typical of the Ligurian Sea. In contrast, the central part of the Corsica-Genoa transect presented within 18 days, in two meteorological perturbed periods, two divergences which were interrupted by a convergence which appeared during the fine weather, separating the two periods of bad weather.

These results show that the waters between Genoa and Corsica are more easily influenced by the weather conditions than those between Imperia and Corsica. Differences in the submarine topography are also a significant factor. The presence of divergences in different seasons may modify direction and speed of the coastal currents, slowing down the renewal of the waters in the Ligurian basin. Such slowing down mainly occurs in the eastern-most part of the Ligurian Sea.

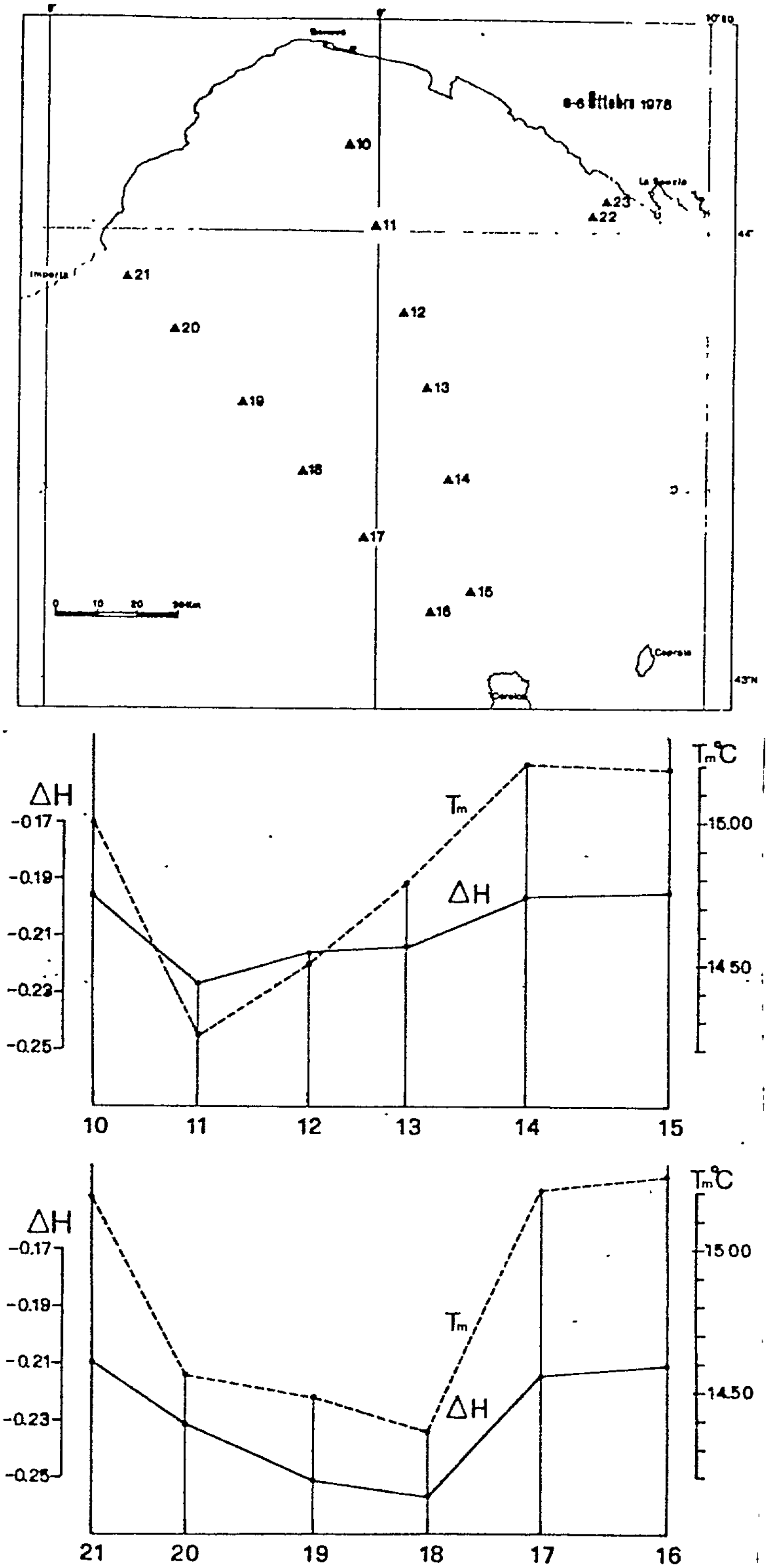


Fig. 1. The mean temperature (Tm) of the water column (0-400 m) and the calculated geodynamic height (ΔH) at twelve stations on two transects in the Ligurian Sea (8 October 1978)

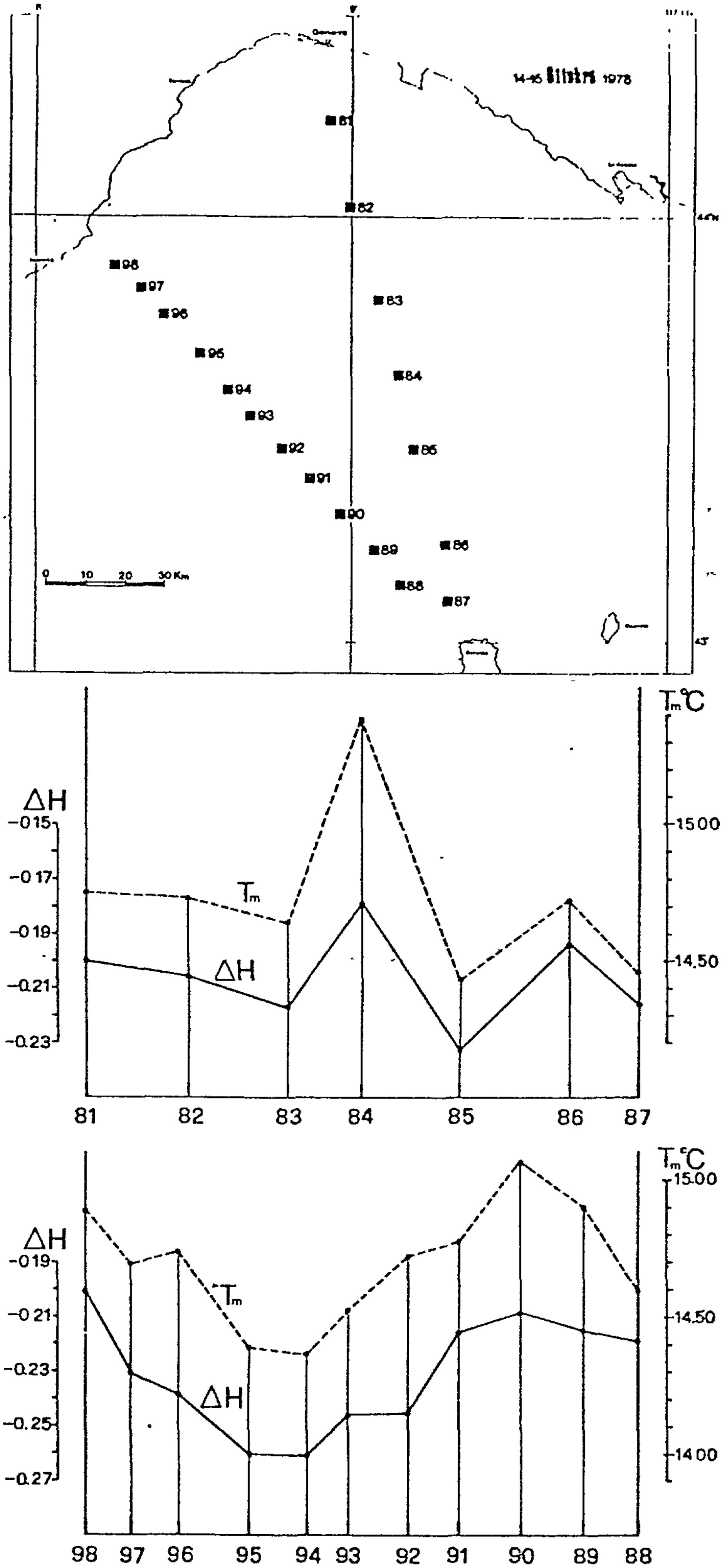


Fig. 2. The mean temperature (Tm) of the water column (0-400 m) and the calculated geodynamic height (ΔH) at twelve stations on two transects in the Ligurian Sea (14-15 October 1978)

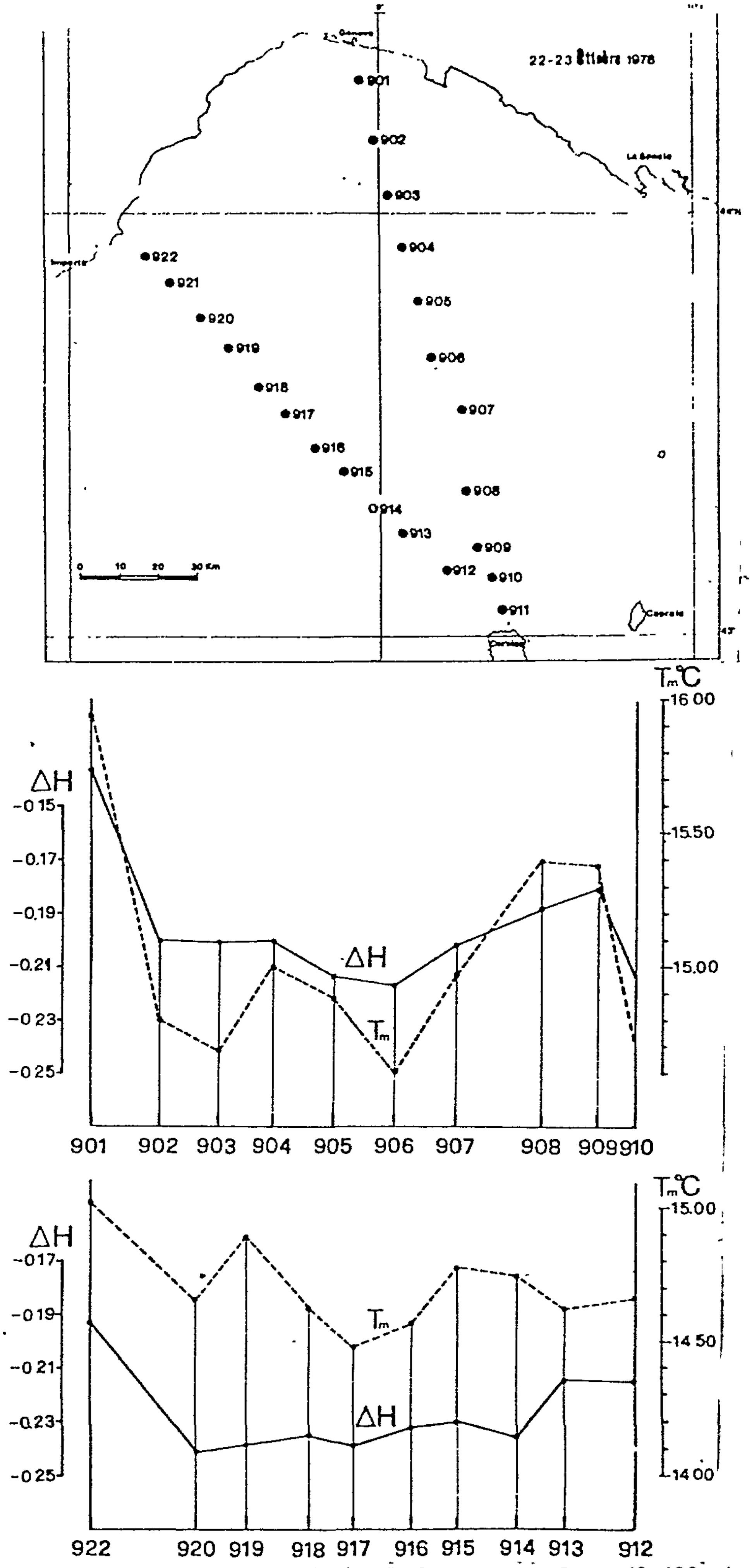


Fig. 3. The mean temperature (Tm) of the water column (0-400 m) and the calculated geodynamic height (H) at twelve stations on two transects in the Ligurian Sea (22-23 October 1978)

Research Centre: University of Malta
MSIDA
Malta

Principal Investigator: D. A. HAVARD

INTRODUCTION:

The coastal water stratification and circulation is being studied under this project. Measurements have been taken of thermal structure and coastal current flow. Previous data of relevance to the project have been collected.

In the study of the problems of the coastal transport of pollutants, which may be considered as either local or external, it is useful to identify the sources and inflow of pollutants. The major effluent outfalls are located at Wied Ghammieq, Malta and Ras il-Hobz, Gozo. Both outfalls have recently been modified and are now submarine outlets. The effluent is mainly domestic waste. Grand Harbour may also be considered as a minor source of pollutants, owing to the concentration of shipping and the presence of dry docks. The other major source of pollutants is from shipping at sea, since Malta lies close to major shipping lanes.

Coastal water and coastline pollution from external sources present a greater problem. The pollutants that reach the coastal region in a relatively concentrated form are oil products. Tar balls may be washed up anywhere along the coastline. The potential threat to Malta of an oil slick being transported on to the coast is serious. The Maltese Islands are relatively small and it would not require a very large spill to damage a large proportion of the coastline. In such a case not only the ecology but also the economy would suffer since tourism is very important to the economy, providing more than a tenth of the foreign exchange earnings. It is interesting to note that the area of the suspected oil spill west of Malta reported by Stumpf and Strong (1974), was nearly as large as Malta. A small spill of only about 100 tons of water-in-oil emulsion reached the east coast of Malta on 4 December 1979. Fortunately this has been successfully cleaned up.

AREA STUDIED:

The area of primary interest selected for the study of surface and sub-surface currents is the eastern coast of Malta.

MATERIAL AND METHODS:

Currents:

Sub-surface currents were measured during the summer of 1978. A recording current meter (Aanderaa RCM 4) is stationed 800 m offshore at the location of the newly constructed submarine outfall (35°54.0'N; 14°32.7'E). The meter was moored 25 m from the surface in a total depth of 35 m using a sub-surface taut-mooring.

Three tapes were sent to the Instituto de Investigaciones Pesqueras in Barcelona where progressive vector diagrammes and component time series plots were prepared by A. Cruzado. A frequency-spectrum analysis is being carried out.

Prior to the arrival of the RCM, spot-flow measurements were taken using a Braystoke flowmeter and a Toho Dentan direct-reading current meter model CM2. These measurements were taken from a moored boat. The data are summarized in Table I.

A drift-card experiment, using vertically floating cards (25 cm x 12 cm) was conducted in 1973 and the results analyzed for this project. 240 cards were released in three experiments. Further drift-card releases in 1977 produced few significant new data.

The cards used in 1979 were horizontally floating cards, which were tracked for a few hours after release. An estimate of the possible speed of the cards was made from the recovery time and the possible path. The largest value from this was considered the most probable velocity.

The changes in coastal currents of the east coast have also been estimated by an indirect method. There are several obsolete submarine telegraph cables running from St. Julians, Malta. Some of these are broken in the coastal region. The potential difference between five cable ends and a reference earth is time-sampled and recorded potentiometrically. The technique is capable of indicating large-scale changes in the coastal currents.

Some remotely-sensed data from 'Landsat 2' have been inspected.

Bottom topography and the thermal structure of the water column have also been studied in other coastal areas around the Islands. To study the exchange between coastal and offshore regions, previous bathymetric, bathythermographic, station and current data have been collected from an area within about 100 miles of Malta.

Mechanical B.T. measurements have been taken at various stations around the Islands. Some samples have been collected using Nansen bottles but the accuracy of the salinity values is not, for several reasons, as high as required for useful intercomparison of results.

Wind speed and direction are continuously recorded at the meteorological station, Luqa. The mean hourly data are tabulated each month and a copy sent to the University for the MED POL projects.

RESULTS AND THEIR INTERPRETATION:

The predominant surface currents in the Malta area are from the north-west (mean speed about 0.2 m/sec) reflecting thhe flow of the surface water from the Western to the Eastern Basin. Levantine intermediate water flows south of Malta over the eastern sill of the Sicilian Channel between Malta and the Medina Bank.

Other factors influencing the water stratification and circulation around the Maltese islands are the local bathymetry and the surface wind field which, when strong, can produce large changes in the speed and direction of the coastal currents.

Fixed current meters - Progressive vector diagrammes and component plots were constructed from the measurements obtained with the recording current meters from May to September 1978. From these the diurnal variations and the mean transport of the water mass in the ESE direction and with an average velocity of 0.1 m/sec were evident.

During periods of light surface winds (less than 10 knots) the current sets along the coast to the south-east for the greater part of the day (about 16 hours) and reverses with weak currents for the rest of the day. During periods of stronger north-westerly winds (more than 20 knots) the current sets always to the south-east with a maximum velocity of 0.5 m/sec., the diurnal variation showing a change in speed but not direction. An increase in temperature of about 5°C, due to the storm-mixing of surface and sub-surface waters, was also recorded during these periods of stronger south-easterly currents.

The spot-flow measurements also show coastal currents setting to the southeast in the range 0.1 - 0.2 m/sec and with a vertical gradient with larger values near the surface.

Drifters, drift cards, drogues - The results of the drift-card experiment in 1973 show a coastal surface water transport in the range 0.1 - 0.2 m/sec over a period of a couple of days, to the south-east along the coast turning south at the south-eastern end of the Island despite light surface winds in other directions. The release in 1977 produced no significant data since a strong westerly wind developed taking the cards out to sea.

The releases in 1979 took place during south-easterly winds which produced a surface current along the coast towards the north-west. A drogue set at 1 m, which was released with a set of the cards, travelled with about half the velocity of the cards. The cards were tracked for the first few hours and had velocities of approximately 0.25 m/sec towards the north-west. Some cards were recovered on the north-east coast of Gozo having been transported 13 miles in less than one day. A change in wind direction to the north-west on subsequent days brought the cards back down the coast, one card being recovered from Marsacala on the south-eastern end of the Island.

Other indicators - Data from the submarine cables show that the current system often exhibits only small variations over periods of several days, whereas on other occasions, particularly in winter, changes of ± 0.5 m/sec may occur in a few hours in the North-South component of the current east of Malta (between Malta and the Hurd Bank). It is sometimes, but not always, possible to associate these with strong winds. The greatest change recorded was during a period of persistent north-westerly gales when this method indicated coastal water transport in excess of 3 m/sec. setting to the south-east.

Previous current data for the area around Malta are available from measurement of ships' drift. These data cannot be well localized or very accurate but they do show a high degree of variability in the estimated current, particularly during the winter months. The mean of a large number of readings over several years gives a value for the current in the range 0.1 - 0.2 m/sec setting to the south-east.

Subsurface currents measured in September 1972, 50 miles south-east of Malta, reported by Ozturgut (1975), have velocities in the range 0.1 - 0.2 m/sec setting to the south-east. The data reported are not inconsistent with diurnal current variations.

Remotely-sensed data from 'Landsat 2' recorded on 28 March 1975 (ERTS E-2065 - 08555 - 4) showed large surface eddy systems north-east of Malta. The complex character of the surface water in this area, observed by aircraft and shipping, has been previously reported (Briscoe et al. 1972). The islands in the flow of surface water from the western to the eastern basin of the Mediterranean generate eddy systems, mainly to the east and south-east of the islands, with complex current flow in the channels between the islands. It is highly probable that similar eddy systems also affect the coastal currents around Malta.

The hydrographic data for the area around Malta clearly shows the less saline surface water flowing south-east past Malta from the western to eastern basin of the Mediterranean and the more saline Levantine intermediate water flowing in the reverse direction south of Malta. In calm summer conditions a diurnal variation in the coastal current has been observed and strong stratification of the water mass also occurs. In winter the water mass is well mixed to depths in excess of 50 m by the winter storms which strongly influence the surface currents, producing highly variable currents.

The immediate problem of the coastal transport of pollutants from the major effluent outfalls has been partly solved by the construction of submarine outlets, the effluent now being rapidly dispersed into a large body of water. However, the potential threat to Malta of an oil slick being transported on to the coast is serious. The coastal current system is so variable, particularly in winter, that no section of the coastline may be considered safe from this potential source of pollution.

Table I. Summary of current data obtained by shot flow measurements

Date	Location	Depth of meter	Current Speed ± 0.03 m/sec	Direction
31.10.75	35°54'N	1 m	0.17	S.E.
	14°33'E	15 m	0.15	
21. 5.76	35°57'N	5 m	0.16	S.E.
	14°28'E	2 m	0.19	
4.11.76	35°54'N	3 m	0.25	S.E.
	14°33'E	15 m	0.24	
28. 4.77	35°4'N	3 m	0.13	S.E.
	14°33'E	10 m	0.14	
		20 m	0.11	
		24 m	0.10	
		15 m	0.12	
		10 m	0.17	
		5 m	0.20	
		1 m	0.25	

The following publications were based wholly or partly on work done in this pilot project:

HAVARD, D. A. (1978). The study of the problems of the coastal transport of pollutants in Maltese coastal waters. IVèmes Journées Etud. Pollution, pp. 555-557, Antalya CIESM.

HAVARD, D. A. (1979). Water stratification and circulation around the Maltese Islands. Rapp. Comm. Int. Mer. Medit. 25/26 7, 153.

References

BRISCOE, M. G. et al. (1972). The Maltese oceanic front: a surface description by ship and aircraft. In Oceanography of the Strait of Sicily SACLANTCEN Conf. Proc. 7, La Spezia, Italy. (Allen et al.eds.), pp. 153-175.

OZTURGUT, E. (1975). Temporal and spatial variability of water masses: the Strait of Sicily (MEDMILOC 72) SACLANTCEN SM-65, La Spezia, Italy.

STUMPF, H. G. and STRONG, A. E. (1974). ERTS-1 views an oil slick. Remote Sensing of the Environment. 3, 87-90 (1974).

Research Centre: Instituto de Investigaciones Pesqueras
Barcelona
Spain

Principal Investigator: A. CRUZADO

INTRODUCTION:

Relatively few oceanographic investigations have been carried out in the neighbourhood of Barcelona and the Catalan coast. Previous investigations in the Catalan Sea consisted mainly of hydrographic studies. The contribution of the Institute to MED POL VI was developed at three levels:

a) A comprehensive oceanographic Study of the Catalan Sea (Project TANIT), completed between 1976 and 1979, included standard observations in a large area of the western Mediterranean Sea, carried out in connection with other biological studies.

b) A detailed analysis of the coastal zone off Barcelona (Project MARESME), developed between 1976 and 1977, included periodic observations along a cross-shelf section, studies on the dispersion of fresh-water discharges (mainly sewage) in the area, and its effects on the distribution of sediments.

c) Development of hydrodynamical models, for the dispersion at the surface of a low-density water discharged at the shore-line, and of a computer algorythm for the integration of the most probable trajectories followed by drift cards (or drifters) in connection with the DRIFTEX (Drift Card Experiment) organized by the IOC within the framework of MED POL VI.

AREA STUDIED:

The area studied is the Catalan Sea (Fig. 1) and adjacent areas in the Golfe du Lion and Balearic Sea, for large-scale studies, and the shelf and shelf-break zone in front of Barcelona (Fig. 2). For the small-scale study the results from DRIFTEX cover a large area of the Mediterranean Sea, most of the western basin, but especially the north-western part from the Golf of La Spezia to the Cap Nao (Alicante).

MATERIAL AND METHODS:

The oceanography of the Catalan Sea was studied by means of three oceanographic cruises (MEDITERRANEO I, from 6 October to 2 November 1976 with 45 stations; MEDITERRANEO II, from 3 to 29 March 1977 with 27 stations coincident with the previous set; TANIT 79, from 4 to 15 August 1979 with 16 stations). The coastal zone off Barcelona was studied by means of 19 daily cruises carried out for miscellaneous studies.

Standard, physical, chemical, biological, as well as related meteorological observations were made on board the two research vessels B/O Cornide de Saavedra and B/O Garcia del Cid. Analyses of samples taken during project MARESME, near Barcelona, were carried out at the Institute's laboratories. Details of the techniques followed may be found in the final report of projects MARESME and TANIT.

No direct measurements of coastal or offshore circulation were taken but some estimations have been made by geostrophic computations from the density distribution of the general circulation of the Catalan Sea and of the longshore flow over the shelf off Barcelona.

A computer programming system for analysing drift-card data was developed. This system, and the systems for processing standard hydrographical, chemical and biological data, for graphic display of results, and for simulation of the theoretical models developed, was always run on a IBM 1130 computer system to which analog I/O and graphics terminals are attached. Sediment sampling, carried out in co-operation with Dr. J. Serra from the Department of Stratigraphy of the University of Barcelona, was done with a Van Veen grab sampler. Analysis of their physical and chemical characteristics were made following the technique described in the final report of project TANIT.

RESULTS AND THEIR INTERPRETATION:

Discussion of the wealth of data gathered throughout these studies cannot be easily summarized and must be considered as very preliminary. Several papers have been published or are under preparation that contain parts of the results obtained and their discussion in view of some proposed goal. However, a global analysis of the observational results, taking into account theoretical models developed and complementary data, especially meteorological, climatological, and sedimentological, has not yet been undertaken. Nevertheless, the following points may be considered:

General circulation:

Present results confirm, in a general pattern, previous analyses made by Allain (1960) of the surface circulation pattern in the Catalan Sea, showing a large cyclonic gyre, linking at the north with the larger gyre extending between the Ligurian Sea and the Golfe du Lion. This counter-clockwise circulation is made up of a fast longshore current on the western side, with speeds up to 40 cm/sec and probably more, responsible for the drift-card trajectories extending from the northern Ligurian Sea, along the coasts of Provence, and into the Catalan Sea, and a less defined current bordering the Balearic Islands with values of the same order as those of the western side, if not larger, and closing the gyre along the northern coast of Corsica and the Italian shores. On the southern end the gyre seems to be closed by a broad turn of the western boundary current south of the River Ebro. This circulation pattern seems to be sustained by the water and heat balance in the region that, in a very preliminary way, shows negative values, with warm, less saline surface water entering the Catalan Sea and cold, saltier water leaving it at greater depths. This implies the generation of deep and intermediate waters in the region. The water mass distribution (Salat and Cruzado 1980) favours the existence of the cyclonic gyre with the saltier Mediterranean water in the central zone and less saline Atlantic and continental waters in the periphery. This density distribution is in equilibrum with, and is maintained by, the divergence created by this circulation pattern.

Wind-driven circulation:

The only known persistent winds in the region are the Mistral from the north and the Tramontana from the north-north-west that often blow in the northernmost part of the Catalan Sea. The Mistral, a north-westerly wind blowing along the River Ebro valley, has only local influence and the easterly Llevant is rather episodic and only shows its influence through the high energy waves developed and the large amounts of rainfall discharged. The dominant winds are breezes blowing along the shores mostly from the south-west and especially in summer. Wind-driven surface circulation therefore shows a low-frequency component with a monthly period caused by the strong and persistent northerly winds that tend to strengthen the cyclonic circulation, especially the western boundary current to the north, near the Cape Creus. The current on the Balearic Islands side is less affected since these winds are seldom very strong in the area. On the other hand, the high-frequency component with a daily period caused by the breeze-like winds tends to be opposed to the main flow along the Catalan coasts and even to reverse it at the surface of shallow waters. The net nearshore flow is thus directed towards the south-west but with a lesser over-all transport than that occuring above the shelf-break. Geostrophic computations show the sense of the vertically integrated transport in the nearshore zone to be opposite to that of the shelf-break zone (Font 1978). Moreover, another effect of the south-westerly afternoon breezes is the mixing to a relatively great depth of the surface and sub-surface waters causing a faster dispersion of the fresh water discharged than otherwise occurs during the night and early morning, (Serra, Salat and Cruzado 1980).

Freshwater dispersion:

The Rhône and the Ebro are the main rivers discharging freshwater into the region. Both discharges, but especially the former, strongly affect the circulation pattern by significantly altering the density of the coastal waters. After temporary excursions to the north-east they are finally entrained to the south-west, along the shores, fertilizing to a considerable extent the coastal zones of the Golfe du Lion and the Golfo de Valencia. Minor rivers discharging along the shoreline may reinforce this effect, substantially altering the local conditions as far as pollution is concerned. However, the major concern comes from the large number of inhabitants discharging their domestic, industrial, and agricultural wastes into the coastal zone. This usage is in contrast with the recreational role given to these waters, frequented by millions of summer visitors.

The dispersion of the freshwater discharged into the sea was studied by round-the-clock observations and by theoretical model building. The former confirmed the expectation that freshwater plumes are basically controlled by surface wind drift thus being subjected to the high frequency oscillations of the breezes. During the night and early morning, or in winter most of the time, the plumes from the Rio Besos and the Barcelona sewage outfalls were seen to be directed towards the south-west, the low salinities confirmed to about one to two hundred meters from the shoreline. During Llevant storms, the same mechanism takes place and the larger depth of the surface mixed layer is balanced by larger freshwater discharges caused by the storms. On the other hand, south-westerly afternoon breezes drag the surface water to the north-east causing marked frontal zones to appear at the discharge points that bend to the north-east and extend offshore. Under these conditions, surface water is mixed with underlying saltier water, retaining some of its characteristics in the vertical direction only as small salinity or temperature minima (Serra, Salat and Cruzado 1980).

Theoretical models of plume dynamics and water dispersion were developed along these lines: Hydrodynamics of thermal plumes were analysed using various models, especially the ones proposed by Shirazi and Davies and by Adams, their application to specific sites being still under study (this work was carried out in cooperation with Dr. L. Jeftic and colleagues from the "Rudjer Boskovic" Institute at Zagreb, Yugoslavia, under a bilateral scientific agreement). Nearshore hydrodynamics flow under high-frequency transient wind regimes. (This part is at a very preliminary stage although the basic dynamics have been established and a proper algorythm is now being developed). A steady state dispersive model (Font and Cruzado 1978) to assess the extent to which pollutant-loaded water might affect the waters around the site of the discharge, was developed. For normal values of the eddy diffusion coefficients it was seen that pollutant concentrations were reduced to less than 1 per cent in a few hundreds of metres. The model appears to be very stable and promising for further investigations, including engineering applications.

In conclusion, although direct current measurements were not made owing to the unavailability of self-recording current meters, multidisciplinary research produced a general overview of the circulation, both in the coastal zone and in the open sea, which was extremely coherent and provided a good general framework for further investigations of local circulation problems related to specific environmental conditions to take place. As a by-product, great concern has developed with regard to the transfer of pollutants from coastal surface into open-sea deep waters via the formation of deep water involving mixing of pollution-loaded, low salinity surface waters with levantine intermediate water. Because of unavailability of funds, this is at present a case study only.

The following publications were based wholly or partly on the work done in this pilot project:

BAS. Cr., Ll. MIRALLES & J. M. SOUSA, 1980. Datos de las estaciones hidrográficas de la campaña Mediterráneo II. Datos Informativos (en prensa).

CRUZADO, A. 1978. Processing the DRIFTEX Data. IVème Journées Etud. Pollutions, Antalya, CIESM (1978): 589-593.

CRUZADO, A., J. SALAT, J. FONT & Ll. MIRALLES, 1979. Development of a computer method for processing drift-card data and analysis of DRIFTEX results. SC/UNEP 558225.

FONT, J. & A. CRUZADO, 1977. Modelo de simulación de un vertido costero. Invest. Pesq. 41(3): 647/654.

FONT, J. & L. MIRALLES, 1978. Circulación en el Mar Catalán. Res. Exp. Cient. B/O Cornide, 7: 155-162.

FONT, J. 1978. Courants généraux dans la mer Catalane en automne, IVème Journées Etud. Pollutions, Antalya, CIESM.

SALAT, J., J. FONT & A. CRUZADO, 1978. Datos oceanográficos frente a Barcelona (1975-1976). Datos Informativos, 5: 1-73.

SALAT, J., M. MANRIQUEZ & A. CRUZADO, 1978. Hidrografía del Golfo de Sant Jordi. Campana Delta (Abril 1970). Invest. Pesq., 42(2): 255-272.

SALAT, J. & A. CRUZADO, 1980. A computer method for processing drift-card data. Vème Journées Etud. Pollutions, Cagliari, CIESM.

SALAT, J. & A. CRUZADO, 1980. Masses d'eau dans la Méditerranée Occidentale.

Vives, F., 1979. Campaña MEDITERRANEO I (Octubre-Noviembre, 1976). Datos Informativos, 7.: 1-164.

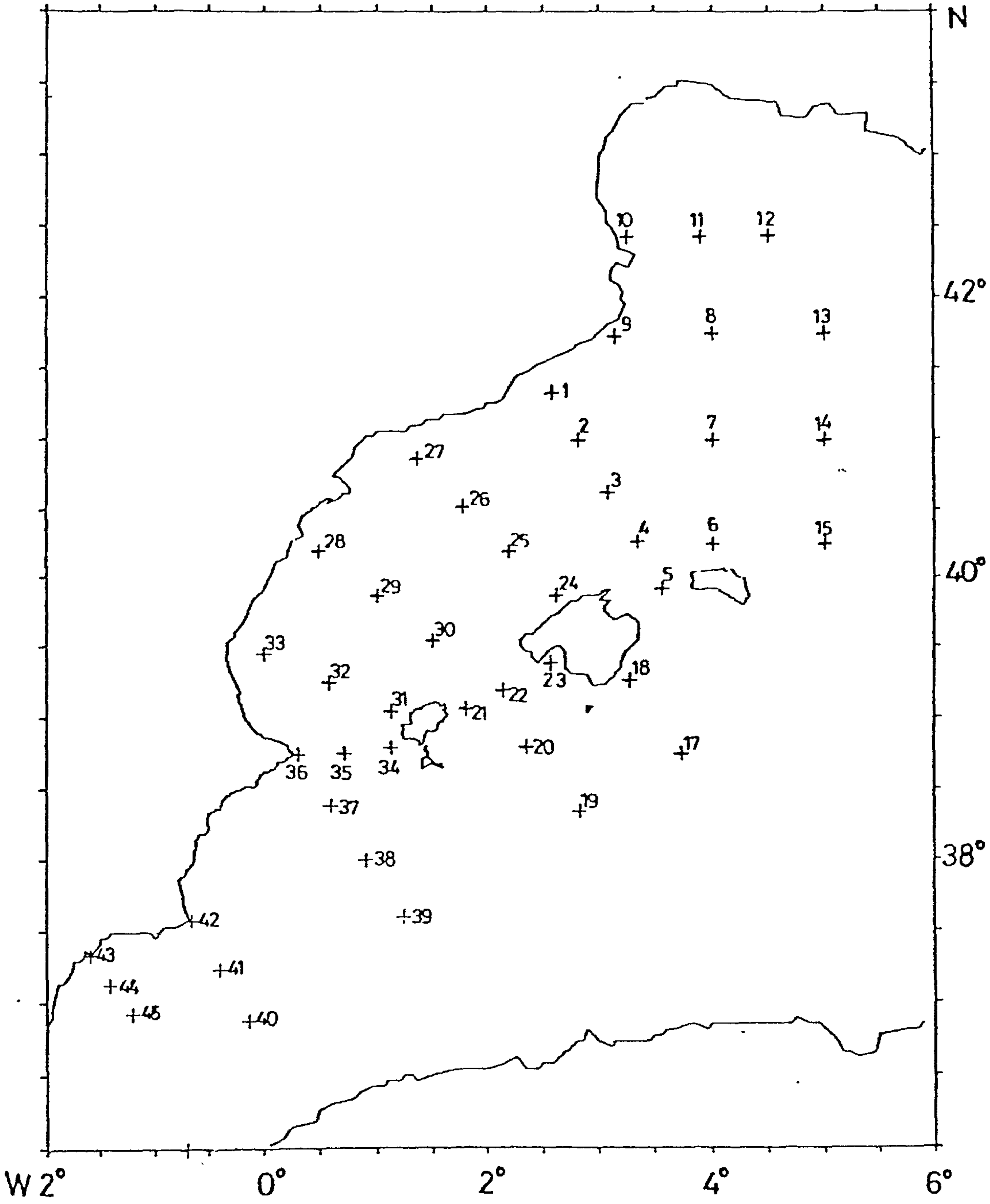


Fig. 1. Hydrographical stations covered by project TANIT

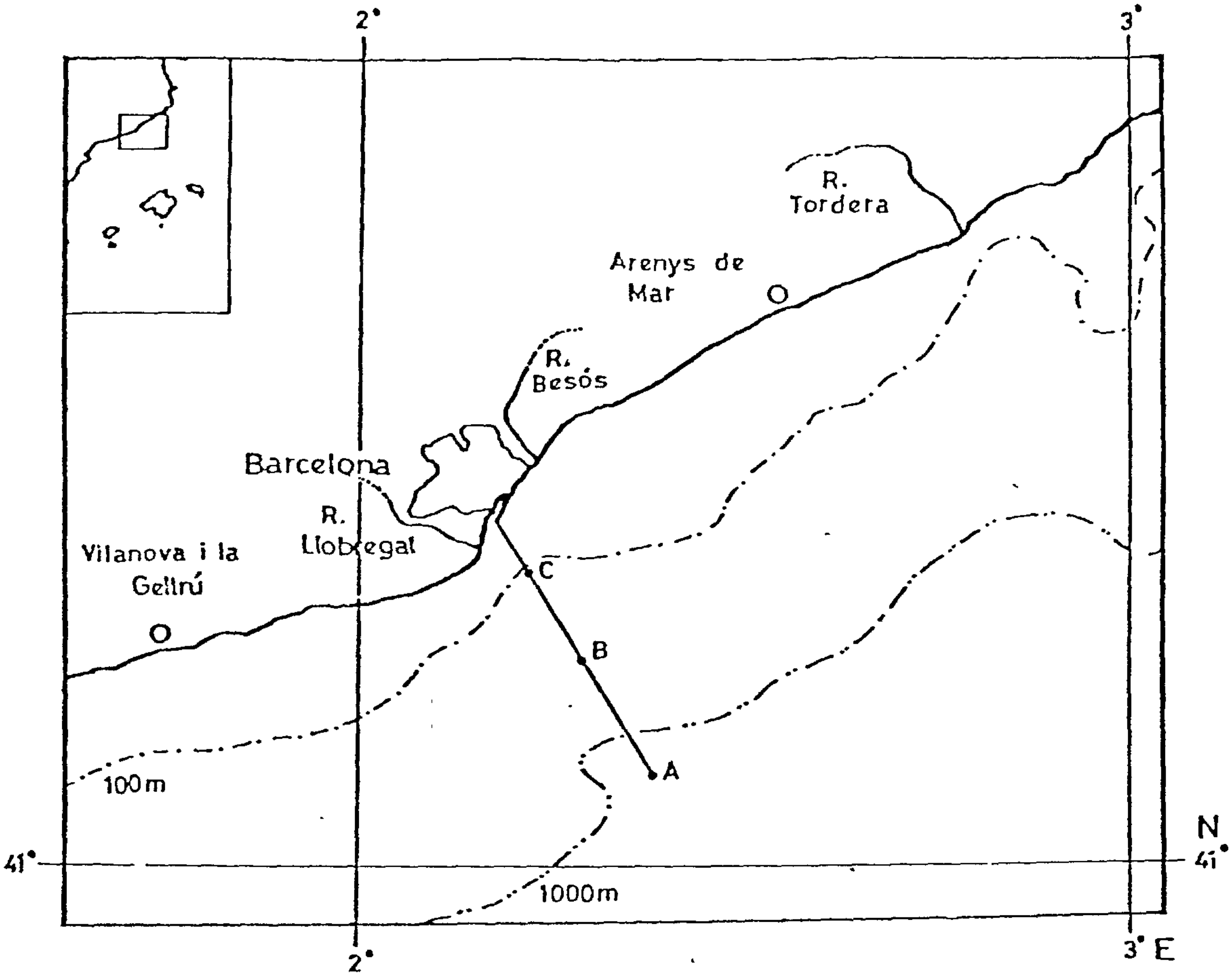


Fig. 2. Area covered by project MARESME. A, B and C hydrographical stations visited

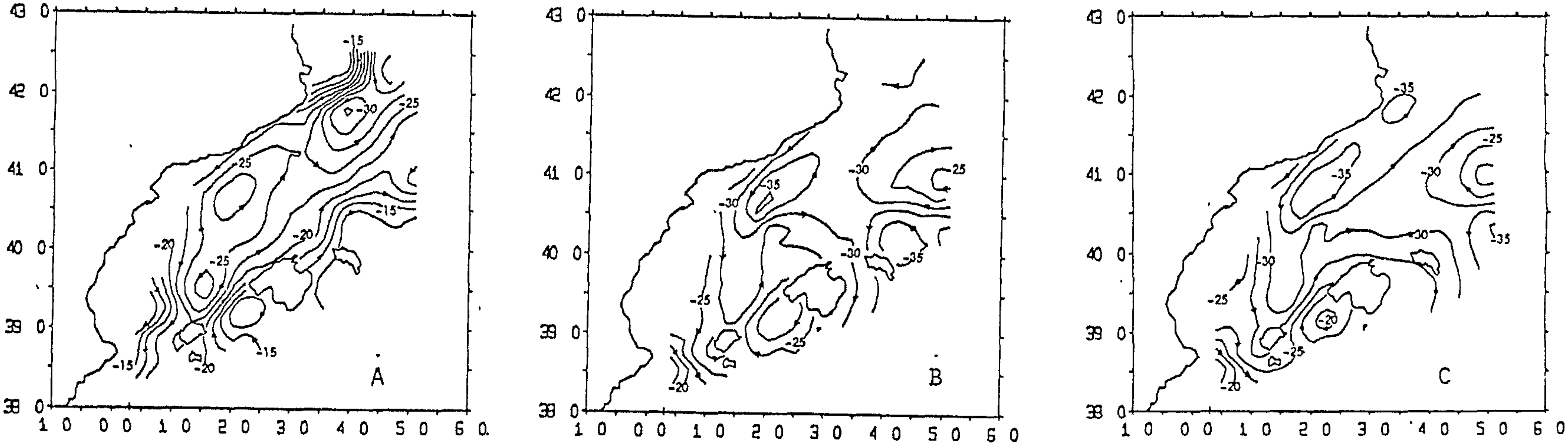


Fig. 3. Distribution of specific volume anomaly and water flow in the Catalan sea.

A = O DB level, B = 50 DB level and C = 100 DB level

Reference level 800 m

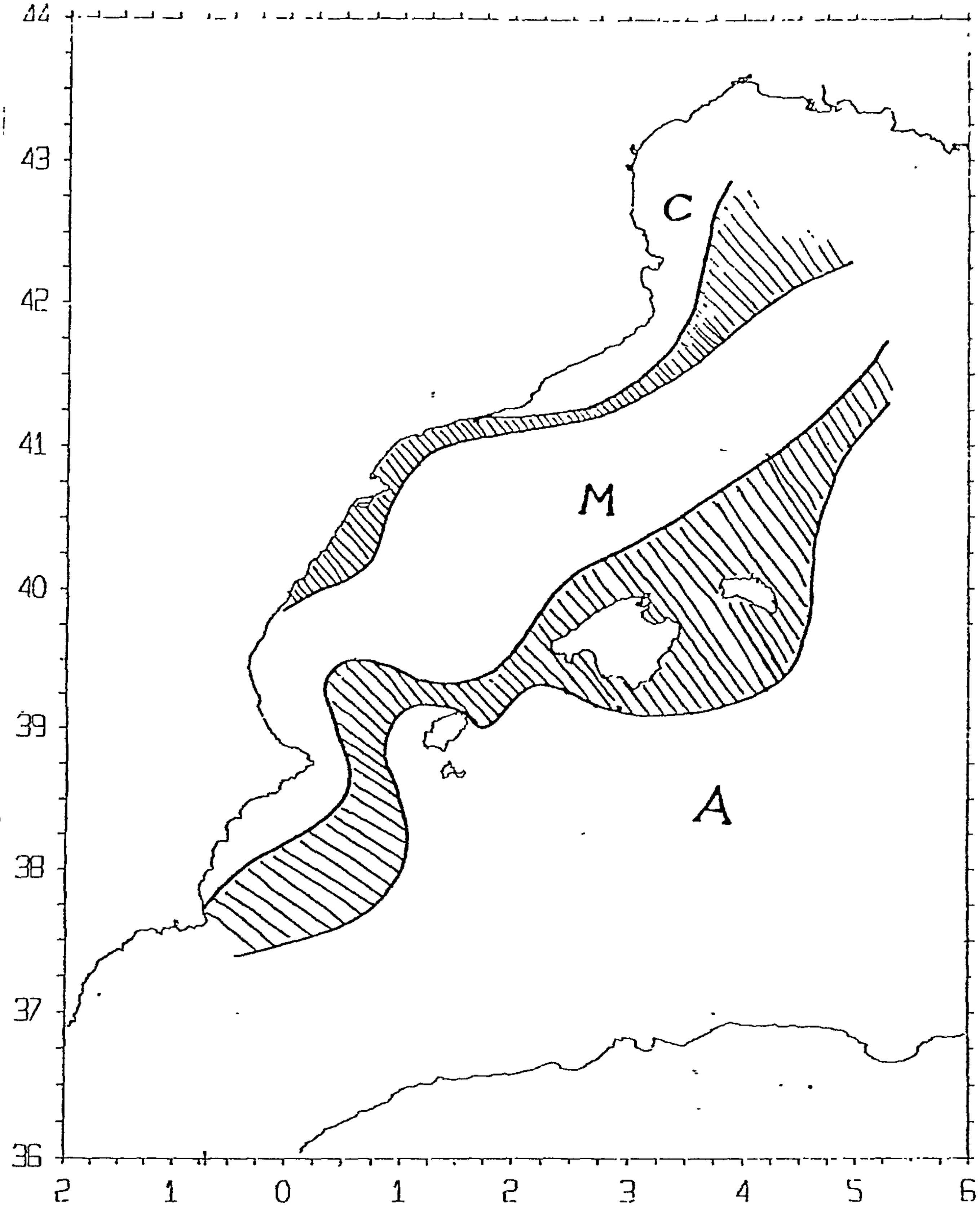


Fig. 4. Water mass distribution in the Catalan sea.
A = North Atlantic water, M = Mediterranean water and
C = Continental water, Shaded area are transitional

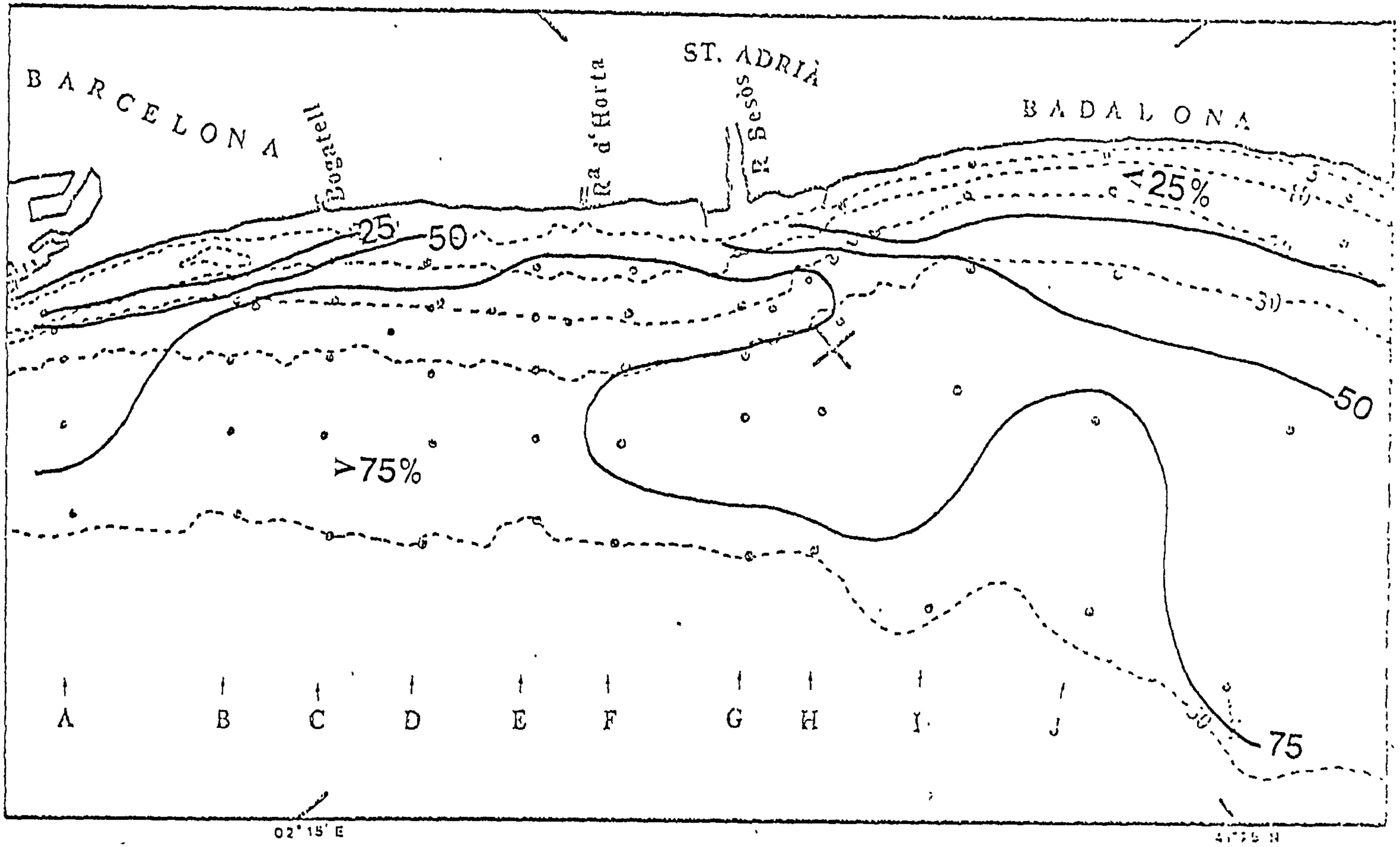


Fig. 5. Distribution of the finer sediments in the area off Barcelona.
Figures are % of total sediments with size below 45 micron

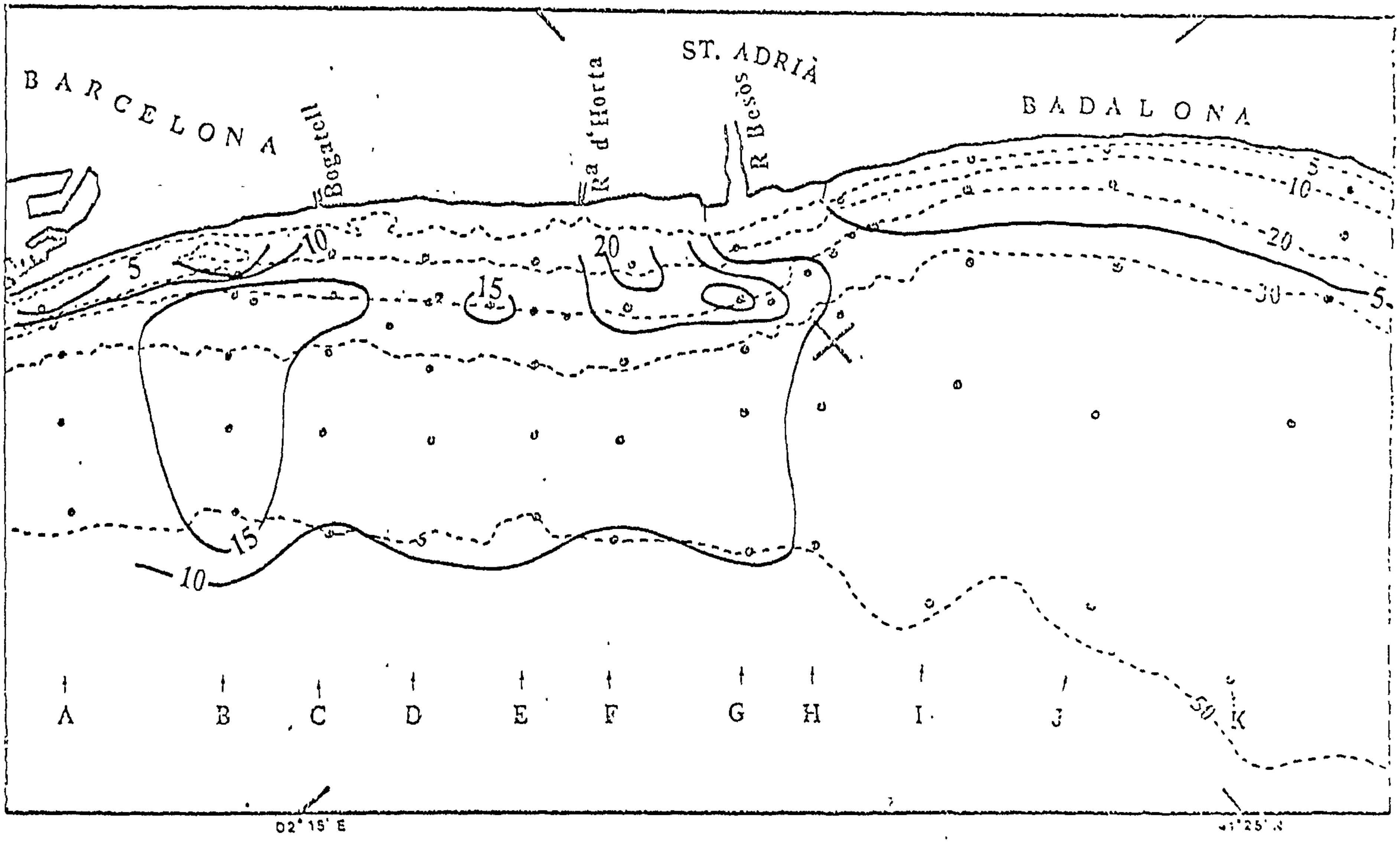


Fig. 6. Distribution of organic matter in the sediments in the area off Barcelona.
Figures are % loss at 400°C

Research Centre: Middle East Technical University
Marine Science Department
Erdemli, Içel
Turkey

Principal Investigator: U. Unlüata

INTRODUCTION:

The physical oceanographic research that may be relevant to the MED POL VI pilot project started prior to the commencement of the project. Since late 1976, the Department of Marine Science, Middle East Technical University, located on the south-eastern coast of Turkey (Fig. 1), has been actively participating in various data-collection programmes independently of MED POL VI.

The lack of previous research on the dynamics of the north-eastern Mediterranean waters is unfortunate because the south-eastern coastal zone of Turkey is undergoing rapid industrial and touristic development requiring knowledge of the motions of the local water masses and the relation of these motions to the larger scale oceanography of the eastern Mediterranean. Therefore, the relevant oceanographic research is now increasing.

The lack of information on the local current systems and the urgent need to develop a data base on the transport of various substances have led to the initiation of the investigation summarized here, as well as other studies.

A steady, counter-cloclwise (cyclonic) circulation has been claimed to exist (Lacombe and Tchernia, 1972). Some statistical information based on ship observations is available in the MEDTERRANEAN (1957) and the MEDITERRANEAN PILOT (1976), which reveal a highly variable current regime in the north-eastern Mediterranean. The variability manifests itself in the form of reversing flows.

An observational programme, as a basis for the assessment of the temporal variability and the energetics of the local current systems is discussed in this report.

AREA STUDIED:

Data have been obtained for the coastal margin of the north-eastern Mediterranean, from Iskenderun, in the east, to Anamur, in the west.

MATERIAL AND METHODS:

From 28 August to 30 December 1978, currents were recorded 3 km off Erdemli in about 35 m of water (Fig. 1). Aanderaa RAC-4 type self-recording current meters were used. A taut-mooring system was utilized with a current meter 20 m below the surface. The current meter was serviced monthly and the tape changed, or the entire instrument was replaced with another. Simultaneous measurements of wind velocity and sea level were made but these variables and their correlation with currents are not reported here.

The current meter was programmed to record data in 10-minute intervals. The digital current records were read and analyzed for alongshore and onshore components. The time series was then analyzed by taking the 24-hour mooring averages to filter out the high-frequency motions. The thus filtered time series was subjected to spectral analysis by fast-Fourier Transform techniques.

RESULTS AND THEIR INTERPRETATION:

The onshore flow as revealed by the low-pass filtered data is found to be insignificant (below 5 cm/sec), reflecting the directional preference of the total motion along the bottom contours. Much of the kinetic energy is in the low-frequency, alongshore component, the time series of which is given in figure 2, and the amplitude spectrum in figure 3.

Figure 2 shows that significant reversals in the current system occur with periods much greater than one day; there are considerable low-frequency motions. This is further exemplified in the amplitude spectrum (figure 3). The primary spectral peak occurs at 15.69 days (0.0637 cpd). A secondary peak is located at 41.83 days (0.0239 cpd). The tertiary peak at about 125 days cannot be regarded with confidence. Smaller energy levels at approximately 11, 6, and fewer days can also be seen in figure 3.

The mean flow over the measurement period is found to be about 6 cm/sec westwards. This agrees with the steady cyclonic flow in the eastern Mediterranean except, perhaps, in magnitude.

The observational programme partially summarized here reveals the existence of low-frequency motions in the coastal margins of the north-eastern Mediterranean. These motions are sufficiently great to dominate the mean flow, if any exists.

The observed fluctuations in the currents can be attributed theoretically to the wind-generated topographic Rossby waves which, as a result, amplify the trapping between Cyprus and Turkey (Unlüata, 1980). It can be shown that the observed motions on the shelf are driven by the off-shore motions; in other words, the coupling of the shelf waters to the inshore waters is rather strong.

The oscillatory nature of the current systems implies a net transport that averages to zero over a given period, unless the non-linearity is strong enough to generate a considerable flow in a particular direction. If not, any material introduced (either externally or internally) into the basin area between Turkey and Cyprus is liable to be trapped to a significant extent. The assessment of this possibility and other aspects of the meso-scale circulation in the north-eastern Mediterranean awaits expanded research.

The following publications are based wholly or partly on the work done on this pilot project:

UNLUATA, U., and LATIF, M. A. Towards an understanding of the shelf dynamics along the southern coast of Turkey. XXVI^{e} Congr. & Plenary Assembly, CIESM, Antalya, 1978.

UNLUATA, U. On the low-frequency motions in the Cilician Basin, submitted to the Journal of Physical Oceanography, 1980.

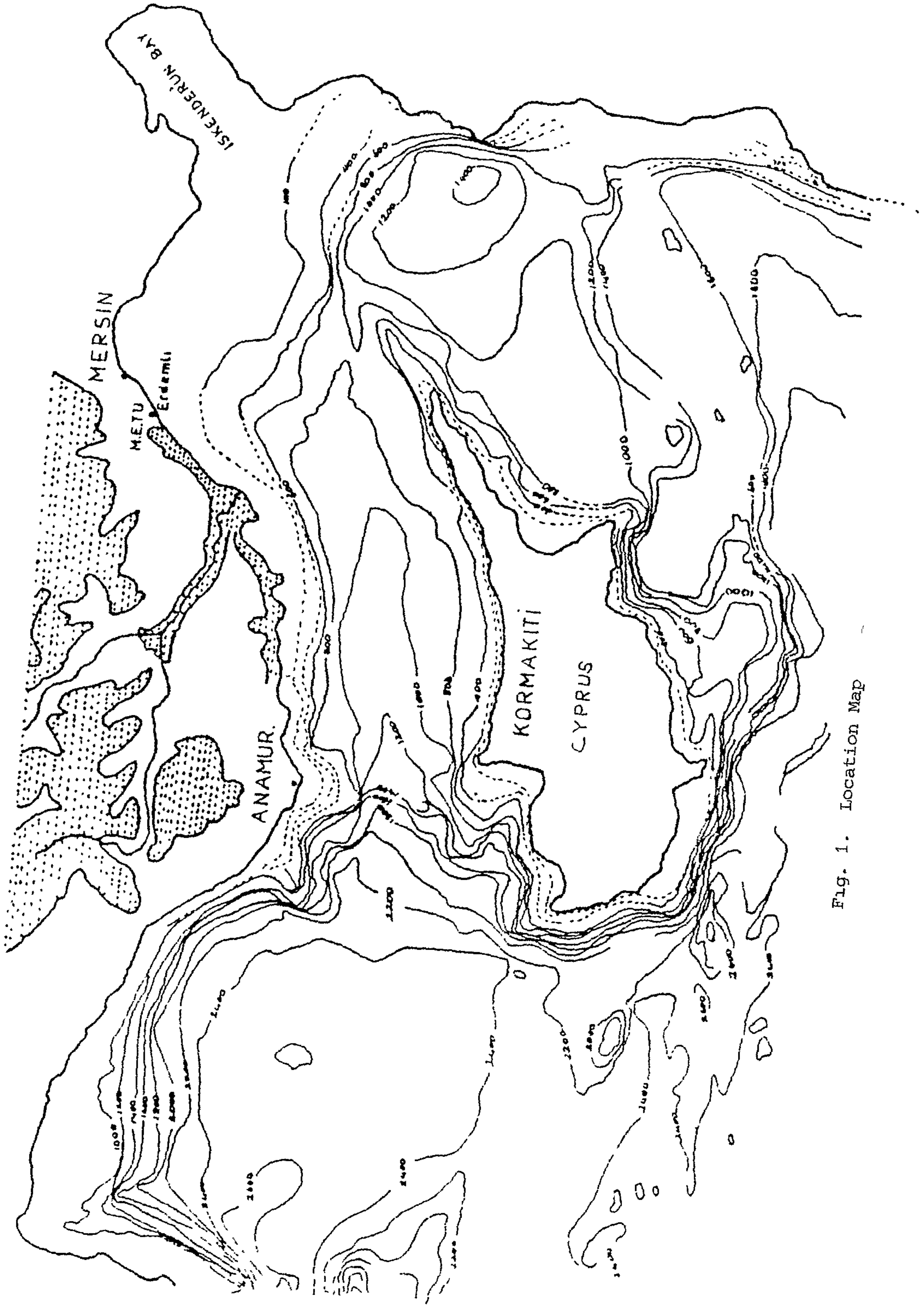


Fig. 1. Location Map

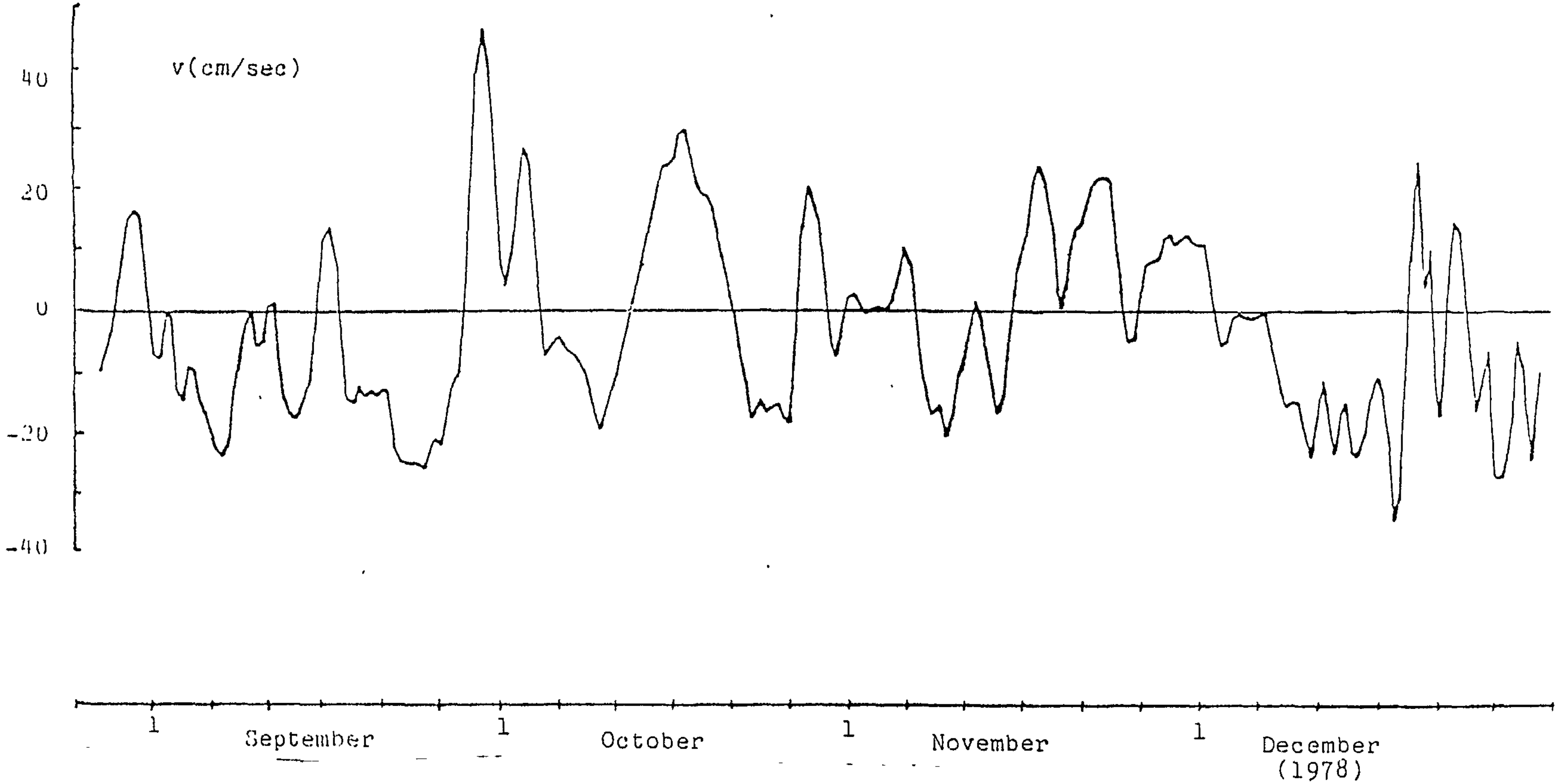


Fig. 2. Time series of alongshore current speed

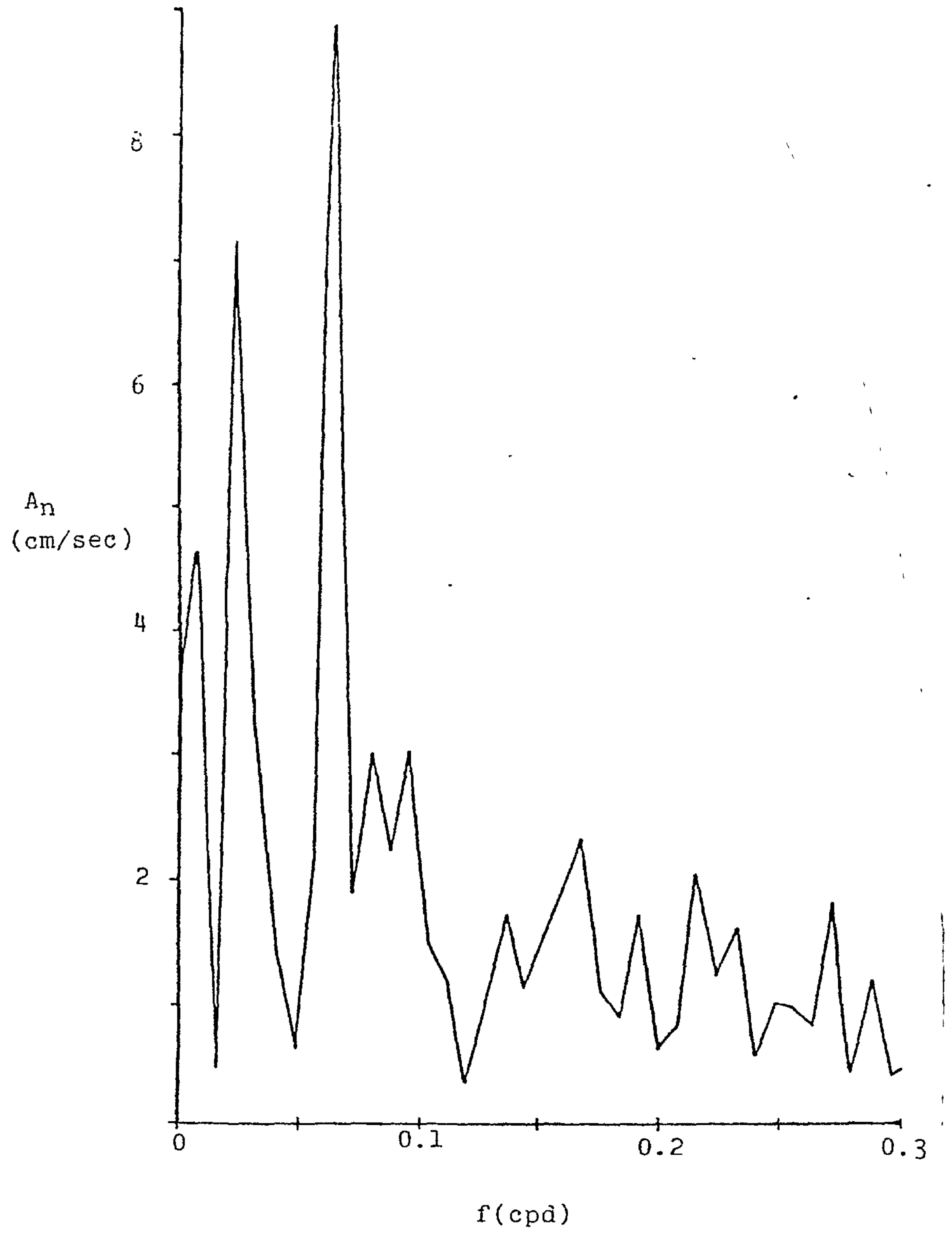


Fig. 3. Amplitude spectrum of alongshore current speed

Research Centre: Centre for Marine Research
"Rudjer Boskovic" Institute
ZAGREB
Yugoslavia

Principal Investigator: L. JEFTIC

INTRODUCTION:

The work done under MED POL VI forms part of a complete environmental study of Rijeka Bay. The research centre started this work in 1974.

AREA(S) STUDIED:

Rijeka Bay is located between the Istrian peninsula, the mainland, Krk island and Cres island (Fig. 1.). It is connected to adjacent waters through three channels: Vela Vrata, Srednja Vrata, and Tihi Kanal. Vela Vrata lies between the Istrian peninsula and Cres island. Srednja Vrata lies between Cres and Krk island. Tihi Kanal lies between the mainland and Krk island. The area of the Rijeka Bay is 449 km^2 and the Bay contains 26.9 km^3 of water. The average depth of the Rijeka Bay is about 60 m.

The only river worth mentioning is the Rijecina (length 17 km, width at the river-mouth 15 m). Rijecina has an extremely variable flow of water averaging 10-50 m^3/sec. At the sea-bottom in the northern part of Rijeka Bay there are fresh water springs of variable activities.

In 1971 the whole region had 300,000 inhabitants. It is projected that by the year 2000 the number will increase to 500,000.

Rijeka harbour has a yearly traffic of 13 millions tons; it is expected that by the year 2000 the traffic will increase to 80 million tons. There are several industrial enterprises operating or under construction along the Rijeka Bay shoreline, mostly around Rijeka, Bakar Bay and the north-western part of Krk island. Some of those enterprises are: a refinery, a fossil-fuel power plant, a petrochemical complex, a deep water oil terminal, a cokery, a paper-mill, and a shipyard.

Estimated BOD_5 load (estimated by means of survey) for Rijeka Bay is 3950 tons per year from domestic sources, 3050 tons per year from industry, and 150 tons per year from tourists.

MATERIAL AND METHODS:

The following basic parameters were measured: temperature, salinity, dissolved oxygen, surface currents (drifters and driftcards), sub-surface currents (autonomous current meters) and meteorological observations; pH, total alkalinity, specific alkalinity, total CO_2, nitrate, nitrite, ammonia, total phosphate, phosphate, silicate, zinc, lead, copper, mineral oils, hydrocarbons, phenols, detergents, surface active substances, phytoplankton, zooplankton, total coliforms, faecal coliforms, heterotrophs, and benthic communities were also measured or assessed.

Fixed current meters: Recording current meters were deployed at two main stations ("Aleksejev BPV-2r" and "Mecabolier") and at the following depths: 3 m below the surface, at the thermocline and at 3 m above the bottom. The current velocity was measured every five minutes during periods of 24 to 72 hours. Hourly, daily and 3-day vectors were calculated from available time-series data. Measurements were made at eleven stations five times per year.

Surface drifters and drift-cards: Six to eight surface drifters were released at 15 stations during each cruise; their movements were followed from the ship, and their mean velocities were calculated.

Driftcards prepared by the Naval Institute were used. At each cruise (five time a year) driftcards were launched at 12 stations (100 cards at each station). Driftcards were of different colours (25 of each colour were launched at each station). Recovery time and position were recorded and relevant calculations were made.

Dynamic computation of surface circulation: The classical method of dynamic topography was used, the 30-decibar surface relative to the sea surface was calculated for Rijeka Bay for ten cruises in 1976 and 1978.

Study of the exchange of Rijeka Bay water with the adjacent sea area: The exchange rate of Rijeka Bay has been calculated using daily current vectors for all three channels connecting the bay with the adjacent sea (Vela Vrata, Srednja Vrata and Tihi Kanal).

Two methods were used; both assume that the component of the current vector that is perpendicular to the cross-section is constant over the width of the channel.

Thermal plume modelling: Seven models were compared in terms of their structural, predictive and implementational characteristics. On the basis of this comparison the Shirazi-Davis model has been chosen for application to the Urinj and Sepen sites where discharges of cooling water from a power plant and a petrochemical plant, both under construction, are planned. The model was successfully applied at both locations to get spatial behaviour of the steady-state temperature field.

RESULTS AND THEIR INTERPRETATION:

Fixed current meters, drifters and drift cards: A large amount of data has been collected, using hydrographic measurements, fixed current meters, drifters and drift cards. Since it would be impossible to present all data collected (even in the most summarized form) in the present report, only representative results will be given.

In figure 2 a comparison of currents measured at various depths in September 1976, December 1976, September 1977 and December 1977 is given.

In Fig. 3 a comparison of circulation patterns in Rijeka Bay obtained by fixed current meters, drifters and drift cards is given. Results are presented for four cruises: December 1976, February 1977, August 1977 and September 1977.

Other indicators: A short summary of the results and conclusions drawn on the basis of (a) dynamic computation of surface circulation; (b) study of the exchange of Rijeka bay water with adjacent sea; and (c) thermal plume modelling at the Urinj and Sepen sites, is given below.

The mean value of the water flow through Rijeka Bay is 0.1 km^3 per hour which corresponds to a flushing time of 11.25 days. This value varies from 0.05 km^3 per hour (τ= 22.5 days) at the begining of June to 0.27 km^3 per hour (τ = 4.2 days) in the middle of December.

In winter (December 1976 - February 1977) in Rijeka Bay, the surface currents are cyclonic. In summer (August 1977) a rotatory flow prevailed, especially in the northern and north-westerly parts of Rijeka Bay. In September 1977 the wind was an important factor in the formation of the current pattern in the Bay.

The exchange of water masses of the Rijeka Bay is achieved by two processes: circulation of water and tides. The circulation contributes two-thirds to the exchange, and tides contribute the remaining third.

Rijeka Bay can be divided into the following zones on the basis of the results obtained and their hydrographic and hydrodynamic characteristics.

The Vela Vrata and Srednja Vrata channels and the southern part of the Bay have the most intensive exchange of water and the more homogeneous hydrographic characteristics. Between Vela vrata and Srednja Vrata there is a water circulation system working either clockwise or counterclockwise.

The part of the bay next to Krk island and the central part of the Bay are fairly often under the influence of inflowing currents from Srednja Vrata, resulting in higher salinity. This zone of higher salinity, depending on the currents, can extend as far as the city of Rijeka.

The northern part of Rijeka Bay is under the complex and variable influence of fresh waters from bottom springs, the river Rijecina and sewage outlets. Most of the time the currents in this zone exhibit a circular behaviour, and it is here that the most pronounced variations in hydrographic characteristics are to be found, especially in the surface layer.

Bakar Bay is an autonomous entity. It is under the strong influence of fresh waters from precipitations and bottom springs. This influence is also evident in the vicinity of Tihi Kanal and in most of the northern part of the Rijeka bay.

It has also been found that the exchange of water in Omisalj and Bakar Bays is governed only by tidal processes.

The value of the drift-card experiment was proved by the great similarity of results obtained by drifcards, current meters and drifters.

On the basis of dynamic topographics of the 30-decibar surface relative to the sea surface it was concluded that a semicircular surface gradient flow exists in the southern part of the Bay and in Vela Vrata and Srednja Vrata. This flow changes direction: from anti-cyclonic during summer months to cyclonic during the rest of the year. These results cannot be accepted with full confidence because of the numerous limitations of the methods.

Calculation of the exchange of Rijeka Bay water with the adjacent sea shows that from the beginning of September to the end of April the water enters through the Srednja Vrata and leaves the basin trough the Vela Vrata (cyclonic direction) at a rate of nearly 0.2 km^3/h, whereas from May to the end of August the water enters through the Vela Vrata and leaves the basin trough the Srednja Vrata at a rate of nearly 0.07 km^3/h (anticylonic direction). It has been shown that Tihi Kanal does not contribute significantly to the exchange. Most often there are two distinct layers with opposite directions of water movement, of which the upper one is dominant. This means that the direction of exchange just described is valid for the upper layer.

Results of the thermal plume modelling at the Urinj site indicated that only the nearest region of the discharge was affected. Annual changes in the ambient conditions apparently caused an order of magnitude change in area, volume and heat content within any particular contour of the plume calculations performed for the ambient conditions measured; the 1°C isotherm had a maximum surface area of 3284 m (December 1975), maximum width of 37 m (December 1976) and maximum depth of 51 m (May 1974).

Employing the Shirazi-Davis model at the Sepen site it was found that the round-jet design was superior since it mixed the heat effluent sufficiently in the vertical direction to reduce surface temperatures without causing bottom interaction. The round-jet discharge with the intermediate temperature difference best satisfied the design criteria.

An investigation of the surface currents with drift-cards is practical, informative, and cheap. The drawback of such an experiment is the inability to measure the real speed of currents in the surface layer. The colour of the driftcards does not play a role in the percentage of recovery, but, for practical reasons, it is advisable to carry out each launching with cards of different colours.

The computer programme developed for calculating the exchange of water masses of small bays with the adjacent open waters needs several days of continued measurements of currents within a year; it gives a reasonable and fast approximation to exchange rates of water in a bay. This is used, in combination with biochemical parameters, to assess the capacity of the bay to receive each specific pollutant.

The following publications were based wholly or partly on the work done in this pilot project.

DEGOBBIS, D. (1977). Hydrography. An ecological study of Rijeka Bay, Annual Report, pp. 25-63 (in Croatian).

DEGOBBIS, D., ILIC, D., JEFTIC, L., NOZINA, I., SMODLAKA, N. and VUCAK, Z. (1979). Hydrographic and hydrodynamic characteristics of Rijeka Bay, IVème Etud. Pollutions, CIESM, Antalya, November 1978, pp. 551-554.

ILIC, D., and NOZINA, I. (1977). Dynamics of water masses. An ecological study of Rijeka Bay, Annual Report, pp. 65-101 (in Croatian).

JEFTIC, L. (1977). Ecological study of Rijeka Bay. Annual Report (in Croatian).

JEFTIC, L. (1978). Ecological study of Rijeka Bay. Annual Report (in Croatian).

KUZMIC, M., JEFTIC, L. and POLICASTRO, A. J. (1977). Modelling of jet-type surface discharge at Urinj Site. Thalassia Jugoslavica 13 (1/2), 139-160.

SEKULIC, B. (1977). Background information on Rijeka Bay. An ecological study of Rijeka Bay, Annual Report, pp. 3-21 (in Croatian).

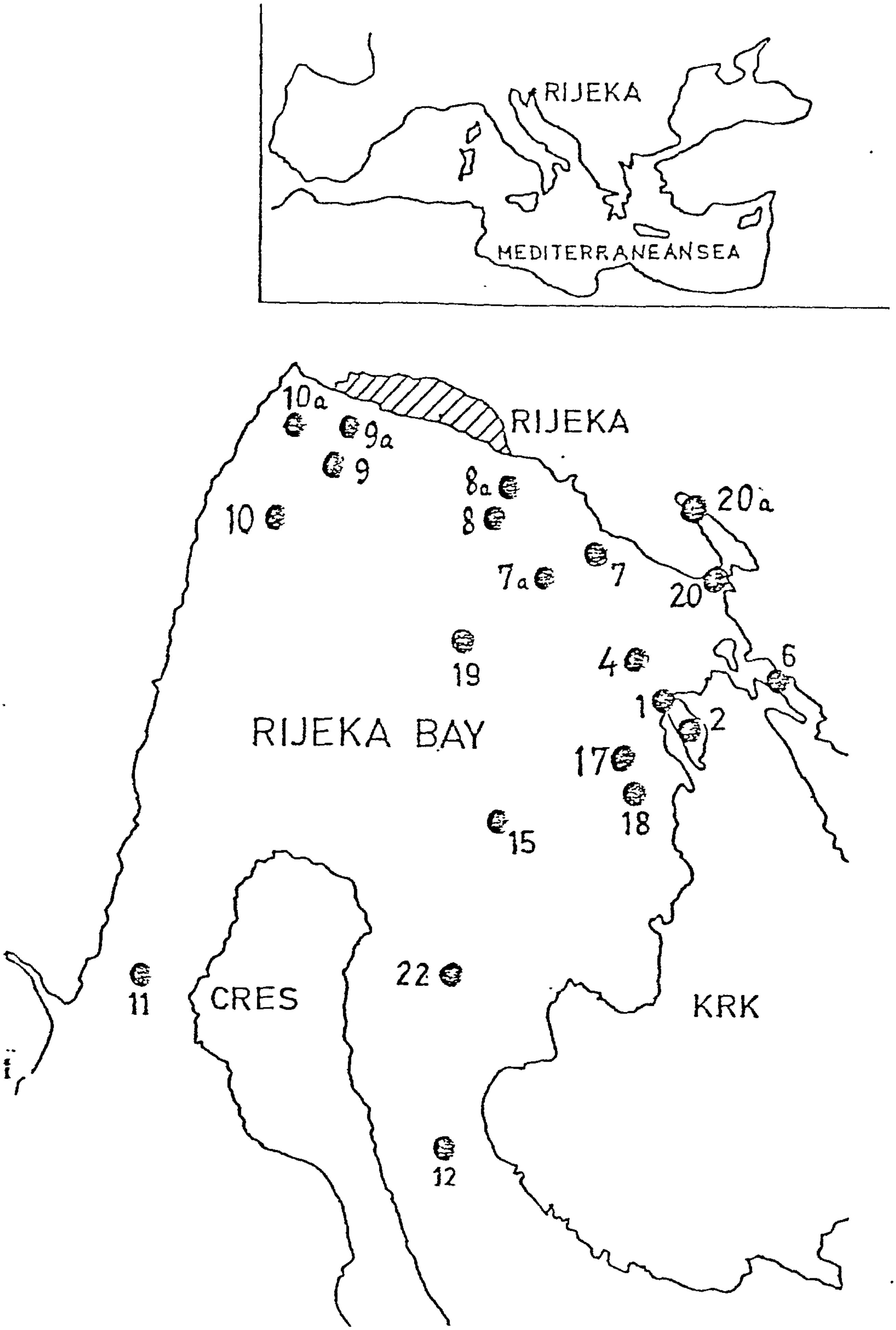


Fig. 1. A map of Rijeka Bay showing station position and numbers

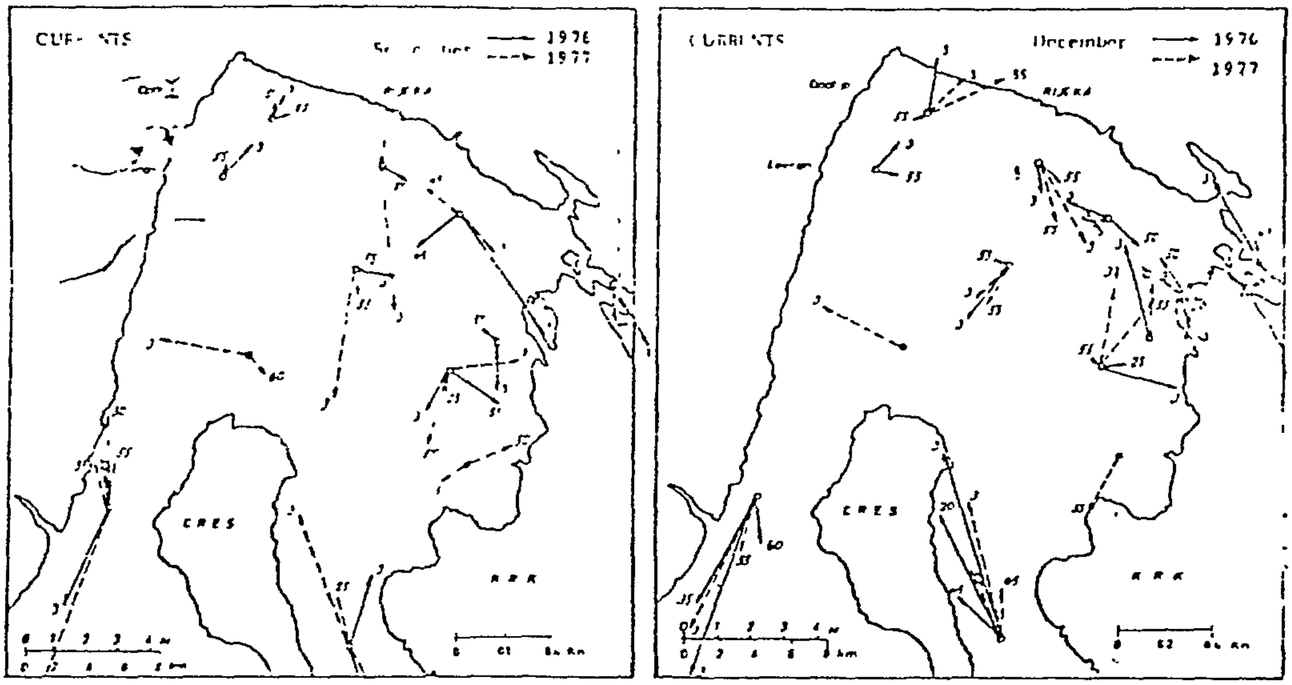


Fig. 2. Average currents measured for a period of 72 hours in channels and a period of 25 hours for other stations. Numbers at tips of arrows indicate the depth at which measurements were taken

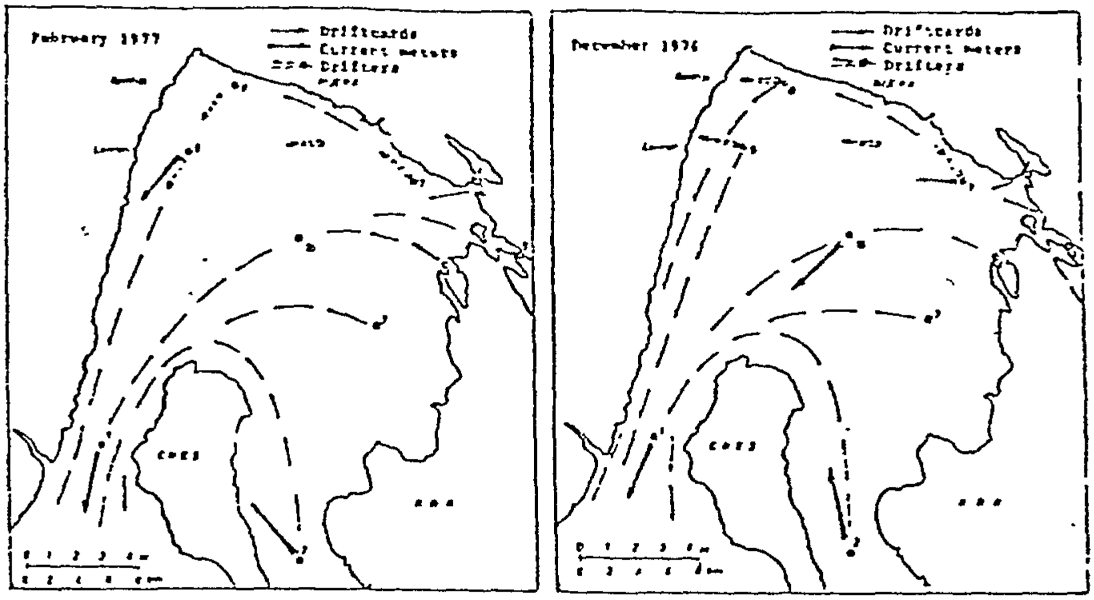


Fig. 3. Results of current measurements by driftcards (⟶), drifters (⟹) and current meters (⟶). Current meter measurements were made at 3 m depth for periods of 24 to 72 hours

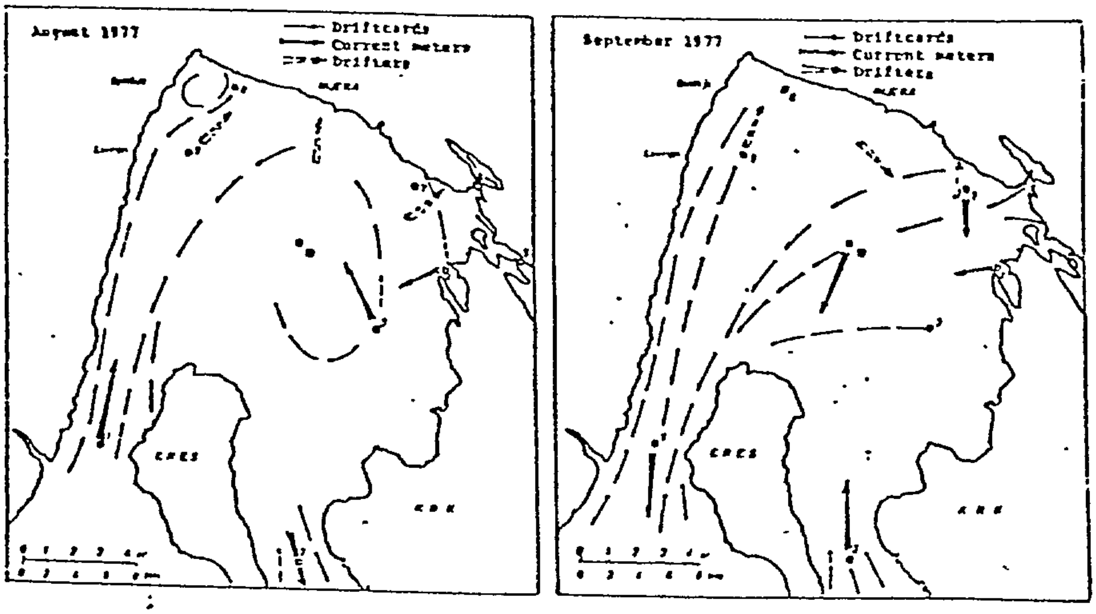


Fig. 4. Results of current measurements by driftcards (———→), drifters (= = =–→) and current meters (━━━→). Current meter measurements were made at 3 m depth for periods of 24 to 72 hours.

Research Centre: Institute for Oceanography and Fisheries, SPLIT Yugoslavia

Principal Investigator: M. ZORE-ARMANDA

INTRODUCTION:

Earlier investigations have been carried out in the whole region covered by this project, partly under the Institute's regular programme and partly to solve some pollution problems for the local authorities. A considerable amount of data was collected from the Zadar area in 1975-1976 in relation to the proposed location of a nuclear power plant, and another series of data for the same period was collected for a locality close to the city of Zadar. For the Split region the Institute has had a long series of data since 1934. Special programmes were carried out in the Sibenik region in 1973-1974 and in the Dubrovnik region in 1970 and 1977. The present report includes data obtained up to December 1979.

AREA(S) STUDIED:

The areas of interest are the following Dalmatian urban centres: Zadar, Sibenik, Split and Dubrovnik. (Fig. 1.).

The main characteristic of the coast is its prominent indentation, with numerous islands, peninsulas and bays lying mostly in the NW-SE direction. The coast is predominantly made of limestone and dolomite. The rivers are short and do not have much water.

From May to October the weather is warm and dry, under the influence of the etesian winds (maestral). In the winter months the typical winds are bora (north-easterly, cold and dry), and sirocco (jugo) (south-easterly, warm and moist).

Coastal currents are weak and predominantly north-western. Surface temperatures are rather high in summer (22° - 26° C) and low in winter (10°C, or lower). Salinity is lower than in the open Adriatic, but still rather high, especially in summer and autumn. Exceptions are some semi-enclosed areas near river mouths or close to the numerous submarine springs. Waters are well oxygenated except in some landlocked basins. Nutrient content and productivity are not very high.

The coastal region is characterized by a strong response to the atmospheric forcing. To study this response on a time scale of several days, we have chosen the region off Dubrovnik and the basin of the Virsko More (Vir Sea) near Zadar. The region off Dubrovnik is characterized by a relatively smooth coastline with a well defined shelf; the Virsko More is taken as a typical small bay.

MATERIAL AND METHODS:

Nine cruises were undertaken: November 1976, April 1977, May 1977, August 1977, November 1977, July 1978, August 1978 and September 1978. Currents were measured by a direct-reading current meter (Kelvin Hughes) in 24-hour series at stations ZI, SI, SI and DI (Fig. 1.). In September 1978 a special experiment was performed in the Zadar area. At four buoy stations, Aanderaa recording current meters were operated for seven days at two depths.

In the Virsko More, measurements with moored current meters were made during summer and winter, since the response should be mostly dictated by vertical density stratification. Previous results on the charasteristics of the response of the Virsko More to the atmospheric forcing during summer have already been published (Zore-Armanda et al., 1977; Gacic, 1979 and 1980).

In the region off Dubrovnik, three moorings with two currents meters were deployed on the profile normal to the coast during the second part of August and in September 1979 so as to determine the characteristics of the oscillations in the current field and its offshore extent. The distance between moorings and coastline was chosen so that only baroclinic oscillations were studied. At the same time STD measurements on the same profile were made over a ten-day period to determine the characteristics of the horizontal density distribution and its relation to the current oscillations. Current measurements have also been made using drift bottles.

Temperature and salinity were measured at three stations in each area investigated (Zadar, Sibenik, Split, Dubrovnik) at standard depths and using standard oceanographic methods (reversing thermometers, salinometer, STD probe). Dye (Rhodamine B) experiments were performed in the Zadar, Split and Dubrovnik areas. Meteorological parameters (wind speed and direction, sea state, direction of waves) were also measured. Furthermore, sea level records are available from Dugi otok, Novalja (Zadar region), Split and Dubrovnik.

Mean daily, monthly or seasonal values were calculated. Hourly and daily mean vectors and direction frequencies were calculated for current meter data as well. Spectral analysis has been made for monthly series of current and sea-level data.

A summary of the stations, parameters studied dates and times is given in Table I.

RESULTS AND THEIR INTERPRETATION:

Fixed current meters - Tables I, II, III, IV, V and VI summarize the current data for November 1976, April 1977, May 1977, July 1977, and August 1977, respectively. The mean vectors calculated from all the available data are given in Table VII.

Mean annual values for the Virsko More show a prevalent north-westerly current at all depths. Average speed is about 11 cm/sec. Tides are not important, and corresponding currents have speeds of a few cm/sec and no influence on the water transport in the basin. The analysis shows that the Virsko More responds strongly to wind forcing on a time scale of approximately two days. During summer, the response is predominantly baroclinic, and, owing to the small dimensions of the Virsko More, the response to local forcing prevails, the upwelling and coastal jet being caused by an offshore wind.

Inertial oscillations were found to occur very rarely, and their energy, on average, is smaller than the energy of tidal oscillations.

During winter, barotropic motions are more important, and crosswind flow due to local forcing does not appear. Shoreward transport is the consequence of the action of the south-east wind over the whole Adriatic.

The analysis of cross-shelf sea-level slope shows the significant influence of the wind, whereas the energy level in the adjusted sea-level spectrum in the frequency range in question is very low, and therefore the oscillations in the current field are predominantly non-divergent. The barometric factor is strongly frequency-dependent and sea-level changes are not generally isostatic.

For the Dubrovnik region, hourly wind data were available for correlation. The study has not yet been completed, but some preliminary conclusions can be drawn. The first period of observations used in this correlation, from 16 August to 20 September 1979, was characterized by moderate-to-weak winds, except at the end when a strong south-easterly wind developed.

At first, current oscillations were predominantly baroclinic induced by the isopycnal surface oscillations. This was determined by comparing daily current vectors with geostrophic velocity calculated from the horizontal density distribution. The oscillations in the current field in the first part of the record had a period of about 10 days, and since the strong winds were absent, these oscillations could be explained in terms of internal Kelvin waves originating probably from the Mediterranean and trapped on the South Adriatic Shelf.

In the second part of the record a strong flow was locally induced by the strong south-easterly wind blowing over this region for more than two days. Thus, although the current field on the South Adriatic Shelf is usually due to the baroclinic oscillations caused by remote forcing, it is locally forced when a strong wind blows.

In the coastal basins, two types of vertical and horizontal circulations are found. In vertical circulation, essentially two layers are important. Some basins behave like dilution basins where water goes out at the surface and enters at the bottom. In others, which are more common, surface water enters the basin and bottom water leaves it. In the latter, the influence of the open sea on the oceanographic properties of the basin is more evident.

It seems that the shape of the basin determines the type of vertical circulation. Basins open to the prevalent north-westerly surface current of the open Adriatic usually belong to the second type (e.g., Dubrovacka Rijeka), but rain or the presence of a river (Sibenik and Dubrovnik areas) could also be important. In the Kastela Bay near Split, water more frequently enters at the surface, although in summer and autumn reversed circulation was found.

Horizontal circulation is mainly cyclonic, as it is for the whole Adriatic, but anticyclonic circulation could also be found. It seems that horizontal circulation depends on meteorological conditions.

Tidal currents are weak with average speeds from 3 to 5 cm/sec, and they do not influence diffusion essentially.

Some experiments with surface drifters were carried out in 1979. The results are summarized in Table VIII.

Dye experiments - These were performed in the Zadar area in October 1977, in the Split area in December 1977 and in the Dubrovnik area in September 1977 to study the isotropic horizontal diffusion. Diffusion coefficients for Zadar were 0.19 m^2/sec, for Split, 0.42 m^2/sec. and for Dubrovnik, 0.21 m^2/sec. It seems that the Split area is more turbulent than those of Dubrovnik and Zadar. The relation between currents (U) and diffusion coefficients (K) may be of special interest: Split - K/U = 1.79 km; Zadar - K/U = 1.69 km; Dubrovnik - K/U = 0.73 km.

These relations show that pollutants would be transported faster in the Split area, with lower concentrations and gradients, than in the Zadar area and, especially, the Dubrovnik area.

A simple model has been developed to study the water exchange between bay and the open sea. The density of contaminant per unit surface is applicable at the entrance to the bay, whereas in the bay itself, the density of contaminant per unit length is used. The intensity of the contaminant source and its density at the mouth of the bay are related by dissolution. The model will be applied to the different bays in the region.

In summary, current speeds in the Dalmatian coastal area are rather low, from 5 to 15 cm/sec., on average. Tides are not important (average annual amplitudes between 11 and 14 cm) and have no significant influence on the water transport. Dispersion of current directions is large. The prevalence of the north-westerly direction is statistically evident, especially during the winter season. The westerly direction is also frequent in the surface layer and could be taken to be the offshore current due to the influence of the bora (cold north-easterly wind) and is connected with the coastal upwelling. The current system is strongly influenced by the atmospheric forcing. During summer the response is predominantly baroclinic, the upwelling and coastal jet being caused by the offshore wind. Summer upwelling was apparent in the temperature. In winter the barotropic motions are more important. Shoreward sea-water transport is the consequence of the south-easterly winds over the whole Adriatic. Oscillations in the current field over a period of about 10 days are present. They can be explained in terms of internal Kelvin waves originating from the Mediterranean.

Fickian diffusion coefficients indicate the peculiarities of the localities investigated. They are smaller in the Zadar area and higher in the Split and Dubrovnik areas. Turbidity measurements show that the Split area (the biggest town and the best developed industry in the region) is the most turbid in the region studied.

The following publications are based wholly or partly on the work done under this pilot project:

BONE, M.(1980) Estimation of water exchange between the bay and surrounding sea. Acta Adriat. 21 (2) : 75-78.

GACIC, M. (1979). Karakteristike spektra strujnog polja u Virskom moru s aspekta utjecaja sinoptickih poremecaja i plimnog vala. (Spectral characteristics of the current field in the region of the Virsko More). Studije i elaborati Instituta za oceanografiju i ribarstvo, Split, 39, 8-14.

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ZORE-ARMANDA, M., BONE, M. and GACIC, M. (1979). Some dynamic characteristics of the East Adriatic coastal area. Acta Adriat. 19 (10), 83-102.

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ZORE-ARMANDA, M.(1980) Some dynamic and hydrographic properties of the Kastela Bay, Acta Adriat. 21 (2) : 55-74 .

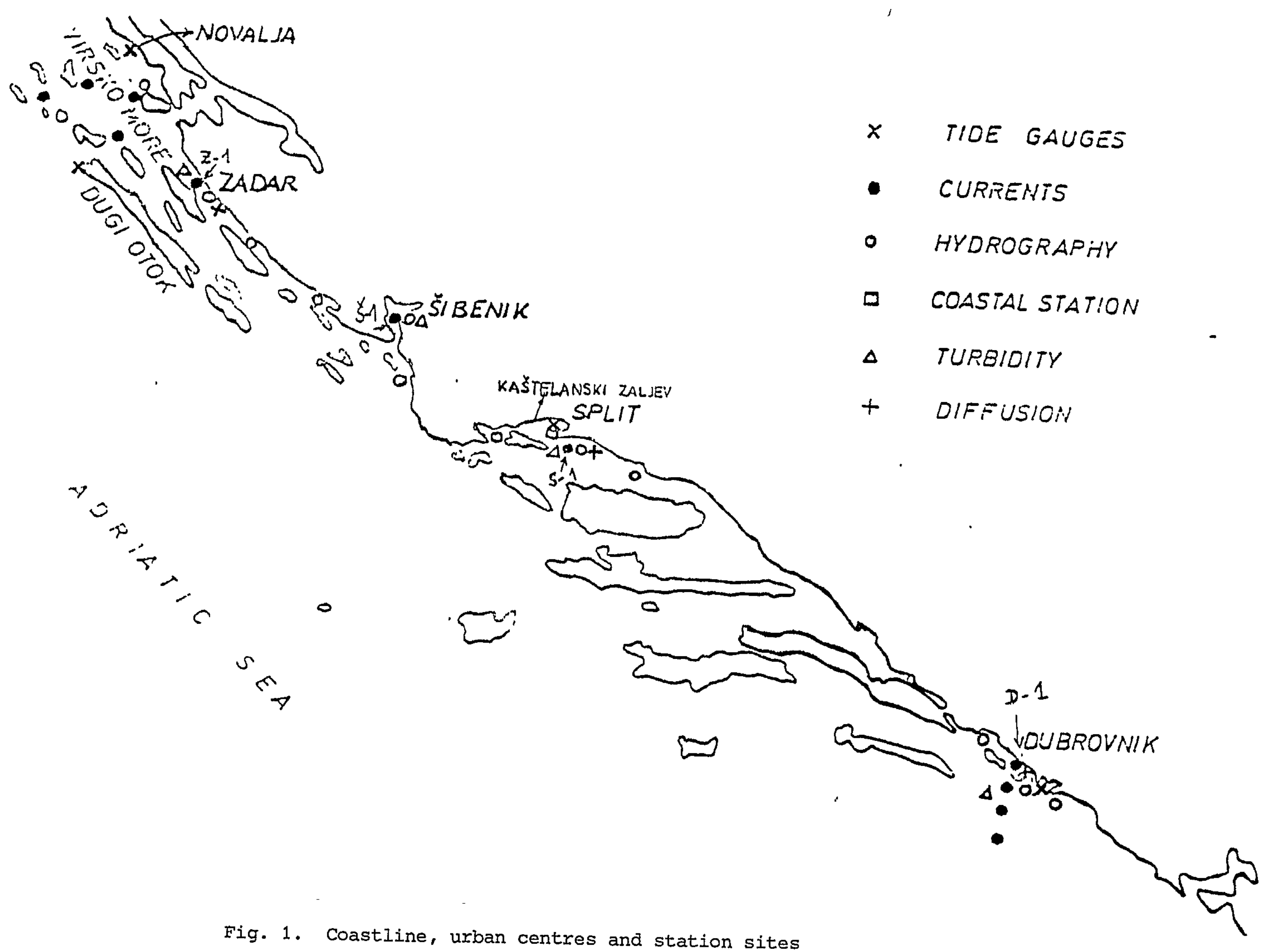

Fig. 1. Coastline, urban centres and station sites

TABLE I. Stations and parameters studied

Region	Station	Parameter	Year	Date	Duration
ZADAR	Z 1	T,S, σ_t	1977	6.4; 18.5; 6.7; 18.8; 3.12	
		Currents		6.7; 17.8; 3.12	6–24 hours
	Z 2	T,S, σ_t		5.4; 17.5; 6.7; 17.8; 3.12	
	Z 3	T,S, σ_t		6.4; 18.5; 7.7; 18.8; 3.12	
	Z 1	T,S, σ_t	1978	21.7; 16.8; 27.9; 9.11	
		Currents		21.7; 16.8; 27.9; 9.11	6 hours
	Z 2	T,S, σ_t		21.7; 16.8; 27.9; 9.11	
	Z 3	T,S, σ_t		21.7; 16.8; 27.9; 9.11	
	Z 4, Z 5	Currents		19.9 – 26.9	7 days
	Z 6, Z 7	Currents		19.9 – 26.9	7 days
	Z 1; Z 2; Z 3	T,S, σ_t	1979	18.8; 7.6; 4.7; 4.9	
	Z 4; Z 5; Z 6	Currents		28.2. – 27.3.	27 days
	Z 7	Currents		28.2. – 27.3.	27 days
ŠIBENIK	Š 1	T,S, σ_t	1977	7.4; 21.5; 11.7; 19.8; 5.12	
	Š 2	T,S, σ_t		7.4; 21.5; 11.7; 19.8; 5.12	
	Š 3	T,S, σ_t		9.4; 22.5; 12.7; 20.8; 6.12	
	Š 1; Š 2	T,S, σ_t	1978	22.7; 17.8; 28.9; 10.11	
	Š 3	T,S, σ_t		22.7; 17.8; 29.9; 10.11	
	Š 1; Š 2	T,S, σ_t	1979	18.4; 7.6; 4.7; 5.9	
	Š 3	T,S, σ_t		19.4; 7.6; 5.7; 5.9	
SPLIT	S 1	T,S, σ_t	1977	10.4; 23.5; 14.7; 22.8; 15.11	
	S 2	T,S, σ_t		9.4; 22.5; 12.7; 20.8; 16.11	
	S 3	T,S, σ_t		11.4; 24.5; 14.7; 23.8; 16.9	
	S 1	Currents		24.5; 13.7; 22.8; 16.11	6–23 hours
	Coastal st.	T,S, Currents		whole year	twice a day

TABLE I. (cont'd)

Region	Station	Parameter	Year	Date	Duration
SPLIT	S 1	T,S, σ_t	1978	23.7; 18.8; 8.9; 11.11	
	S 1	Currents		23.7; 18.8; 9.9; 11.11	6-8 hours
	S 2; S 3	T,S, σ_t		24.7; 19.8; 9.9; 12.11	
	Coastal st.	T,S, Currents		whole year	twice a day
	S 1; S 2	T,S σ_t	1979	19.4; 9.6; 5.7; 6.9	
	S 3	T,S, σ_t		20.4;10.6; 5.7; 6.9	
	Coastal St	T,S, Currents		whole year	twice a day
DUBROVNIK	D 1	T,S, σ_t	1977	13.4; 27.5; 16.6; 18.7; 27.8	
	D 1	Currents		27.5; 18.7; 26.8; 21.11	12-24 hours
	D 2	T,S, σ_t		13.4; 26.5; 17.7; 26.8; 18.11	
	D 3	T,S, σ_t		13.4; 27.5; 17.7; 26.8; 18.11	
	D 4; D 5; D 6	T,S, σ_t		15.6; 28.8; 19.11	
	D 7; D 8	T,S, σ_t		16.6; 28.8; 20.11	
	D 1; D 2; D 3	T,S, σ_t	1978	25.7; 21.8; 10.9; 15.11	
	D 1	Currents		26.7; 21.8; 10.9; 14.11	6 hours
	D 1; D 2; D 3	T,S, σ_t	1979	22.4; 12.6; 8.7; 8.9	
	D 9	Currents		16.9. - 26.9.	40 days
	D 10	Currents		16.8. - 30.8.	13 days
	D 10	Currents		10.9. - 26.9.	16 days

Table II. The main characteristics of the currents in three areas in November 1976.

Station	Depth m	Max. speed cm/sec	Min. speed cm/sec	Average speed cm/sec	Resultant Current Direction Degree	Resultant Current Direction Compass	Resultant Current Speed cm/sec
Zadar	0	22	2	14	166	SE	7
	20	14	2	4	41	NE	5
Split	0	25	5	16	106	E	10
	20	23	1	15	76	E	11
	35	24	8	17	88	E	18
Dubrovnik	0	22	5	13	257	W	9
	20	23	4	15	81	E	9
Average		22	4	13			10

Table III. The main characteristics of the currents in four areas in April 1977.

Station	Depth m	Max. speed cm/sec	Min. speed cm/sec	Average speed cm/sec	Resultant Current Direction Degree	Resultant Current Direction Compass	Resultant Current Speed cm/sec
Zadar	0	16	0	5	346	N	7
	20	24	0	5	348	N	10
Šibenik	0	15	5	11	264	W	5
	30	25	8	16	243	SW	8
Split	0	22	0	5	243	SW	2
	20	36	0	13	253	W	7
	35	35	0	13	97	E	14
Dubrovnik	0	36	0	7	146	SE	2
	20	44	0	9	207	SW	9
Average		28	1	9			7

Table IV. The main characteristics of the currents in four areas in May 1977.

Station	Depth m	Max. speed cm/sec	Min. speed cm/sec	Average speed cm/sec	Resultant Current Direction Degree	Compass	Speed cm/sec
Zadar	0	18	0	5	308	NW	6
	20	14	0	6	137	SE	9
Šibenik	0	19	0	4	243	SW	6
	28	26	0	6	254	W	13
Split	0	16	0	6	68	E	3
	20	6	0	1	162	S	3
	35	6	0	1	211	SW	6
Dubrovnik	0	15	0	5	326	NW	2
	20	34	0	13	42	NE	6
Average		17	0	5			6

Table V, The main characteristics of the currents in four areas in July 1977.

Station	Depth m	Max. speed cm/sec	Min. speed cm/sec	Average speed cm/sec	Resultant Current Direction Degree	Compass	Speed cm/sec
Zadar	0	6	0	1	194	S	4
	20	2	0	0	-	-	-
Šibenik	0	10	1	6	279	W	3
	28	24	5	14	320	NW	9
Split	0	15	0	4	76	E	2
	20	23	0	6.	101	E	8
	35	26	0	5	77	E	5
Dubrovnik	0	7	0	1	248	W	3
	20	27	0	4	166	S	11
Average		16	3	5			6

Table VI. The main characteristics of the currents in four areas in August 1977.

Station	Depth m	Max. speed cm/sec	Min. speed cm/sec	Average speed cm/sec	Resultant Current		
					Direction		Speed
					Degree	Compass	cm/sec
Zadar	0	25	0	5	305	NW	6
	20	26	0	8	262	W	7
Šibenik	0	9	0	5	254	W	4
	28	19	0	10	225	SW	3
Split	0	23	0	10	259	W	11
	20	33	0	17	219	SW	6
	30	20	0	5	156	SE	5
Dubrovnik	0	14	0	1	45	NE	5
	20	26	0	6	7	N	8
Average		22	0	7			6

Table VII. Mean vectors in the investigated areas (values are obtained from all the available data

		Direction	Speed (cm/sec)
ZADAR	Surface	319°	5.0
	Mid-depth	127°	7.5
SPLIT	Surface	270°	5.0
	Mid-depth	320°	2.2
DUBROVNIK	Surface	304°	16.3
	Mid-depth	280°	8.1

Table VIII. Results of experiments with drifters in 1979

Station	Date	Sea state	Wind m/sec	Current direction	Speed cm/sec
ZADAR (Z 1)	18.4	2	NE_{10}	315	4
	7.6	0	SE_2	290	3
	4.7	2	W_6	105	10
SIBENIK (S 1)	18.4	2	NE_8	170	5
	8.6	1	SW_3	310	2
	4.7	1	N_3	145	2
SPLIT (S 1)	19.4	2	SE_3	250	5
	9.6	1	SW_4	75	5
	5.7	1	NE_2	210	7
DUBROVNIK (D 1)	22.4	0	0	310	4
	12.6	0	0	245	2
	8.7	0	SE_2	260	4

PUBLICATIONS IN THE MAP TECHNICAL REPORTS SERIES

No. 1 UNEP/IOC/WMO: Baseline studies and monitoring of oil and petroleum hydrocarbons in marine waters (MED POL I). MAP Technical Reports Series No. 1. UNEP, Athens 1986.

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