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Mediterranean Coastal Areas (Island of Rhodes,
Kastela Bay, Syrian Coast, Malta and Cres/Losinj Islands)

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IMPLICATIONS OF EXPECTED CLIMATIC CHANGES ON KASTELA BAY

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PREFACE

As part of the efforts of the United Nations Environment Programme (UNEP) to analyze the potential implications of predicted climate change and to assist the governments in designing policies and measures which may avoid or mitigate the expected negative effects of this change, or to adapt to them, the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of the United Nations Environment Programme (UNEP), in co-operation with several intergovernmental and non-governmental organisations, launched, co-ordinated and financially supported a number of activities designed to contribute to an assessment of the potential impacts of climate changes and to the identification of suitable policy options and response measures which may mitigate the negative consequences of the expected changes.

As part of these efforts, Task Teams on the implications of climatic changes were established in 1987 for six regions covered by the UNEP-sponsored Regional Seas Programme (Mediterranean, Wider Caribbean, South Pacific, East Asian Seas, South-East Pacific and South-Asian Seas) with the initial objective of preparing reviews of the expected impacts of climatic changes on coastal and marine ecosystems, as well as on the socio-economic structures and activities of their respective regions. Five additional Task Teams were established later, two in 1989 (West and Central African, and East African regions) one in 1990 (Kuwait Action Plan region) and two in 1992 (Black Sea and Red Sea).

During the work on the Mediterranean regional study, it was felt that while the general effects might be similar throughout the Mediterranean region, the response to these effects would have to be highly site-specific. Therefore in the framework of the Mediterranean Task Team six specific case studies were prepared (deltas of the rivers Ebro, Rhone, Po and Nile; Thermaikos Gulf and Ichkeul/Bizerte lakes) by the end of 1989. The first site specific case studies had concentrated on low lying deltaic systems including these of the Ebro, Rhone, Po and Nile rivers. Following their publication by UNEP, the reports of the Mediterranean Task Team were published commercially in Book form by Edward Arnold (Jeftic *et al.*, 1992, Climatic Change and the Mediterranean). In preparing these case studies it had become apparent that prediction of impacts was constrained by the absence of scenarios of future climates on a regional, sub-regional and local scale.

Accordingly the Climatic Research Unit of the University of East Anglia had been commissioned by UNEP to attempt to produce a Mediterranean Basin scenario and to develop scenarios of future local climate for the selected case study areas. The scale of existing Global Circulation Models is such that determination of future temperature and precipitation patterns at a local level involves considerable uncertainty concerning future conditions. Without such local scenarios assessment of future impacts involves even greater levels of uncertainty, reducing the value of such assessments for immediate planning and management purposes. A suite of scenarios for the Mediterranean region were developed using the output from the GCM's coupled with a finer scale meteorological database. Scenarios for local sub-regions and areas were subsequently developed for those areas which were to be examined in more detail during the second generation of case studies.

Using the experience of these initial case studies, in 1990 the preparation of the "second generation" of site-specific case studies was initiated for the island of Rhodes, Kastela Bay, the Syrian coast, the Maltese islands and the Cres-Losinj islands.

The objectives of these studies were:

- to identify and assess the possible implications of expected climate change on the terrestrial, aquatic and marine ecosystems, population, land- and sea-use practices, and other human activities;

- to determine areas or systems which appear to be most vulnerable to the expected climate change; and

- to suggest policies and measures which may mitigate or avoid the negative effects of the expected impact, or adapt to them, through planning and management of coastal areas and resources;

using the presently available data and the best possible extrapolations from these data.

The "second generation" case studies utilised the regional and local scenarios developed by the University of East Anglia in attempting to assess and evaluate the implications of future changes on specific islands and areas covered by the Mediterranean Action Plan.

The Task Teams assembled for each of the second generation case studies were composed of experts from a wide variety of natural and social science disciplines, with specific knowledge of the areas concerned. In addition, the national and local authorities responsible for planning and developments in these areas were brought into the work of the Task Team from an early stage. Thus for example the Municipal authorities of Rhodes included the work of the Task Team within their coastal development planning and the Municipal authorities of Cres and Losinj hosted several meetings of the Task Team.

In order to ensure that the Task Teams retained as wide a perspective of the problem as possible several UNEP experts on Climate Change Impact Assessment were included at all stages of the preparation of these individual assessments. The full list of Task Team members responsible for this report is given in the Appendix to this report. A final joint meeting of representatives of the Task Teams and UNEP experts was held in Malta in September 1992 at which the conclusions and recommendations of each Task Team were reviewed, compared and finalised.

This report represents one of the five site specific assessments covered during the course of this work. Whilst it is important to recognise that climatic changes and sea level rise will have an impact on future use and development of the Mediterranean coastal areas, it is equally important to recognise that the rate and scale of other sources of change, such as land-use patterns and demographic changes may be of more immediate concern in certain areas. In this context, actions designed to address the future impacts of climatic change and sea level rise must be founded on a sound basis of immediate actions designed to reduce the rate of adverse changes resulting from uncontrolled development and use of the Mediterranean coastal environment and its resources.

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ANNEX Temperature and precipitation scenarios for the Kastela Bay region - Report to the UNEP Co-ordinating Unit for the Mediterranean Action Plan - January 1992 - by the Climatic Research Unit, University of East Anglia

EXECUTIVE SUMMARY

The Task Team was asked to: identify and assess the potential impacts of expected climatic changes on the terrestrial, aquatic and marine ecosystems, on human populations, land and sea-use practices and other human activities; determine areas or systems which appear to be most vulnerable to the expected climatic changes; give recommendations for planning and management of coastal areas and resources, as well as for planning and design of major infrastructure and other systems; and, provide inputs into the Coastal Area Management Programme for Kastela Bay, of the Mediterranean Action Plan of UNEP, and other projects and developments relevant to the subject of the study.

According to the climate change scenario for the Kastela Bay region, developed by the Climate Research Unit of the University of East Anglia, Norwich, UK., the expected temperature change is close to the global value (i.e. 1 °C per degree global change) in all seasons. In winter and spring the predicted change will be slightly below the global mean, 0.9 °C per degree global change. In summer and autumn the change is likely to be slightly greater than this, but not more than 1 °C per degree of global change.

These scenarios suggest that precipitation will show an increase in all seasons except autumn. In winter the change is likely to be around +2% per degree of global temperature change. In spring an increase of 6% per degree of global change is indicated. The greatest change is likely to occur in summer, over 10% per °C of global change. However, this is the season of very low rainfall amounts so that only a small absolute increase can be expected. In autumn a slight reduction, of between 0 and 2% / °C is indicated by the scenarios.

Sea level increase is expected to be 18 ± 12 cm by the year 2030, 38 ± 14 cm by the year 2050 and 65 ± 35 cm by the year 2100.

Assessments of the possible impacts of expected climatic changes were made on the basis of the existing state of knowledge concerning the characteristics of each domain, ecosystem or human activity. There are many uncertainties in the predictions particularly in the case of impacts on natural ecosystems. Therefore, the possible impacts are described qualitatively and, wherever possible, quantitatively. Actions to address the major expected impacts are proposed.

1. INTRODUCTION

1.1 Background

The greenhouse effect is Man's most pressing environmental problem, one which presents major scientific challenges that span a wide range of disciplines. Changes in global climate between now and the middle of the 21st century are likely to be dominated by the influence of global warming due to increasing concentrations of carbon dioxide and other gases in the atmosphere. These greenhouse gases individually and collectively change the radiative balance of the atmosphere, trapping more heat near the Earth's surface and causing a rise in global-mean surface air temperature. In spite of uncertainties surrounding predicted climatic changes, greenhouse gases seem to have accumulated in the atmosphere to such a level that the changes may have started already and their continuation may now be inevitable. As a consequence substantial global warming is virtually certain.

There is a consensus in the scientific community that if allowed to continue to build up, a doubling of the greenhouse gas concentration (relative to the pre-industrial era) will occur sometime in the 21st century, possibly as early as 2030 AD. A corresponding global increase in mean surface temperature of between 1.5 and 4° C is predicted to occur some 2 to 3 decades later, reflecting the time lags, due to inertia of the earth's climate system.

Cyclogenesis and rainfall are often promoted by land-sea temperature contrasts. Because land and sea have different effective thermal inertias, a large-scale warming could affect this contrast, which might possibly be reduced in the winter months. This could in turn lead to reductions in rainfall and in storminess, particularly in the Eastern Mediterranean Basin. On the other hand, warmer sea surface temperatures both in the Mediterranean and in the North Atlantic could lead to increases in atmospheric moisture and thus increased precipitation.

Another major consequence of a warmer atmosphere is an acceleration in the current rate of sea level rise, due to the melting of alpine and polar glaciers and thermal expansion of ocean surface water. Sea level has been rising since the last glacial maximum (120 m rise in the last 16,000 years, at rates as rapid as 8 to 12 mm yr^{-1}). In recent historical times, the rate has been between 0.5 and 1.5 mm yr^{-1}. Analysis of tide gauge data, the principal source of evidence for detecting relatively short-term sea level trends, suggests that the world-wide rise has been about 10-15 cm in the past 100 years.

Depending on the extent of oceanic thermal expansion and on the behavior of the polar ice caps (Greenland and the western Antarctic ice sheet), conservative to moderate estimates of sea level rise range from 13-39 cm, by 2025; 24-52 cm, by 2050; and 38-91 cm, by 2075. The Villach Conference in 1985 concluded that a global warming of 1.5 - 4.5 °C would lead to a sea-level rise of between 20 and 140 cm. Future sea level rise was estimated at a meeting of experts in Norwich, September 1987 which produced a best estimate of a rise of 14 to 22 cm between 1985 and 2030: the same approximate rate of rise in sea level as has occurred over the past 100 years.

The Second World Climate Conference (Geneva, 29 October - 7 November 1990) concluded, on the basis of the work of the Intergovernmental Panel on Climate Change (IPCC) that without actions to reduce emissions, global warming would reach 2 to 5 °C over the next century, a rate of change unprecedented in the past 10,000 years. The warming is expected to be accompanied by a sea level rise of 65 +/- 35 cm by the end of the next century. There remain uncertainties in predictions, particularly in regard to the timing, magnitude and regional patterns of climate change, as well as in the numerous secondary effects of this warming and sea level rise.

The Second World Climate Conference adopted the Conference Statement and Ministerial Declaration which were prepared on the basis of presentations made at the Conference; the deliberations of task groups of participants organized to address various specific issues; and plenary discussions.

The effect of the probable climate warming in the next few decades is a question of concern both to the world in general and to the Mediterranean in particular (Wigley, 1988). Several case studies on the possible impacts of expected climatic changes have been prepared within the framework of the Mediterranean Action Plan of UNEP. One of these is the case study on Kastela Bay (Figure 1). A Task Team of 7 local and 3 international experts was established in February 1992 to undertake this study.

1.2 Basic Facts concerning Kastela Bay

The geographic area covered by this study of the impacts of climate changes is shown in Figure 2. The area encompasses Kastela Bay and neighbouring maritime areas including the Brac and Split Channels and the coastal strip bounded by the slopes of the Kozjak mountains to the north, the city of Trogir in the west, and the river Zrnovnica in the east.

Kastela Bay is the largest bay in the coastal region of central Dalmatia with a total area of 61 km^2 and a volume of 1.4 km^2. It is an oblong basin, 14.8 km long with the short axis of 6.6 km located on the meridian of Kastel Luksic. The bay is connected to the adjoining Split channel by a 1.8 km wide inlet which is also the deepest part of the bay. The average depth of this inlet is 40 m with a maximum of 56 m, while the average depth of the entire bay is 23 m (Figure 3).

The Split channel, together with the Brac Channel form a single water body. The former is bounded by the islands of Ciovo, Solta and Brac, while the Brac channel is bounded by the island of Brac and the slopes of the Mosor and Biokovo mountains. In the southeast the Brac channel is connected to the Hvar channel and the Split channel is connected to the open sea by a very narrow strait between the islands of Brac and Solta. There are two inlets, one between the islands of Solta and Drvenik Veli and a second, between the island of Drvenik Veli and the mainland.

The sea shore is surrounded by a relatively narrow coastal plain, with a high mountainous region rising in the immediate hinterland.

The main input of freshwater into the bay is through the River Jadro (annual inflow of about 0.32 km^3) with lesser inputs from a number of underwater springs.

At present the bay itself and its immediate surroundings are home to more than 300,000 inhabitants, concentrated in the towns of Split (250,000), Solin (15,000), Trogir (10,000), and in smaller settlements, such as the seven Kastelas.

In the post-war period the region underwent rapid development and the initial number of inhabitants increased six fold. A number of large industrial plants were built and existing ones were significantly expanded; the commercial harbor reached a capacity of 1 million tones per year; agricultural production was substantially increased; and Split developed as the major centre for passengers transiting to the Dalmatian islands. Due to the geographic configuration of the bay and of its surroundings, most of this development took place in the narrow coastal zone.

Unfortunately this intensive economic development and population growth have not been accompanied by adequate development of infrastructure. Urban sanitation, sewage treatment, disposal of industrial wastes and surface transport systems for goods and people, are all inadequate.

1.3 Methodology and assumptions used in the study

The main tasks assigned to the Task Team were as follows:

- to identify and assess the possible implications of expected climatic changes on the terrestrial, aquatic and marine ecosystems, populations, land-use and sea-use practices and other human activities;

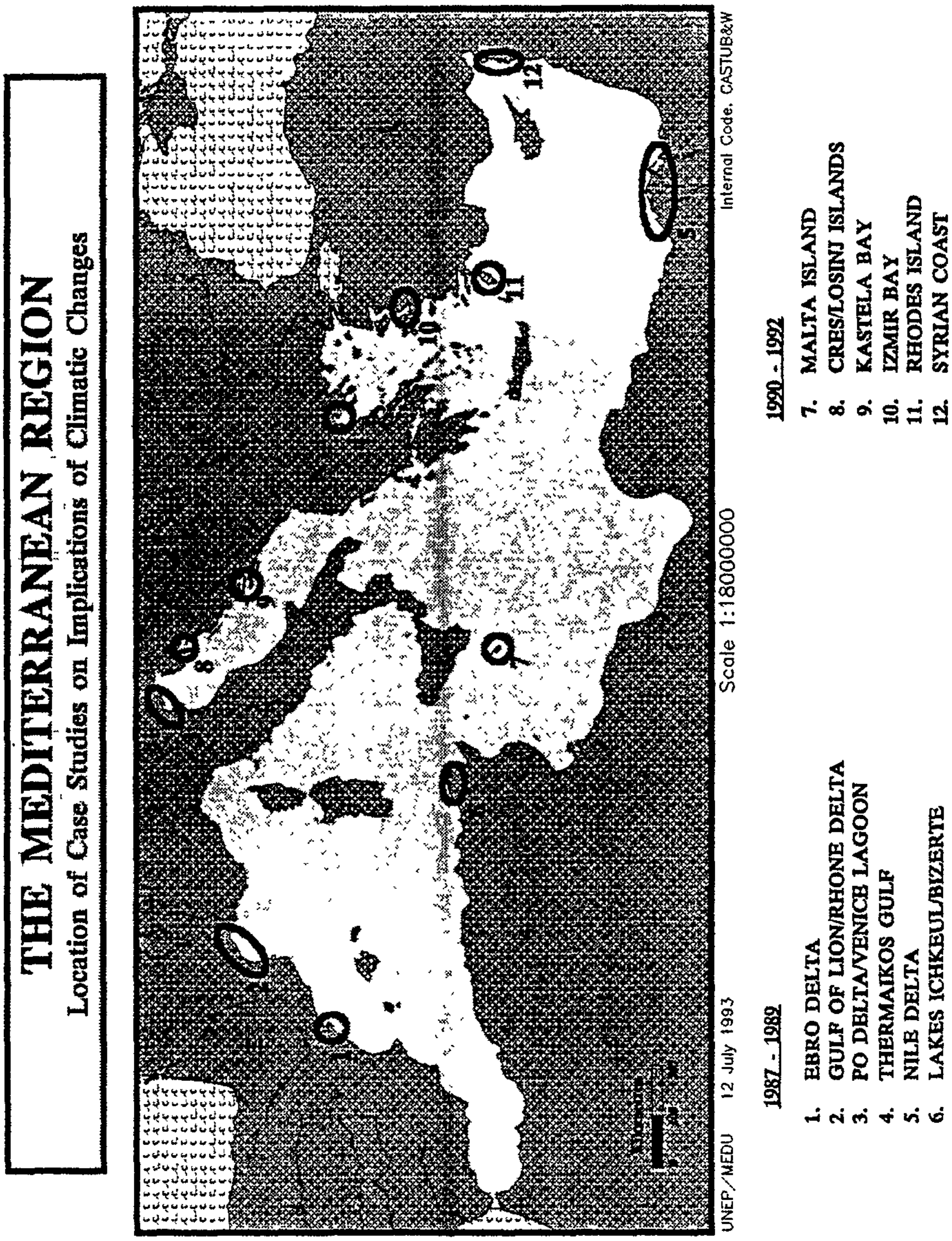


Figure 1 - The Mediterranean basin showing the location of UNEP supported case studies on the implications of climatic changes including Kastela Bay

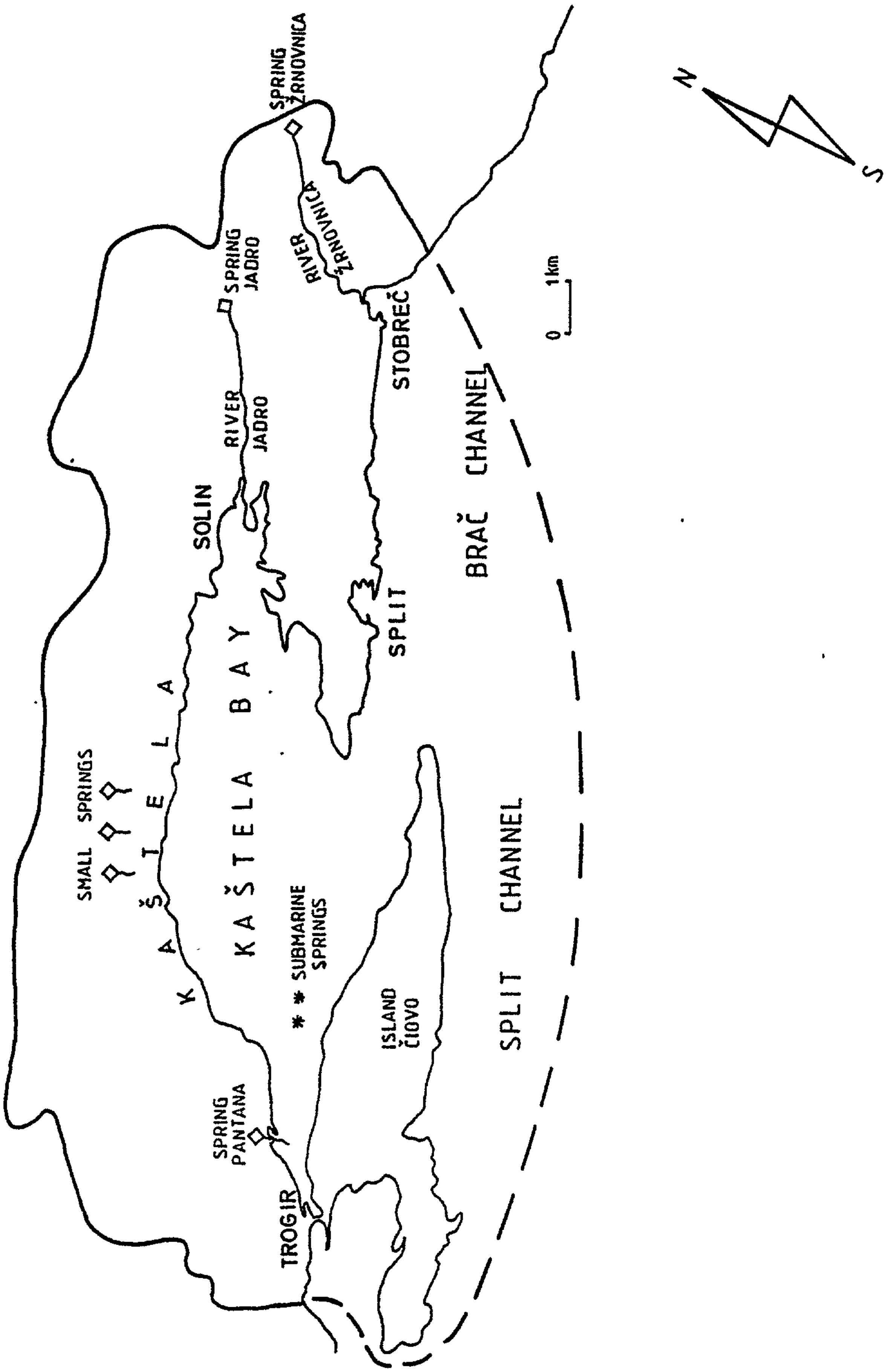


Figure 2 - Map of the Kastela Bay study area

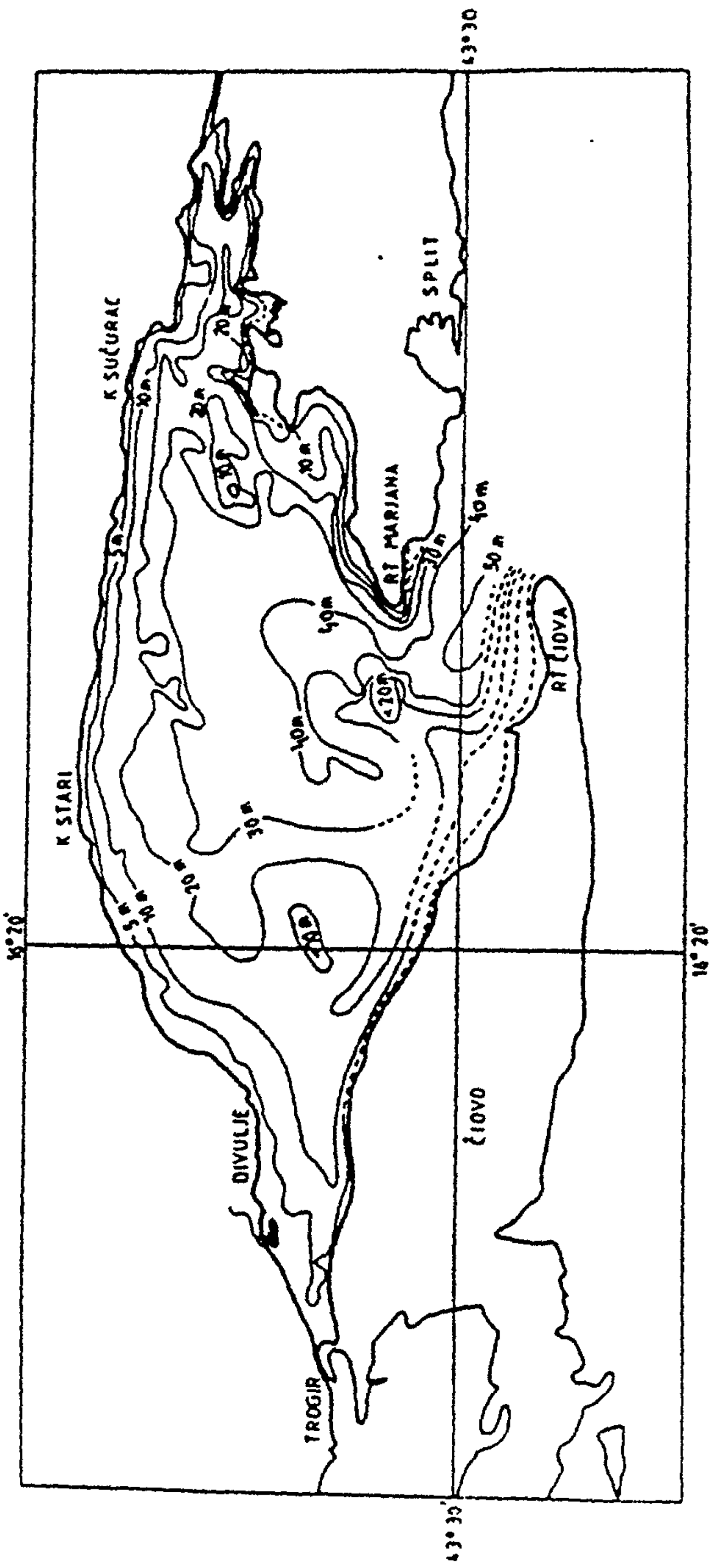


Figure 3 - Bathymetry of Kastela Bay

- to determine areas or systems which appear to be most vulnerable to the expected climatic changes;
- to give recommendations for planning and management of coastal areas and resources, as well as for planing and design of major infrastructure and other systems; and,
- to provide an input into the Kastela Bay comprehensive Coastal Area Management Programme of the Mediterranean Action Plan and into projects and developments relevant to the subject of the study.

To meet these goals, each member of the Task Team drafted one or more chapters of the report. These draft chapters were discussed between individual members of the team and, at joint meetings of the Task Team (April 1991, January 1992 and July 1992). Each chapter addresses one particular domain: natural and managed ecosystems; various human activities; and, population and settlement patterns. Each chapter contains a description of the present situation and characteristics, as well as documenting changes which have occurred in the recent past.

Assessments of the possible impacts of expected climate changes were made on the basis of the existing situation and knowledge of the characteristics of each domain, ecosystem or human activity. The possible impacts were described qualitatively and, wherever possible, quantitatively.

The expected temperature and precipitation changes in the area of Kastela Bay (Annex I) are shown on seasonal and annual maps. The seasonal changes of temperature lie within the range of 1.8 to 1.0 °C per degree of global change. Scenarios of future precipitation suggest an increase in all seasons except autumn, with an overall annual increase of up to 2% per degree of global change. The greatest increase is suggested for the summer (over 10 %) however, as the summer season is characterized by low precipitation, even a small increase in absolute amount will appear as a high percentage.

The expected rise in absolute temperature and precipitation values for the area of Kastela Bay are given in Table 1 based on calculations made for the three operative scenarios set at time horizons of 2030, 2050 and 2100 (Guo *et al.*, 1992).

TABLE 1

Scenarios for future Climate Changes in Kastela Bay
Deduced from Scenarios suggested by IPCC and the University of East Anglia

SCENARIOS	**TIME HORIZON**		
	2030	**2050**	**2100**
IPCC GLOBAL Temperature Sea level	 +1.8 °C +18 +/- 12 cm		 +2 to +5 °C +65 cm +/- 35 cm
University of East Anglia for Kastela Temperature Annual Winter Spring Summer Autumn	°C per °C of global change +0.8 to +0.9 +0.9 to +1.0 +0.8 to +0.9 +0.9 to +1.0 +0.8 to +1.0	as for 2030	as for 2100
Rainfall Annual Winter Spring Summer Autumn	% per °C of global change +2% +1% to +2% +4% to +6% +10% 0% to -2%	as for 2030	as for 2100
Operative Scenario for Kastela Bay Temperature Annual Winter Spring Summer Autumn Sea level	°C +1.44 to +1.62 +1.62 to +1.80 +1.44 to +1.62 +1.62 to +1.80 +1.44 to +1.80 +18 +/- 12 cm	°C +1.8 to +2.0 +2.0 to +2.3 +1.8 to +2.0 +2.0 to +2.3 +1.8 to +2.3 +38 +/- 14 cm	°C +2.8 to +3.2 +3.2 to +3.5 +2.8 to +3.2 +3.2 to +3.5 +2.8 to +3.5 +65 +/- 35 cm
Rainfall Annual Winter Spring Summer Autumn	 + 3.6% +1.8 to +3.6% +7.2 to +10.8% +18.0% -3.6 to 0%	 +4.5% +2.25 to +4.5% +9.0 to +13.5% +22.5% -4.5 to 0%	 + 7% +3.5 to + 7% +14 to + 21% +35 % -7 to 0 %

2. IDENTIFICATION AND ASSESSMENT OF THE POSSIBLE CONSEQUENCES OF CLIMATE CHANGE

2.1 Climate Conditions

In order to study climatic conditions and long term variability, historical data covering the period from 1949 to 1988 were analyzed. This 40-year data set includes monthly means for air pressure, air-temperature, relative humidity, sea-surface temperature, sea-level, and monthly total rainfall. Special attention is given to the wind regime given its importance in the area. Data sets for some of these selected variables cover shorter periods and where this is the case it is indicated in the discussion.

Meteorological conditions in the Kastela Bay area were determined from data collected at the meteorological station at Split-Marjan and some data collected at meteorological station at Split airport. These data may be considered representative of the wider area since the characteristic spatial scale of meteorological variables generally exceeds 10 km.

2.1.1 Analysis of historical data

2.1.1.1 Wind Field Characteristics

The region of Split is markedly windy. Makjanic (1978) showed through an analysis of 10-year wind data collected at a few stations on the Adriatic coast, that Split has winds stronger than 3 Beauforts (B) for more than 75% of the time. The winds in Kastela Bay and along the entire Adriatic coast are extremely changeable in the winter period fluctuating on a synoptic time scale of a few days. Such changes are connected with the passage of low-pressure disturbances across the Adriatic region which bring about a change from a southerly (southeast) to a northerly (northeast) wind direction (Cadez, 1964). The north wind also blows on the Adriatic when the region is at the edge of a cold quasi-stationary winter high pressure system. In such situations cold air caught by circulation of the high-pressure system passes across the mountain barriers all along the eastern Adriatic coast.

In contrast, during the summer period the wind is generally weaker and the greatest changes occur on a daily time scale. These changes are the result of day-night changes in circulation. The wind direction rotates over the 24 hour period in a clockwise direction, so that at night a light northeasterly wind prevails, while during the afternoon a southwesterly wind is predominant. The afternoon or southwesterly wind may be stronger than the night wind, because it represents the sum of thermally induced sea-to-shore winds. The so called etesian winds, which form part of the general summer circulation of the eastern Mediterranean region, generally blow from the northwest, although locally their direction may correspond to the direction of on-shore winds connected with the day-night circulation (Makjanic, 1978).

Table 2 shows monthly frequency and average wind speed in Beauforts based on data obtained over the 28-year period from 1949 to 1976 at the Split-Marjan station, which is located 130 meters above sea level. The northeast wind ("bura") is most frequent and this blows 25% of the time with an average force of over 3 B in some autumn and winter months. Generally speaking, except in May and June, the frequency of "bura" wind never drops below 20%. "Sirocco" or the southeast wind is frequent in February, April and November, so that the local maximum frequency of "bura" coincides with the local minimum of sirocco and *vice versa*. The average force of the "sirocco" exceeds that of the "bura" for much of the year.

In the summer period the frequency of the southwest wind is high. In contrast, the frequency of the southeast and northeast winds is at a minimum in the summer months, since the passage of low-pressure systems over this area is minimal during this period. During summer, the frequency of the northeast wind is somewhat greater than that of the southeast wind, since it regularly occurs during the night time as part of the sea-breeze circulation.

TABLE 2

Mean frequency (F) in parts per thousand and force (J) of winds in Beauforts over the period 1949-1976

	N		NE		E		SE		S		SW		W		NW	
MONTH	F	J	F	J	F	J	F	J	F	J	F	J	F	J	F	J
1	178	3.1	276	2.7	213	3.6	140	4.1	68	2.1	36	1.6	26	1.8	41	1.8
2	196	3.7	299	3.5	160	3.9	198	3.3	64	2.7	31	2.3	26	1.7	19	2.2
3	167	3.2	219	3.2	158	3.8	176	4.2	88	2.2	79	1.9	28	1.4	64	2.1
4	129	3.3	216	3.2	149	4.2	197	4 2	82	3.1	129	2.2	29	2.7	53	2.1
5	136	2.7	140	2.4	136	3.3	120	3.7	122	2.2	168	2.3	47	2.1	77	1.8
6	97	2.8	169	2.6	130	3.0	156	3.3	127	2.0	187	2.2	35	1.9	57	1.9
7	151	3.1	235	2.9	102	2.4	84	2.5	92	2.1	173	2.4	64	2.0	54	1.8
8	149	2.6	229	2.3	88	1.9	68	2.6	118	2.2	194	2.3	45	1.9	62	1.8
9	193	3.4	285	2.8	101	2.5	84	3.5	120	2.2	133	1.9	22	1.1	38	2.0
10	195	3.5	305	3.2	101	3.3	99	3.3	120	2.3	80	1.9	33	1.8	39	1.6
11	160	2.8	252	2.9	178	3.8	185	4.0	86	2.6	37	1.6	33	2.0	54	1.4
12	177	3.3	316	3.2	127	3.4	111	3.2	95	1.8	58	1.5	36	1.8	52	1.6
YEARLY AVERAGE	161	3 2	245	3.2	137	3.4	135	2.3	98	2.2	109	2.1	35	1.8	51	1 8

When estimating the effects of wind on ocean currents, it is important to know not only the force of the wind but also the wind's duration. Although there are no extensive records of the duration of winds at the Split station, it has been shown that both the northeast and southeast winds, generally last for two or three days and rarely for only one day (Makjanic, 1978). This is sufficient time to establish wind generated quasi-stationary currents. A wind of shorter duration may also, through non-linear processes, affect residual circulation.

2.1.1.2 Intra-annual temperature variations

Surface air temperature is controlled by the wind and other weather processes and reflects the local balance of incoming and outgoing radiation, as well as heat storage in water bodies.

Monthly mean air temperatures over the annual cycles are presented in (Table 3 and Figure 4). Annual mean temperature is 16.0 °C and annual mean temperature range (difference in mean temperature between the coldest and warmest months) is 17.9 °C.

January is the coldest month with a mean temperature of 7.6 °C and July the warmest month with mean a temperature of 25.5 °C, which is in agreement with changes in global irradiance.

TABLE 3

Monthly mean air temperatures (°C) at the Split-Marjan station over the period from 1949 to 1988

MONTH	01	02	03	04	05	06	07	08	09	10	11	12
Mean Temp.(°C)	7.6	8.1	10.3	13.8	18.7	22.6	25.5	25.0	21.5	16.9	12.3	9.2

Persistence of extreme air temperature conditions is an important climatic feature. Days can be classified as hot, warm or cold using the following criteria:

Hot days - maximum daily air temperature ≥ 30 °C
Warm days - maximum daily air temperature ≥ 25 °C
Cold days - minimum daily air temperature < 0 °C

Data for the mean number of days each month in each category are presented in Table 4 and clearly demonstrate that the study area is subject to warm temperature conditions.

TABLE 4

Mean number of hot, warm and cold days each month

MONTH	01	02	03	04	05	06	07	08	09	10	11	12
HOT	-	-	-	-	0.2	4.9	15.7	14.3	2.1	-	-	-
WARM	-	-	-	0.2	7.6	21.4	29.4	28.4	16.4	1.3	-	-
COLD	2.8	2.4	0.9	-	-	-	-	-	-	-	0.1	0.1

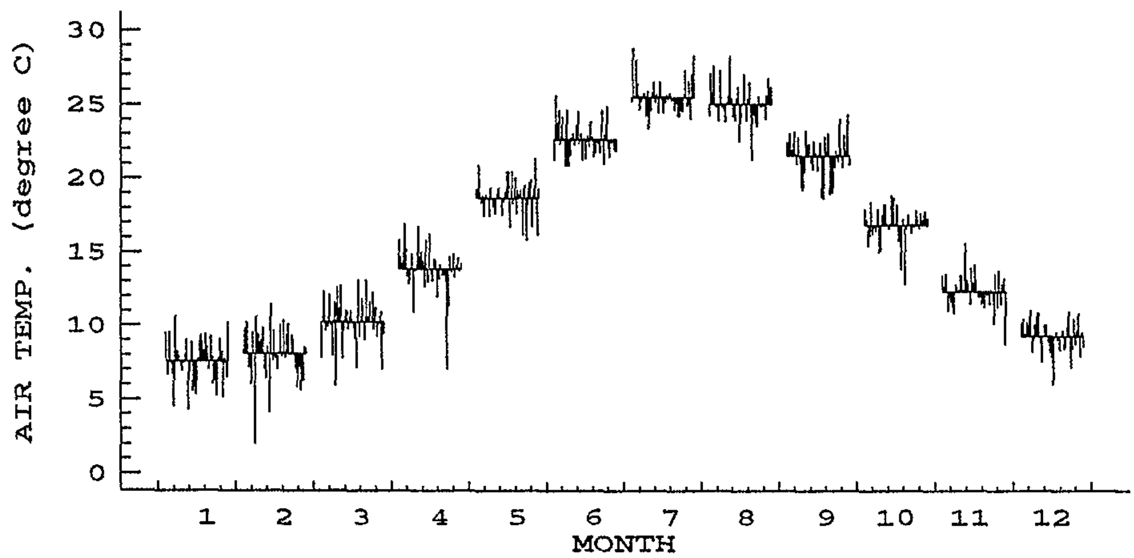


Figure 4 - Monthly mean air temperature for Split-Marjan over the period from 1949 to 1988

2.1.1.3 Inter-annual temperature variations

Annual mean air temperature and monthly mean temperatures are highly variable. During the period of observations annual mean temperatures varied from 14.9 °C to 17.4 °C (Figure 5) with greatest inter-annual variation in monthly mean temperature occurring in February and August (Table 5).

Annual mean temperatures display strong inter-annual variation which can be as high as 1 °C. However, the time-series displays no long term trend in air temperature. In addition, Figure 5 indicates that the period between 1961-1975 was characterized by less extreme inter-annual variation than the *remainder of the time series.*

Annual maximum air temperatures ranged from 32.5 °C in 1977 to 38.6 °C in 1950 while annual minimum ranged from -9.0 °C in 1963 to 3.2 °C in 1974.

TABLE 5

Range of air temperature for Split-Marjan station over the period from 1949 to 1988

MONTH	01	02	03	04	05	06	07	08	09	10	11	12
t_1 (°C)	10.6	11.4	13.1	16.9	21.6	25.6	28.8	28.2	24.3	18.8	15.6	11.0
t_2 (°C)	4.3	2.0	7.1	11.3	15.8	20.8	23.3	21.2	18.6	12.8	8.7	6.0
t_1 -t_2 (°C)	6.3	9.4	6.0	5.6	5.8	4.8	5.5	7.0	5.7	6.0	6.9	5.0

t_1 = Maximum monthly mean temperature over the period 1949-1988
t_2 = Minimum monthly mean temperature over the period 1949-1988
t_1 - t_2 = Range of monthly mean air temperatures over the period 1949-1988

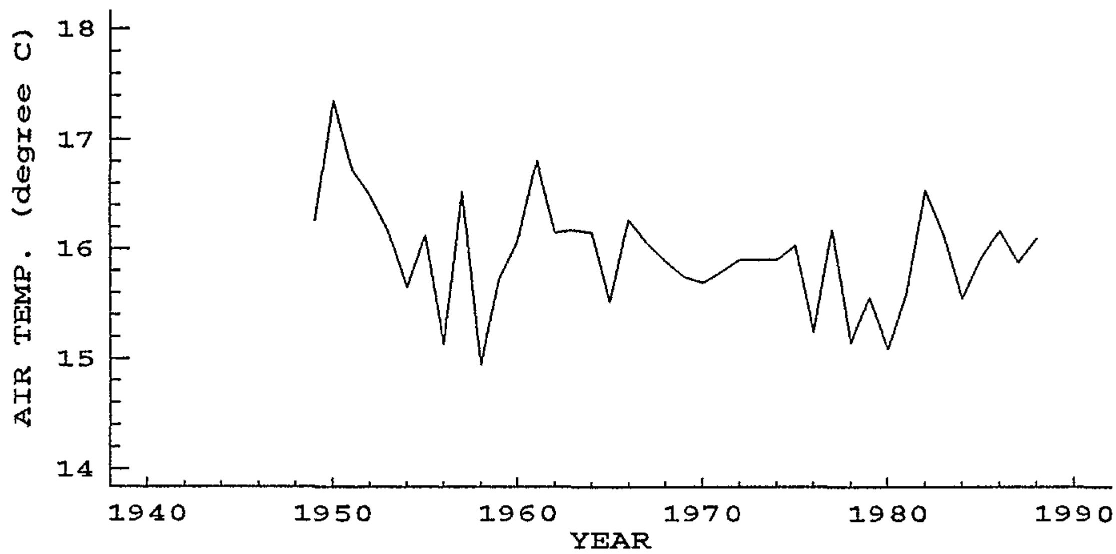


Figure 5 - Interannual variation in mean annual air temperature, at Split-Marjan, over the period 1949 to 1988

2.1.1.4 Precipitation

Long-term data for the period 1949-1988 indicate that mean annual precipitation in the Split area is 820.6 mm with a minimum of 613.0 mm and a maximum of 1101.5 mm. Precipitation is on average, lowest in July and highest in December (Figure 6). Annual variation in precipitation is characteristic of coastal areas, and the great inter-annual variability in total precipitation reflects the maritime character of the climate in the Split region. Most of the annual precipitation occurs in the colder part of the year, while the summer is characterised by relatively low precipitation and dry summers are frequent.

The annual distribution of rainfall is the result of both cyclonic activity and local orographic effects. Since orographic uplift and convection is affected by the local topography, a single rainfall recording station can not be representative of the spatial distribution of rainfall over the entire Kastela Bay area. Monthly rainfall data for two locations in the Kastela Bay area are presented and compared (Table 6 and Figure 6). The time-series for the second location at the Kastela airport however, covers a shorter period (1949-1970) than that for Split-Marjan (1948-1988). Inter-annual variations for both stations are detailed in Figure 7.

TABLE 6

Monthly total precipitation (mm) for the Split-Marjan station over the period from 1949 to 1988, and for the Kastela - Airport station over the period from 1949 to 1970

MONTH	01	02	03	04	05	06	07	08	09	10	11	12	ANNUAL TOTAL
SPLIT MARJAN	79.7	70.2	69.1	60.5	56.2	51.1	30.4	44.3	60.1	74.8	113.0	111.0	820.6
KASTELA AIRPORT	102	83	72	82	58	63	31	65	71	99	177	165	1068

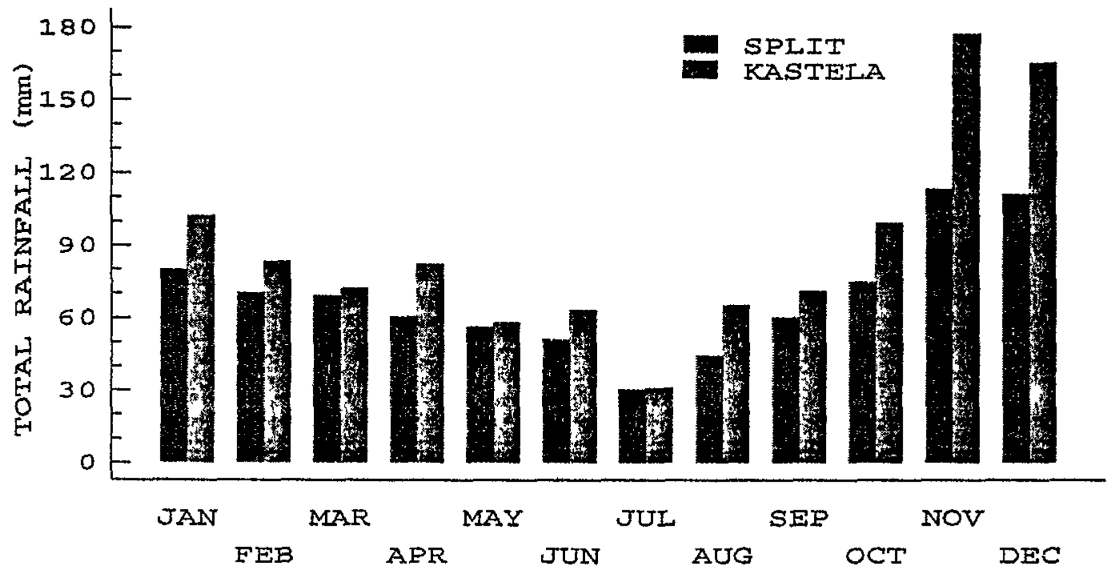


Figure 6 - Monthly total precipitation at Split-Marjan over the period from 1949 to 1988 and, at Kastela-Airport over the period from 1949 to 1970

Comparison of the monthly rainfall figures suggests that the mean monthly total precipitation at the Kastela Airport station is generally higher than that at the Split-Marjan station, a difference which can be attributed to orographic effects. The Kastela Airport station is situated in the vicinity of the highest mountain in the area which is oriented in an ENE-WSW direction, practically perpendicular to the sirocco. This is the wind which carries humid and relatively warm air and therefore usually results in rainy weather. The greatest differences between the two stations occur in November and December when rainy days are also the most frequent (Table 7). Table 7 presents data for the frequency of rainy days each month classified on the basis of the following criteria:

N1 = mean number of days with daily precipitation ≥ 0.1 mm

N2 = mean number of days with daily precipitation ≥ 1.0 mm

N3 = mean number of days with daily precipitation ≥ 10.0 mm

TABLE 7

Mean number of days with characteristic precipitation for Split-Marjan station over the period from 1949 to 1988

MONTH	01	02	03	04	05	06	07	08	09	10	11	12
N1	12.5	11.1	10.7	10.1	10.0	8.8	5.3	5.9	8.3	8.8	10.7	12.9
N2	9.5	7.9	7.6	6.3	6.9	5.6	3.3	3.7	6.0	7.2	8.3	10.3
N3	3.6	2.9	2.1	1.7	2.1	1.4	0.9	1.4	2.1	1.9	3.1	4.5

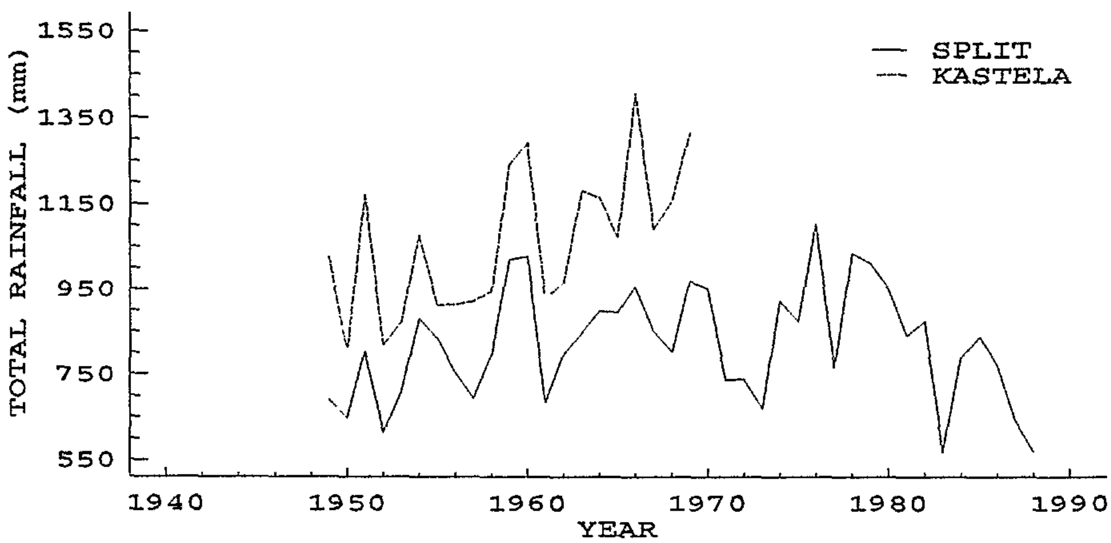


Figure 7 - Inter-annual variation in precipitation at Split-Marjan over the period from 1949 to 1988 and, at Kastela-Airport over the period from 1949 to 1970

2.1.1.5 Relative Humidity

Annual variations in relative humidity display a reverse seasonal pattern to that of air temperature. Minimum values of relative humidity are recorded in the warmer part of the year, while the highest humidity occurs in the winter months (Table 8 and Figure 8). Inter-annual variations in relative humidity are presented in Figure 9, the long-term annual mean is 59% ranging between 54 and 62.5%. Inter-annual variation in the relative humidity is high and in addition the data display a decreasing trend from the early 1960's. Based on a time-series of only 40 years it is difficult to conclude whether this is in reality a long-term trend or due to some low frequency variability.

TABLE 8

Annual and monthly, mean and minimum values and absolute minimum values of relative humidity (%) at Split-Marjan over the period from 1949 to 1988

MONTH	01	02	03	04	05	06	07	08	09	10	11	12	ANNUAL MEAN
MEAN	61	60	60	59	59	56	50	51	58	62	65	63	59
MEAN MIN.	25	25	27	26	30	28	27	27	29	29	30	28	17
ABSOLUTE MIN.	12	10	15	6	21	9	12	18	18	18	15	15	6

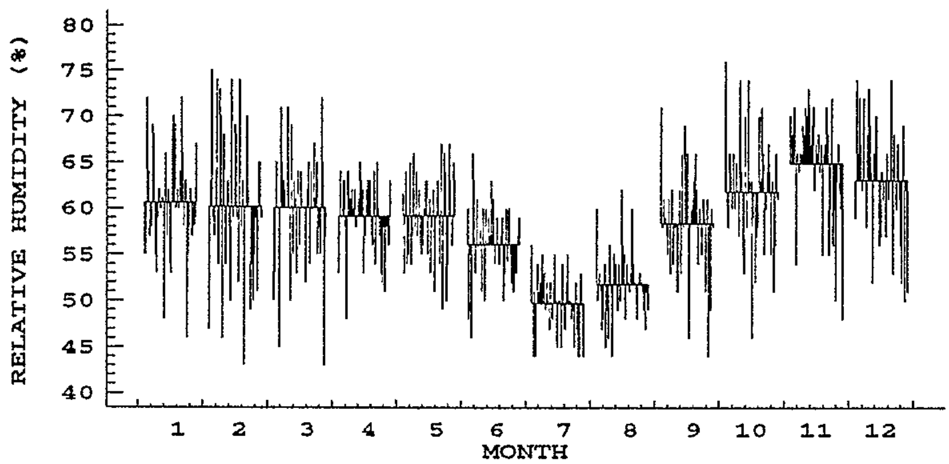


Figure 8 - Seasonal changes in mean relative humidity at Split-Marjan over the period from 1949 to 1988

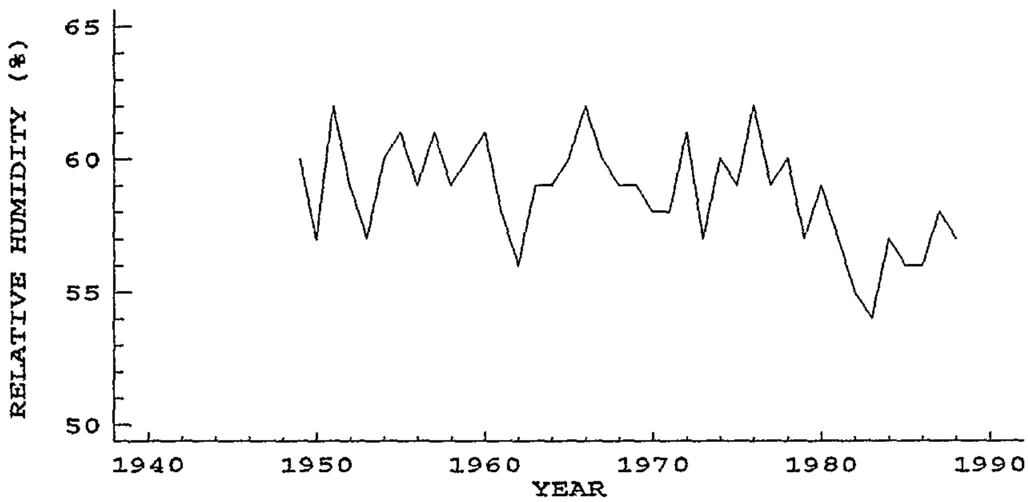


Figure 9 - Inter-annual changes in mean humidity at Split-Marjan over the period from 1949 to 1988

2.1.1.6 Air pressure

Monthly mean and long-term variations in annual mean air pressure over the Adriatic are closely related to general circulation patterns, and to the paths and frequency of passage of mid-latitude cyclones.

Over the period from 1949 to 1988 annual mean air pressure was 999.7 hPa with a maximum in October (1002.1) and minimum in April (997.8) (Table 9 and Figure 10).

TABLE 9

Monthly mean air pressure (hPa) at the Split-Marjan station over the period from 1949 to 1988

MONTH	01	02	03	04	05	06	07	08	09	10	11	12	ANNUAL MEAN
MEAN	1000.1	999.1	998.9	997.8	998.8	999.6	999.1	999.1	1001.4	1002.1	1000.6	1000.0	999.7

Inter-annual air pressure variation is shown in Figure 11 which displays strong year-to-year differences which are greater than any long-term trend. From the mid 1960s there is some evidence of a trend towards increasing air pressure paralleling the trend in relative humidity noted above.

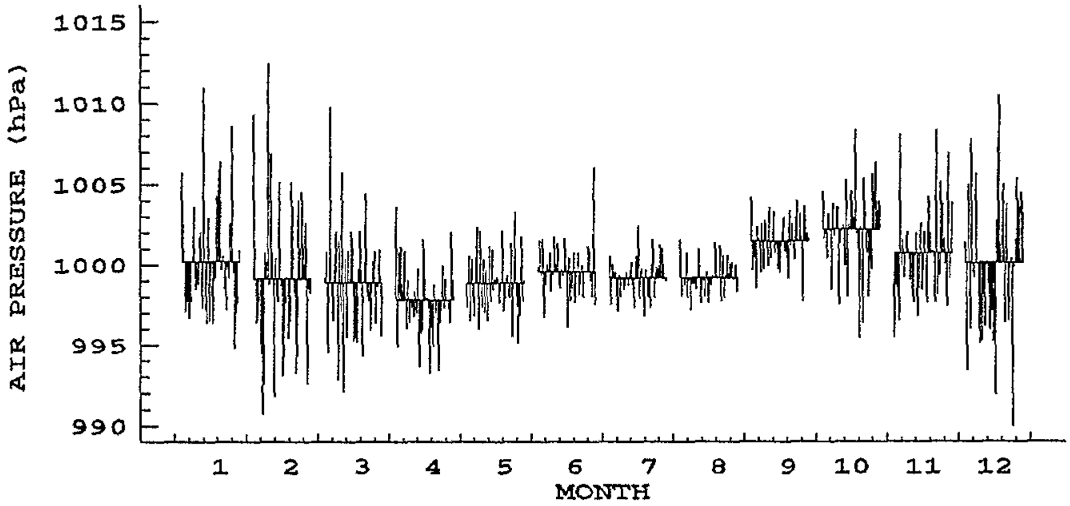


Figure 10 - Monthly mean air pressure at Split-Marjan over the period from 1949 to 1988

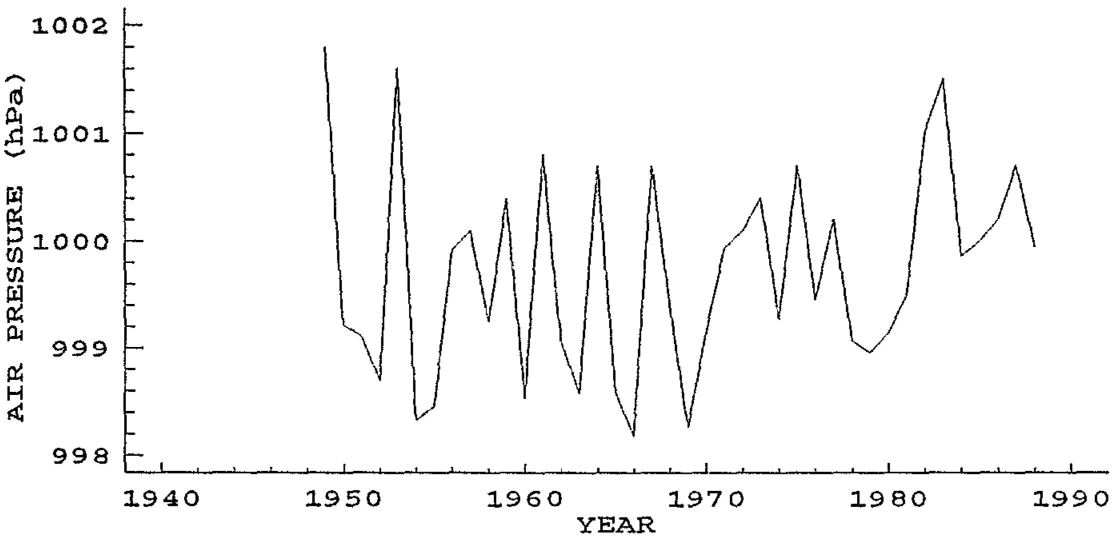


Figure 11 - Inter-annual variations in air pressure at Split-Marjan over the period from 1949 to 1988

2.1.1.7 Sea surface temperature

Measurements of sea surface temperature in Kastela Bay have been made between 1950 and 1988. Temperatures were recorded twice daily at 7.00 a.m. and 2.00 p.m. at the Marjan promontory.

The monthly mean values of sea surface temperature are at a minimum in February and at a maximum in August (Table 10 and Figure 12). Inter-annual variations (Figure 13) are characterized by strong year-to-year changes being of the order of one degree. The annual mean temperature is 17.2 °C and no long-term trend is observable in the present data set.

TABLE 10

Monthly mean sea surface temperature at the Marjan promontory over the period from 1950 to 1988

MONTH	01	02	03	04	05	06	07	08	09	10	11	12
Temp. (°C)	12.0	11.2	11.7	14.0	17.6	21.4	23.5	23.6	21.9	19.4	16.5	13.8

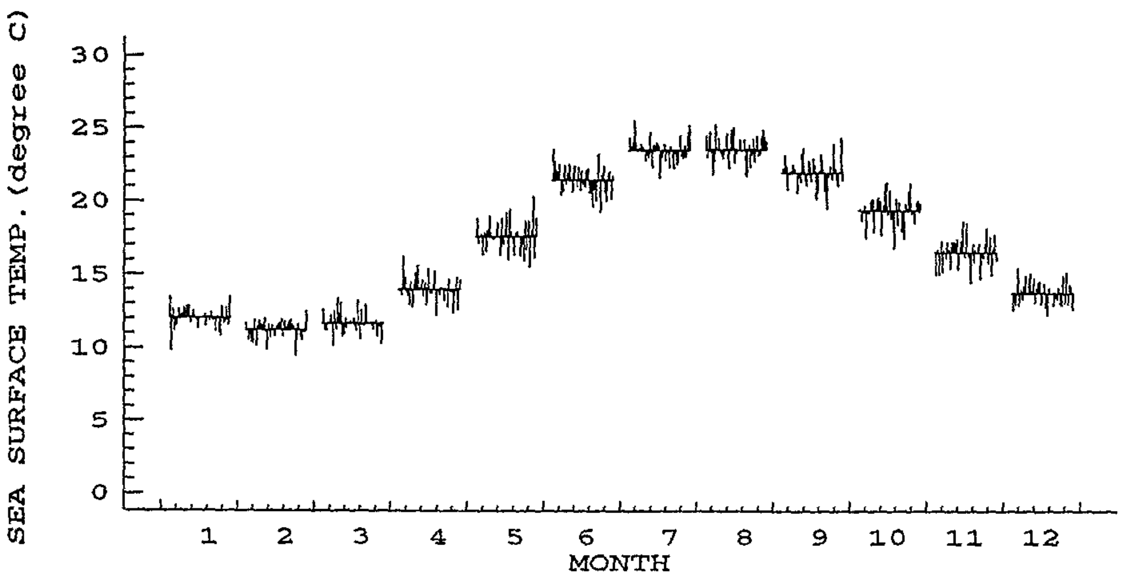


Figure 12 - Monthly mean sea surface temperature at the Marjan promontory over the period from 1950 to 1988

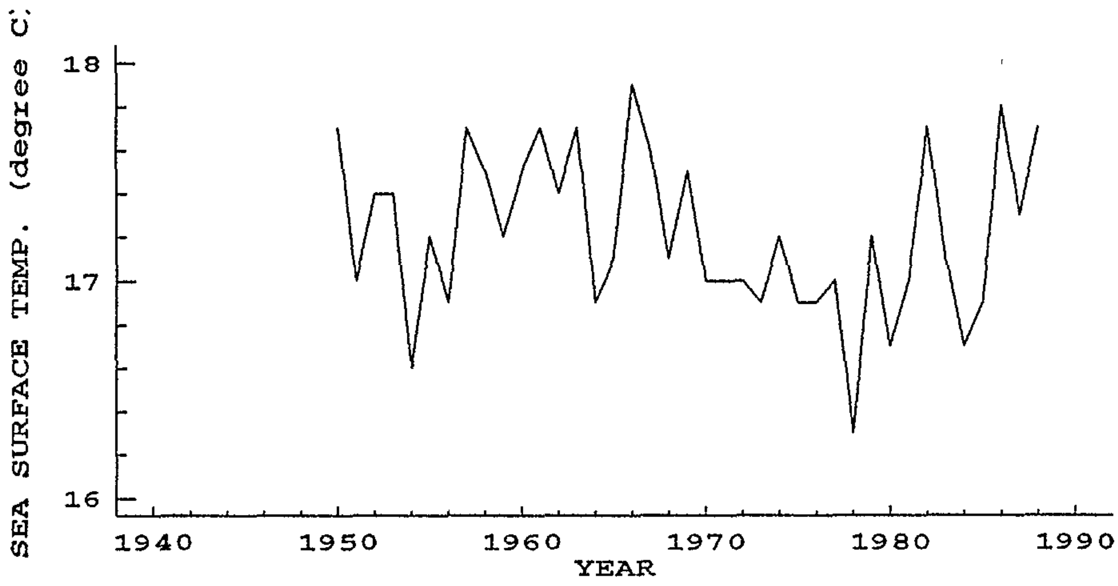


Figure 13 - Inter-annual variations in sea surface temperature at the Marjan promontory over the period 1950 to 1988

2.1.1.8 Sea level

Sea level data have been recorded continuously at the Marjan promontory tide-gauge station since 1955. Mean monthly sea level data are presented in Table 11 and Figure 14 while inter-annual variation for the period from 1955 to 1988 is presented in Figure 15.

TABLE 11

Monthly mean sea level computed from the data for the period 1955 to 1988 recorded at the tide-gauge station at Marjan promontory

MONTH	01	02	03	04	05	06	07	08	09	10	11	12	ANNUAL MEAN
Sea level (cm)	61	60	57	58	57	57	55	55	57	62	66	65	59

Sea level is at a minimum in July and highest in November. The fact that seasonal changes in sea level are not completely in phase with changes in atmospheric pressure suggests that the static response signal on these time scales is very weak. It is probable that seasonal heating and consequent density changes have the greatest influence on seasonal sea level variations. In contrast, it seems that atmospheric pressure has a stronger influence on the inter-annual variation in sea level than is the case with intra-annual changes. No evidence of a long-term trend can be observed, in the sea level time-series.

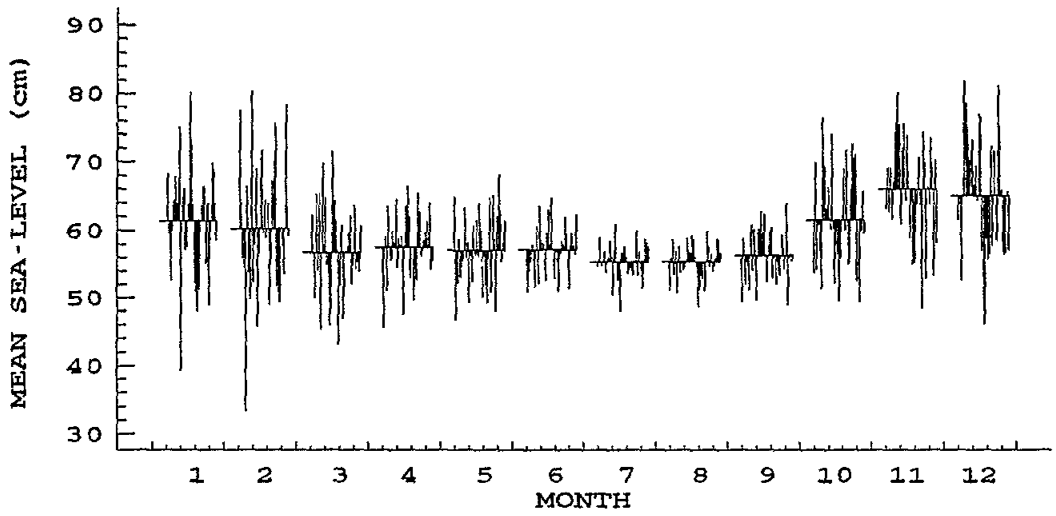


Figure 14 - Monthly mean sea level at the Marjan promontory over the period from 1955 to 1988

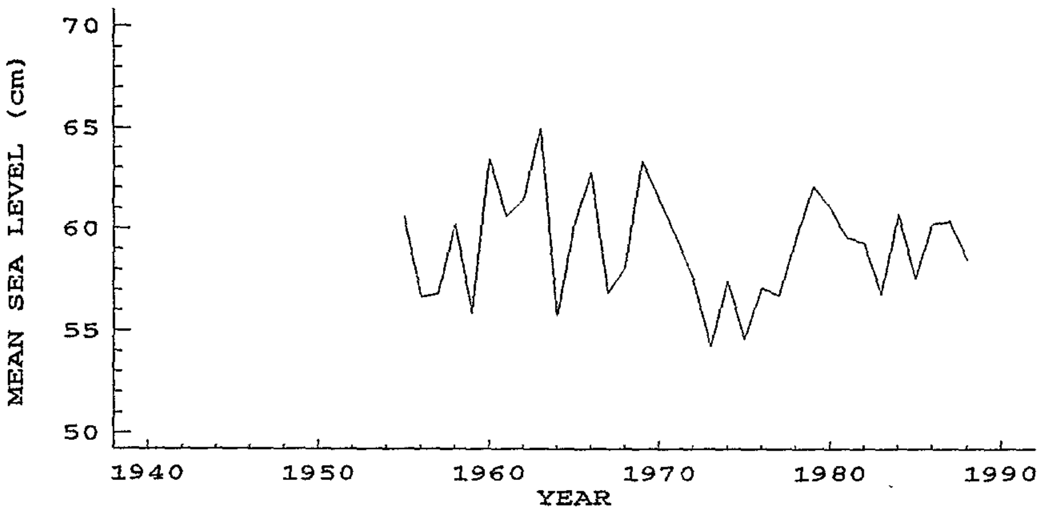


Figure 15 - Inter-annual changes in sea level at the Marjan promontory
over the period from 1955 to 1988

2.1.2 Inter-annual variability of air-sea interaction

Based on the available data, it is not possible to say very much about the interaction between various oceanographic and meteorological variables in the Kastela Bay area. Recent worldwide scientific interest in air-sea interactions in different regions on a climatic time scale has revealed that sea-level and sea-surface temperature variations are good indicators of oceanic circulation, water mass and heat balance variations. Sea level and sea surface temperature seem very closely related in longer time series (Gacic, 1980; Kovacevic *et al.* 1990).

In order to analyze in a more quantitative way the relationship between oceanographic and meteorological variables on a climatic time scale, an empirical orthogonal function (EOF) analysis is used. This is a statistical method which represents different variables by linear combinations of modes, representing simultaneous variations in various sub-groups of the parameters and, more importantly, the physical processes responsible for these changes. Further details of this method can be found in Kutzbach, 1967; North and Moeng, 1981; North *et al.*, 1982; Servain and Legler, 1986. The total variance for all climatic parameters can be explained by EOF modes. Each mode, derived statistically, contributes a certain percentage to the total variance, and represents the pattern of variability explained by that mode (Preisendorfer, 1988).

In the following analysis, time series for the period from 1959 to 1984, of monthly means for the following parameters were used:

air temperature; rainfall; barometric pressure; relative humidity; sea surface temperature; and sea level.

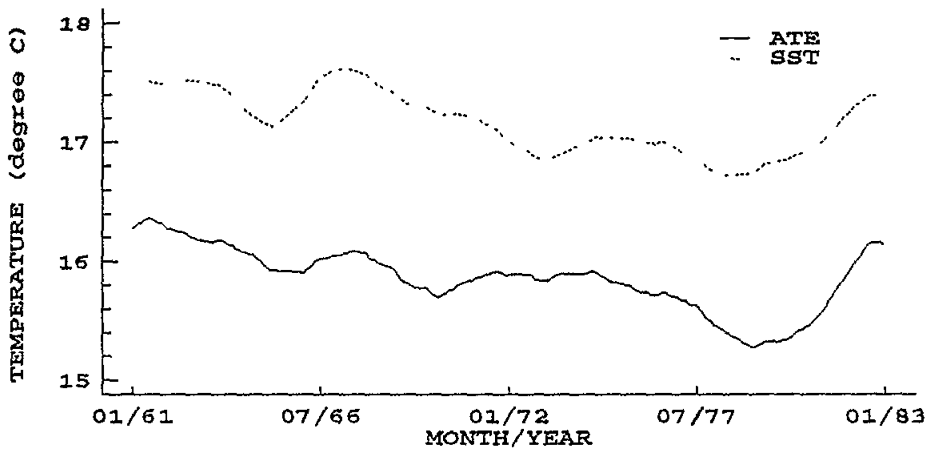
The length of the period for which data covering all parameters was available is less than that for individual parameters and stretches from 1961 to 1985. Prior to the analysis seasonal signals and all variations with periodicity shorter than a year, were removed by a convenient low-passed filter. Interactions between various oceanographic and meteorological variables with time scales longer than two years are thus analyzed. Low-pass curves for all data sets are presented in Figure 16. Comparing them with curves of time series of yearly means it can be seen that they are much smoother due to a removal of high frequency variations of periodicity shorter than two years.

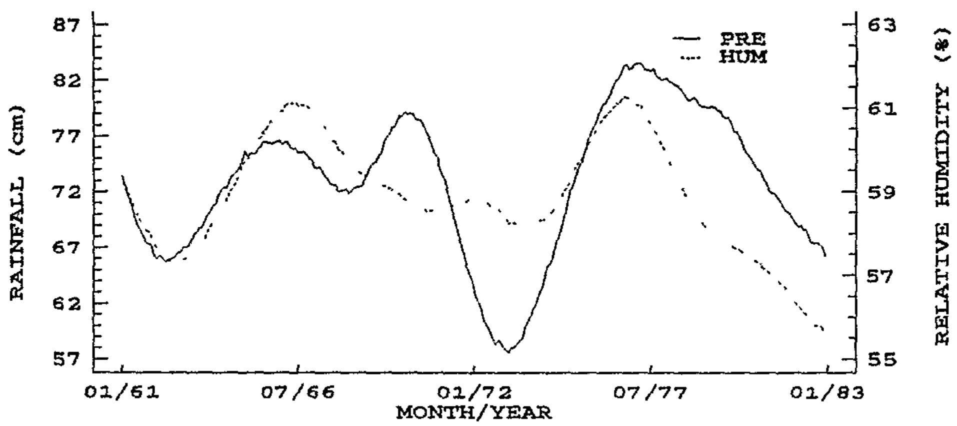
The analysis is restricted to the first three modes which together contribute 91% of the total variance, with each mode accounting for 40, 33 and 18 percent respectively. The first mode, reflects the static influence of atmospheric pressure, and explains about 40% of the overall variance in sea level. Higher atmospheric pressure represents lower frequency of mid-latitude cyclones and lower rainfall. Only about 24% of the sea level variance, however, is associated with that mode. At the same time, about 80% of the variance in both atmospheric pressure and rainfall is contained in that mode.

A major proportion of the low-frequency sea level variability (75% of the variance) can be explained in terms of thermal effects which are contained in the second and third modes. The second mode which contributes about 33% to the total variance, can be interpreted in terms of sea level changes due to thermal expansion. In this second mode, high sea surface temperature is associated with high sea level and *vice versa*.

More than 40% of the sea level variance is attributed to the third mode, which reflects the sea level response to latent heat transfer, since it demonstrates strong correlations between sea level and relative humidity. The third mode accounts for about 18% of the overall variance, more than 50% of the variance in the relative humidity and around 33% of the sea level variance.

In conclusion, one can state that about 75% of the low-frequency sea level variations are due to thermal effects (solar heating and latent heat transfer) and that an increase in the water temperature will certainly affect future sea levels in the area of Kastela Bay. The thermal effects are three times as strong as atmospheric pressure effects on sea level, however, it should be noted that no trend in sea surface temperature has been observed over the past 40 years.





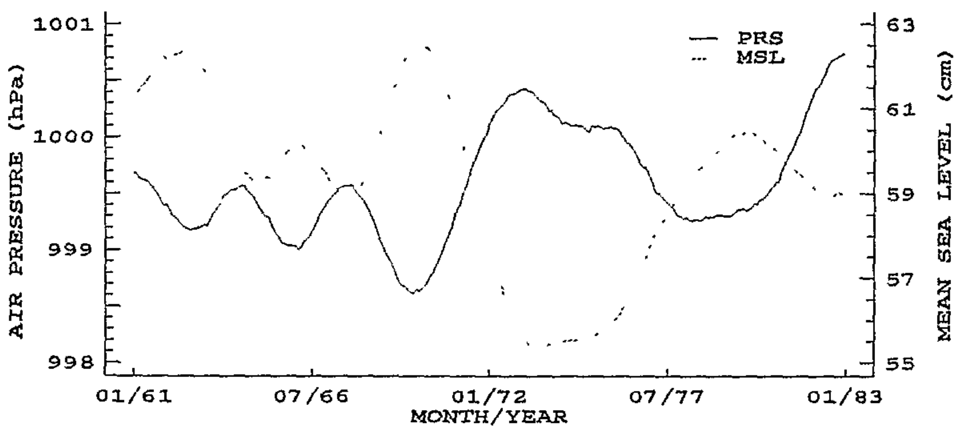


Figure 16 - Filtered data set at Split-Marjan station (meteorological data) and at Marjan promontory (oceanographic data) for the period from 1959 to 1988

2.2 Lithosphere

2.2.1 Geology

Geologically, the area under investigation forms part of a large Cretaceous - Tertiary sedimentary complex, which belongs to a structural unit of the Adriatic, Cretaceous carbonate sediments (Marincic, *et al.*, 1967; Figure 17). These sediments are composed of the Turonian limestones with rare layers of dolomite. The limestones are well stratified, bedded and banked; and within these facies are strata of dolomites. The Senonian is composed of fragmented massive, banked limestones and dolomites. The limestones are strongly fissured, irregularly and often strongly karstified and permeable, and the surface is waterless.

A great proportion of the study area is composed of the Paleogenic sediments: Eocene-Flysch marls, sandstones, and claystones with frequent, irregular, rhythmic succession; Foraminiferal limestones; Eocene breccias and breccia conglomerates, with lenses of limestones and Eocene limestones breccias.

The Flysch complex is very often tectonically folded and fractured, impermeable, subjected to irregular weathering and erosion. With respect to their hydrological characteristics and the soil types formed on them, Paleogenic limestones and breccias are similar to Cretaceous limestones. The Flysch complex is often covered by quaternary, colluvial deposits (0.5-2 m), which are very significant from the pedological point of view.

During the quaternary period the main landscape forming process was erosion, followed by transport and local deposition of material. Quaternary deposits are very variable with respect to their composition (ratio of the colluvial components) and thickness or depth. From the perspective of ecology and vegetation, the ratio of the components in terms of inorganic and organic soil particles, chemical composition and depth are very important. These characteristics depend on the nature of the parent material, it's origin and distance of transport. Alluvial deposits can be found only at the mouths of the Jadro and Zrnovnica rivers, and occupy only very small areas.

2.2.2 Soils

2.2.2.1 Past trends and present situation

The soils of the Kastela area have been systematically surveyed and a 1: 25.000 soil map (Figure 18) has been produced (Milos, 1991). The soils are very variable, resulting from the great variation in the influence of different soil forming factors over short distances, including the composition of the parent material, topography, and human interference.

Figure 19 shows the topographic diversity with mountainous land forms, gently inclined fields typical of coastal flatlands and the terraced slopes of surrounding hills. The relative position and relationship between topography, geological structures and altitudinal distribution of soil types (soil mapping units) are illustrated in the schematic cross section A-A' (Figure 20).

There is a close relationships between the spatial distribution of the different soil types and these soil forming factors. Flatlands and gently sloping relief are covered by arable anthropogenic terraced soils. Abandoned terrace soils are found in areas of steeper slope and on the very steep slopes, natural, shallow and skeletal soil types are developed on the underlying limestones and dolomites.

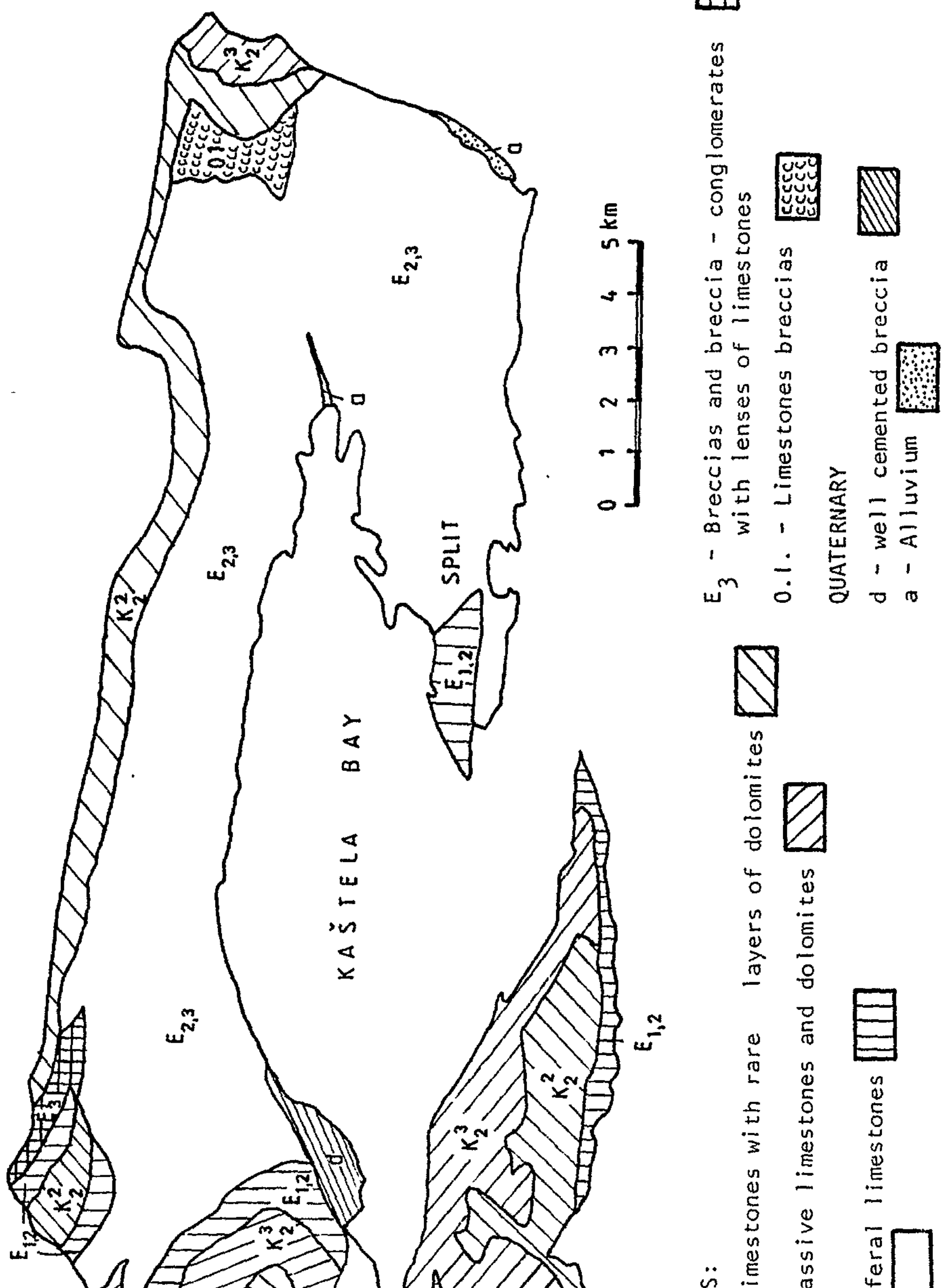


Figure 17 - Geology of the Kastela Bay area

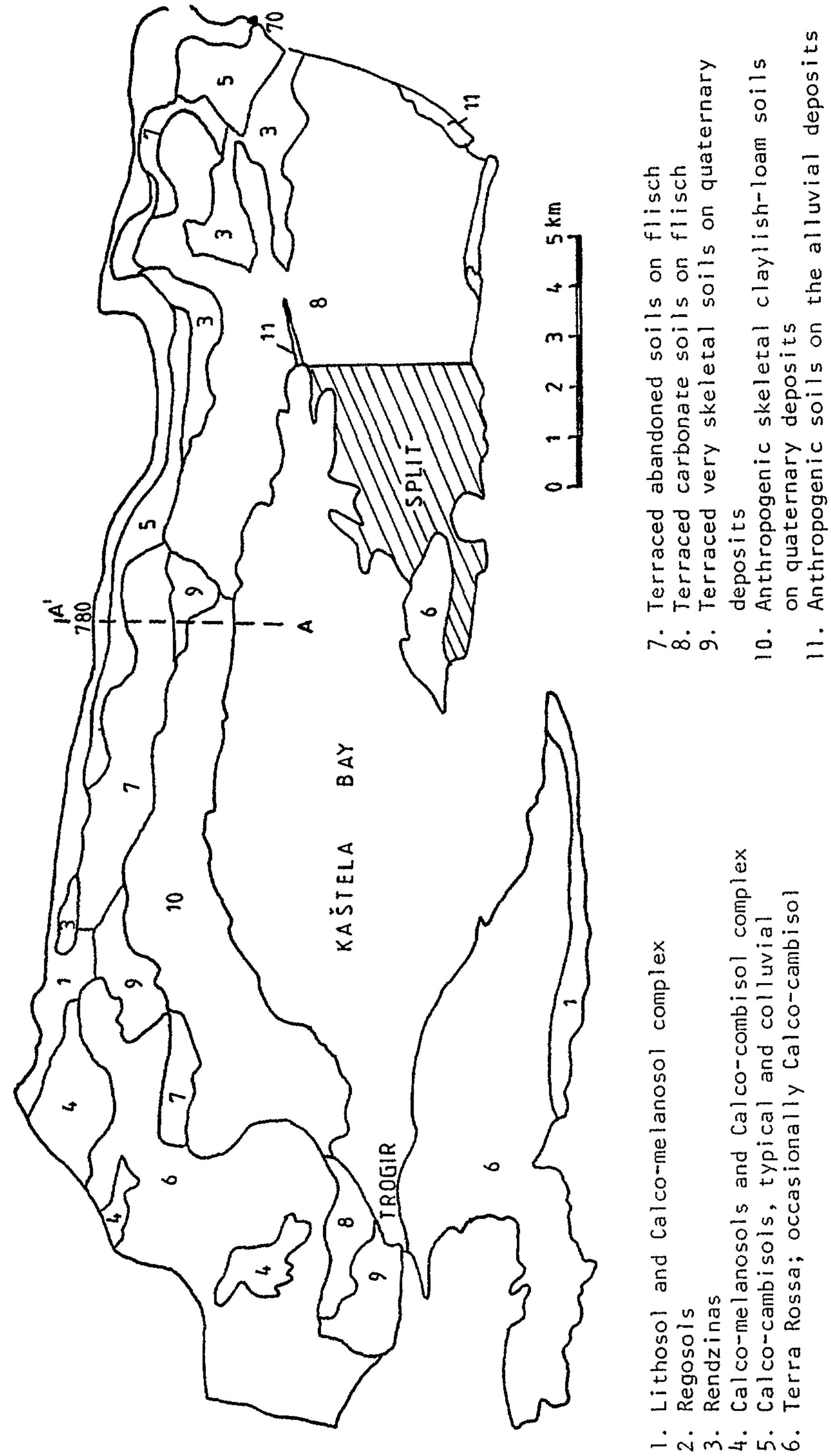


Figure 18 - Soil map of the Kastela Bay area

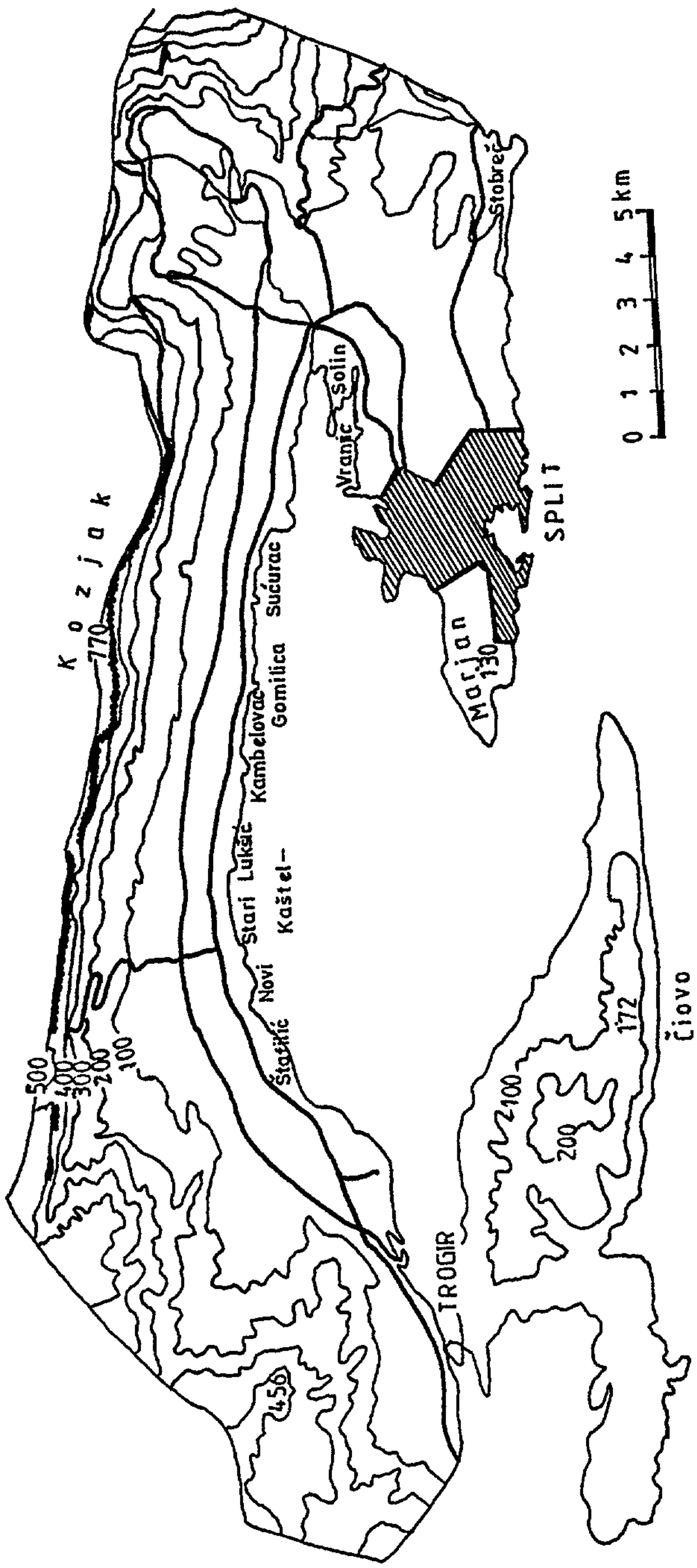


Figure 19 - Topography of the Kastela Bay area

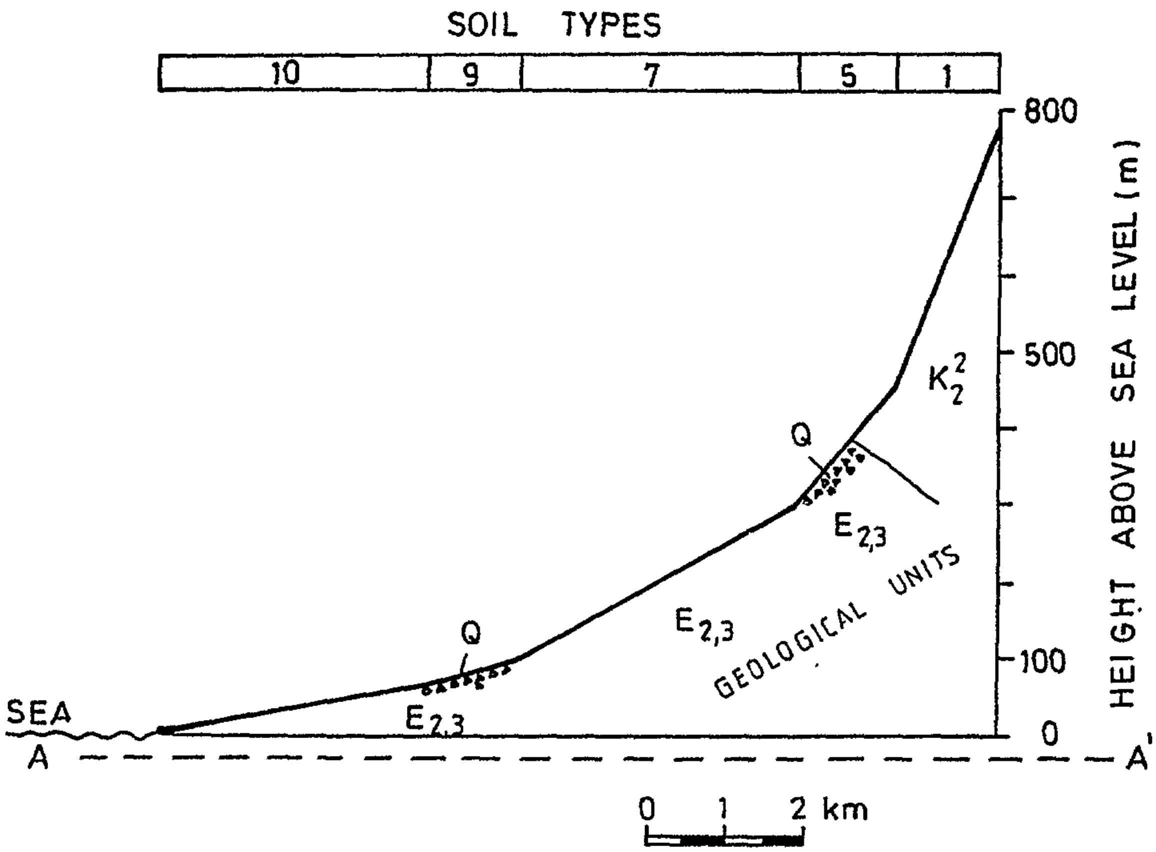


Figure 20 - Schematic cross-section along the section marked A-A' on Figure 19 (K_2^2 - Turonian limestones, $E_{2,3}$ - Eocene - Flisch marls, Q - Quarternary deposits)

Soil types

The following types of soils have been formed in this area: Lithosols, Calcaric Regosols, Rendzinas, Calco-melanosols, Calco-Cambisols, Terra Rossa (Cromic-Cambisols and Cromic Luvisols) and Anthropogenic soils. The chemical properties and texture of some soil types are given in Table 12.

Natural soil types

Lithosols are soils without well developed genetic horizons, made up of skeletal limestones. Their appearance is unstratified due to the physical, friable nature of the limestone, to the karstic hydrology and to intensive erosion of the smaller soil particles. On flat ground, these soils are very shallow (10-20 cm); on the steep slopes lithosols are found in combination with Calco-melanosols and colluvial soils, which are much deeper and very skeletal. The properties of colluvial soils depend on the quality of the material that is transported, the distance of transport and the physical characteristics of the environment.

Calco-melanosols are shallow soils with well developed organic horizons which lie above the limestones. Chemically, these soils have a high humus content (mull- type), an excellent soil structure and the $CaCO_3$ content is very low. Shallow depth and dryness resulting from low water retention capacity and under-lying karst hydrology are the principal limiting factors to potential production on these soils. Calco-melanosols are found in combination with Cambic soils.

Rendzinas are humus-carbonate soils and represent a further stage in the development of the carbonate regosols. These are mostly plateau type soils covered with forest vegetation. Their productivity depends on the thickness of the humus horizon, depth of the profile and the properties of the parent material. Rendzinas formed on the marl regolites have a deep soil solum, in contrast to rendzinas on marl limestones or sandstones which are in direct contact with the parent rock.

Soils developed on the impermeable Flysch marls with a high content of silt and fine sand, are particularly prone to physical degradation such as crusting of the soil surface and erosion in mountainous areas. The intensity and consequences of erosion processes differ, depending on the geology, topography, climate, soils, vegetation cover and human activities. The area surveyed is made up of two completely different geological substrata which affect the hydrological characteristics of the soils. In the impermeable Flysch marls, with silty and clayey soils, sparse vegetative cover and mountanous topography, erosion processes are important.

TABLE 12

Depth and chemical composition of Kastela Bay soil types

SOIL TYPE	HORIZON	DEPTH (cm)	pH H_2O	pH nKCl	$CaCO_3$ (%)	CaO (%)	HUMUS (%)	TOTAL N (%)	K_2O (mg/100g)	P_2O_5 (mg/100g)	SOIL FRACTION (%) Coarse sand (2.0-0.2 mm)	Fine sand (0 2-0.02 mm)	Silt (0.02-0.002 mm)	Clay (<0.002 mm)
Calco-melanosols	Amo	0-33	7 34	6.51	1 2	0	10.1	0.47	27.0	2.4	5 0	26.1	29.4	39 5
	Amo	0-18	7.21	6.34	0 3	0	15.2	0.50	37.2	4.2	1.0	25.6	33.7	39.7
Rendzinas	Amo	0-25	8.10	7.40	52.4	24.1	4 2	0.19	36.0	1.2	4 1	28 9	39.0	28 0
Terra Rossa	Aoh	0-0	7.55	6.70	0	0	14 5	0.44	44.0	1.8	0.5	26.2	33.0	40.3
	(Brz)	8-45	7.55	6.75	0	0	7.9	0 39	33 5	2.0	1.0	22 7	28.1	48.2
	Aoh	0-12	7.66	6 70	1.3	0	9.1	0 41	47.0	3.4	0.5	26.4	30.9	42.2
	(Brz)	12-60	7.87	6.90	4 8	0.5	3.5	0.18	29.1	1.6	1.3	16.5	26 8	55.4

Cambic soils are formed on Cretaceous limestones and dolomites; and on Paleogenic foraminiferal limestones, breccia and conglomerates. The ground where they are formed is characterized by a high density of stones and the well developed karstic sub-soil morphology of the parent material. As a consequence, wide variation in soil depth is a basic feature of these soils affecting their ecological value. In contrast to the erosion processes in the areas of Flysch, the Cretaceous limestones, have high infiltration capacity which reduces or precludes the possibility of surface run-off and hence surface erosion and mass movement.

As a result of the conditions affecting soil formation, in particular those relating to the parent rocks of the area and the action of the climate on the limestones, Calco Cambisols and Terra Rossa soils may also be formed.

Table 13 shows that in all types of natural soils, humic acids dominated so that the ratio of Humic to Fulvic soluble fractions (Ch/Cf) is greater than 1. Humic acid fractions are absorbed primarily by calcium ions, and considerably less by R_2O_3. The insoluble humus fraction (residual) accounts for over two thirds which means that 33% is soluble.

The nature of the humus, expressed in terms of the ratio of carbon to nitrogen is highly variable, although favorable forms (C/N < 12) are most common. Soils with high C/N ratio have lower nitrogen content and microbiological activity is low due primarily to dry environmental conditions. These are stable forms of humus (mull type) resistant to humus decomposition processes.

TABLE 13

Quality of organic mater in different soil types

SOIL TYPE	HORIZON	DEPTH (cm)	HUMUS (%)	C/N	C in residue (%)	PERCENTAGE OF HUMIC ACIDS BONDED TO R_2O_2	Ca	RATIO OF HUMIC TO FULVIC ACID
Calco-melanosols	Amo	0-22	10.1	12.4	75.6	11.7	88.3	1.12
	Amo	0-18	15.2	17.6	66.1	22.5	77.5	1.47
Rendzinas	Amo	0.25	4.2	12.5	84.5	8.1	91.9	1.20
Terra Rossa	Aoh	0-0	14.5	18.8	71.1	13.8	86.2	1.24
	(B)	8-45	7.9	11.7	70.9	14.8	85.7	0.96
	Aoh	0-12	9.1	12.9	69.8	20.8	79.2	1.45
	(B)	12-60	3.5	11.2	77.4	18.6	81.4	1.08

Anthropogenic soils

As distinct from natural soils, man made soils have developed as a result of human influence directed towards increasing the fertility of the natural soils and adapting them to the needs of particular plants.

The classification and delineation of man made soils is based on physiographic features of the landscape and on the natural soil-types from which the man-made soil originated. Additional division has been made according to their use for different plant types as this is a good indicator of the intensity of human influence.

Abandoned terraced soils

These soils are located on steep slopes and have been largely abandoned. The reasons for abandonment of farmland are diverse and complex but include the following:

- low productive potential of the soil due to: shallow soils, high stoniness, destruction of terraces, and soil erosion;

- adverse water conditions: due to infrequent or unsuitable rainfall distribution during the year, low soil water retention capacity, and, impossibility of water storage;

- small size and fragmentation of individual land holdings; and,

- limited possibility for use of agricultural machinery due to: narrow terraces, stoniness, and, lack of road communications.

The characteristics of these soils, especially their depth and texture, vary according to the type of parent material. Terraced soils on the flysch marls contain high levels of free carbonates, their texture is silt/clay and, they show a tendency towards physical degradation and erosion. The humus content varies from 1.3-5.2% and they are low in available nutrients especially phosphorus.

Abandoned terraced soils on colluvial deposits are very skeletal and therefore resistant to physical degradation and erosion. Total $CaCO_3$ and free carbonate is lower than in the terraced soils on the flysch marls. These soils contain more humus which varies from 3.0 to 6.5%, the average being 4.5%.

Terraced carbonate soils on the Flysch

These soils are found on gently sloping relief to the southeast of Split, and are built from flysch marls and carbonate sandstones. The total $CaCO_3$ content is very high, varying from 12.0 to 65.1% with an average of 49.2%. These soils have a heavy texture and a high free carbonate content which varies from 6.5 to 22.0% with an average of 16.3%. The high carbonate contents represent the crucial limiting factor for the cultivation of calciphobic plants. In terms of their texture these soils are silty clay, with a poorly marked structure, showing a tendency towards physical degradation including crusting of the soil surface and erosion.

The humus contents varies between 1.3 and 7.1% (mean 3.2%) and available nutrients vary depending on the extent of human influence and plant species. For example the average contents of potassium and phosphorus in vineyards and olive-groves is 44.7 mg K_2O and 7.7 mg P_2O_5 per 100 g soil. In soils planted with vegetables the mean content of potassium is 104.0 mg and that of phosphorus 20.1 mg per 100 g of soil.

Anthropogenic soils on the quaternary deposits

These soils are situated in altitudinally lower positions and on the more gently sloping plateaux in the central and western part of the Kastela Bay area (Figure 18). High variability in soil properties and consequently productivity are a result of the varied nature of the quaternary deposits, which differ in thickness and $CaCO_3$ content.

Mineral soils containing more than 70% parent material are located to the north of Trogir and in the northwestern part of the Kastela Bay area. $CaCO_3$ content in these soils varies from 15.0 to 31.0%; free carbonate from 3.5 to 13.4%; and mean humus content is 5.2%. Soils used for growing vegetables contain the highest nutrient levels and averages are, 160 mg K_2O and 36.5 mg P_2O_5 per 100 g of soil.

Due to favorable soil temperature conditions these soils are very suitable for growing winter vegetables. Slightly skeletal, silty-clay anthropogenic soils on quaternary deposits have very variable chemical properties, especially in terms of their carbonate content which is the main limiting factor for growing calciphobic crops.

Anthropogenic soils on the alluvial deposits

These soils cover very small areas in the valleys of the rivers Zrnovnica and Jadro. Alluvial soils are intensively cultivated with crops including vegetables, cereals, and fruit. Soil texture varies from silty to clay loam, soil structure is not well developed and there is a moderately fine granular surface soil layer, overlying a structure-less subsoil.

The water table varies from 0.4 to 1.5 m below the surface and the lower-lying parts of the Zrnovnica valley have a very shallow groundwater table. Irrigation is required for maximum yields on these soils.

Physical features of the coastal zone

The narrow coastal plain along the northern coast of the bay is bounded by the slopes of the Kozjak mountains (Figure 19). Its width varies between 1 and 3 kilometers. Two low-lying alluvial plains are present in the bay: one, Pantana in the western part; and the other, the estuary of the Jadro and Dujmovača at the eastern end of the bay. In the eastern part of the study area an alluvial plain extends along the river Žrnovica. The island of Čiovo which encloses Kaštela Bay is rocky and hilly, while the Split peninsula is smooth and ends in the Marjan hill.

Most of the coastline is developed or artificial and the natural coastline extends around only 30 % of the total shoreline. Natural coastlines includes that of the island of Čiovo, the western part of the Split peninsula and most of the eastern part of the study area. The coastline of the island of Čiovo and the northern part of the Split peninsula are rocky, while the remainder is muddy and sandy.

2.2.2.2 Possible consequences of expected climatic changes for the soils of the Kastela Bay

The following assessment of the effects of global warming on soils and agriculture in the area is based on the operative scenarios for Kastela Bay for the three time horizons contained in Table 1.

A calculation of potential evapotranspiration using the method of Thornthwaite has been undertaken (Table 14). Results indicate that the annual potential evapotranspiration will increase, implying a drier climate than at present. Results also suggest that increase in potential evapotranspiration will be greatest in summer: 13.1 to 14.5% by 2030; 16.6 to 19.5% by 2050; and, 21.5 to 28.5% by 2100.

TABLE 14

Potential evapotranspiration in Kastela Bay area under different operative scenarios of future climate

PERIOD OF YEAR	TIME HORIZON						
	PRESENT	2030		2050		2100	
	mm	mm	% incr.	mm	% incr.	mm	% incr.
WINTER	54	59-60	9.2-11.1	62-63	14.8-16.7	67-68	24.1-25.9
SPRING	166	177-180	6.6-8.4	183-186	10.2-12.0	195-202	17.5-21.7
SUMMER	435	492-498	13.1-14.5	507-520	16.6-19.5	544-559	25.1-28.5
AUTUMN	191	208-213	8.9-11.0	216-222	13.1-16.2	231-237	20.9-27.1
ANNUAL	846	936-950	10.6-12.3	968-991	14.4-17.1	1037-1066	22.6-26.0

The increases in summer precipitation of 18% by 2030, 22.5% by 2050 and 35% by 2100 suggested by the operative scenarios, will be insufficient to compensate for increases in evapotranspiration losses under higher temperatures. This would reduce crop-water availability and decrease yields because the period of soil moisture stress would be extended.

Since the water deficit occurs in the warm period of the year (May to September), which is presently the period of most intense plant growth, the expected drop in soil moisture will result in a reduction in plant productivity. The drop in soil moisture will have different effects in the various soil types and under different cultivation regimes. The productivity of skeletal and shallow soils with low water retention capacity will be particularly threatened.

The coastal area is mostly steep and rocky, and therefore a sea level rise of 18 (+/-12) to 65 (+/-35) cm will not cause increased coastal erosion. On the beaches developed from flysch-marls and quaternary deposits, coastal erosion will be more likely. Sea level will however, affect alluvial soils in the Zrnovnica and Jadro estuaries, since the level of ground water will rise. Alluvial soils at low elevations will be exposed to increased salinization which will affect the saline marshlands near Pantana in particular. Part of these marshlands will be inundated.

Accumulation of nutrients and harmful substances in soils, due to intensive use of fertilizers and industrial air pollution will be greater than their leaching from the soil. This is due to the fact that mineral nutrients and heavy metals are almost insoluble and therefore immobile in highly carbonate soils with high retention capacity and exchangeable base, mainly calcium ions.

However, an increase in the transfer of pollutants to the sea is possible through increased soil erosion. There are indications that precipitation in a warmer world would occur as more frequent, intensive storms, which would tend to encourage higher rates of soil erosion, particularly on steep slopes of flisch terrain. Therefore, the monitoring of nutrient and pollutant levels in the soil is important as is the implementation of measures aimed at preventing erosion of terraced Flysch soils.

With increasing air and soil temperatures and decreasing soil moisture, the balance between production and accumulation of organic matter by vegetation and its decomposition by microorganisms will be changed. Total nitrogen content will tend to decrease, but the rate of loss will be very small. It will not cause any significant change to soil structure. Total content and humus quality will not change significantly in soils with favorable and stable forms of humus, resistant to degradation processes (mull types) where $C/N < 12$; $Ch/Cf > 1$; and, more than two thirds of the humic acid fraction is insoluble; or where humus is mostly incorporated in metal, clay, organic complexes.

Unlike other domains, the pedosphere has its own specific spatial and temporal limitations. Thickness or depth of soils and extent are the main finite, spatial limitation. Temporal limits to soil formation and evolution are closely connected to the problems of soil renewal or regeneration after natural and man-made deterioration and destruction. The time needed for the natural formation of a well developed soil body is a very long process, and soils can not be renewed in a human-life time. It is clear that the need for improved or optimum land use and protection of soil resources, especially in anthropogenic systems, has never been greater than at present.

Generally speaking the future state and changes in the soil will depend primarily on man's influence, that is on the quality of the land-use policy and implementation on soil protection measures.

2.3 Hydrosphere

2.3.1 Past trends and present situation

Hydrological system of Kastela Bay

The area surrounding Kastela Bay has relatively abundant fresh water resources. The average annual precipitation is 845 mm, so that this area can be considered as one of the areas of the Mediterranean with abundant rainfall. The quantities of rainfall and their frequency (over 100 days a year) result in large volumes of water being delivered to the bay through run-off. The hydrological characteristics of the bay are defined to a great extent, by the climatological characteristics of the area, which are presented in detail in Chapter 2.1. On the basis of these data one can state that: 35% of all precipitation occurs in September and October; 31% in the period from December to February; 21% between February and May; and, only 13% between June and August. In terms of the temperature range: the winter average is 9.21 °C; the spring average is 15.16 °C; summer, 25.4 °C; and the autumn 17.88 °C.

The geological characteristics of the coastal zone govern the underground and surface flows, via rivers, small surface streams, and groundwater, which passes into Kastela Bay by diffuse and concentrated flows (Bonacci *et al.*, 1991). Figure 21 presents a general hydrological scheme for the area and the location of the various water resources is illustrated in Figure 2. From these figures it can be seen that fresh water enters the bay via three basic routes:

- directly by rainfall to the sea surface;
- directly from the coastal catchment area; and
- via tributaries whose catchment area is outside the watershed area of the bay.

As a result of the presence of the impermeable flisch formations a barrier runs parallel to the coast behind which is formed an aquifer. With an average annual rainfall of more than 0.845 m yr^{-1}, the total water quantity falling in the bay area, exceeds an annual total of 51,500,000 m^3. The volume of water which evaporates from the surface of the bay is around 45,000,000 m^3 yr^{-1}, with 70% of this occurring during the dry period of the year. This evaporation does not significantly influence the hydrological regime of the bay due to the exchange of water through the Brac channel and consequent good flushing of the bay.

The local coastal catchment area is almost twice as large as the surface area of the waters of the bay (ca 120 km^2), so that the total water falling in this area is double (ca 101 million m^3). Intensive urbanization of this area continually alters the characteristics of the catchment area, such that all larger precipitation events result in concentrated surface flow. This flow passes through a series of streams and channels (storm runoff, sewage systems) into the bay. Given the relatively small catchment area, this outflow is directly related to the seasonal intensity and duration of precipitation and during the summer the majority of streams dry up.

Part of the water in this area is delivered to the bay via underground flows, which operate continually throughout the year, but vary in volume. It should be noted that underground water is delivered to the bay through diffuse flows to the sea surface and by concentrated flows below sea level (submarine springs).

In the winter months these submarine outflows are very high, such that they are visible on the bay surface. It is very difficult to determine accurately the capacity of each spring, and it is generally estimated on the basis of the total amount of the groundwater. A detailed hydrological analysis of the coastal catchment area has never been made such that the actual quantities involved in these flows are not known. Surface and underground flows can be approximately estimated on the basis of the total rainfall of 101 million m^3 yr^{-1} of which, 40.5 million m^3 yr^{-1} come from the surrounding terrain, and 40.5 million m^3 yr^{-1} from the urban area.

The water which is lost by evapotranspiration directly from the catchment area, can be estimated at around 30 million m^3, of which 40% is lost during the rainy period and 60% during the dry summer period.

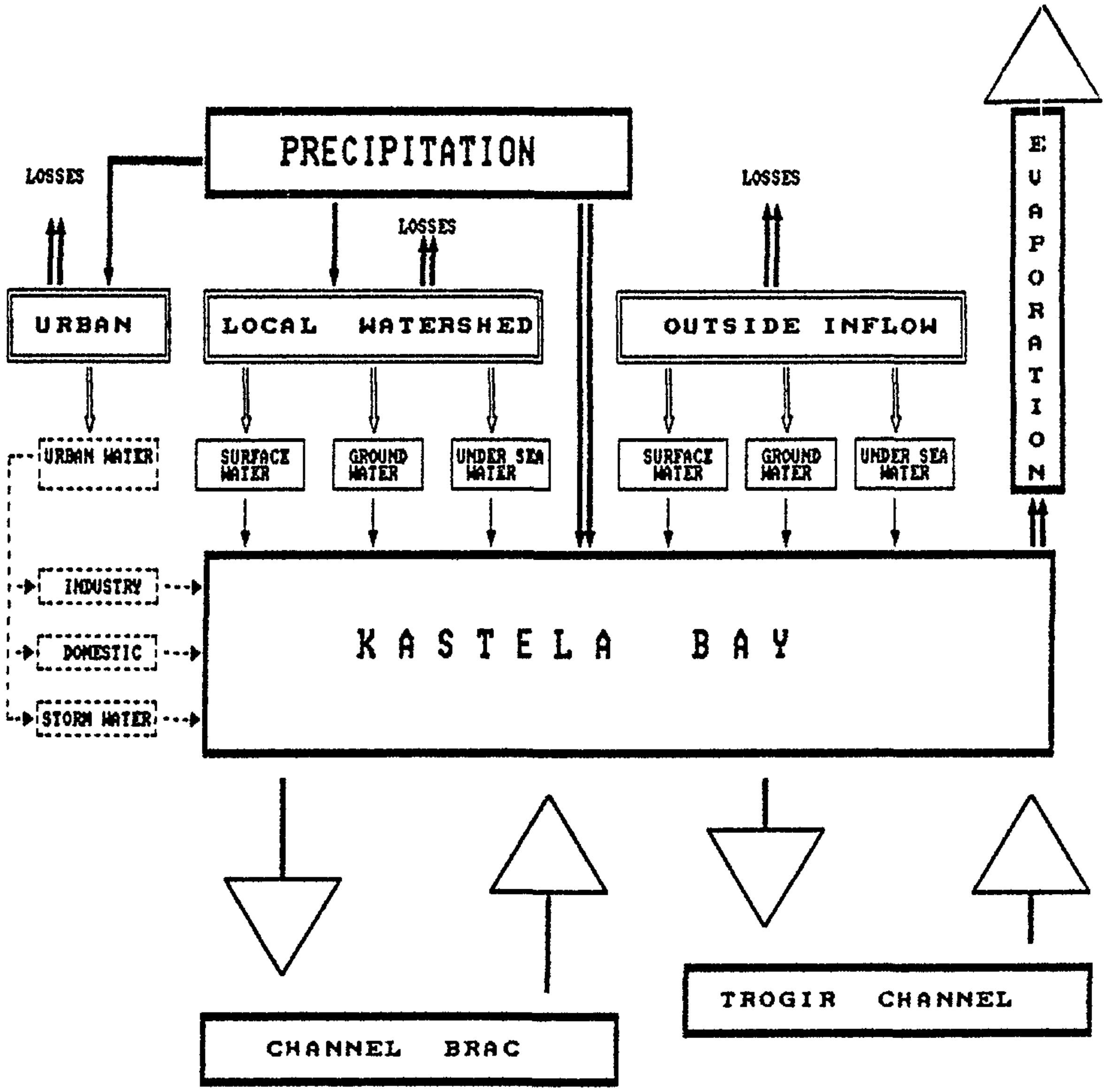


Figure 21 - General hydrological scheme of Kastela Bay

The greatest volume of fresh water draining into this area flows through the Jadro River and the Pantana Spring. The spring at the headwaters of the Jadro River is at an elevation of 27 m asl. and at a distance of some 10 km from the bay. It flows through the Solin area to its estuary at the sea. The catchment area for these water resources is located outside the coastal watershed area in an underground reservoir developed in the basin behind the flysch geological barrier which stretches along the inland edge of the coastal belt. The catchment area for these springs covers an area in excess of 260 km^2 in the hinterland (Bonacci and Margeta, 1986).

The average annual discharge of the Jadro Spring is around 9.5 $m^3\ sec^{-1}$, the average minimum discharge is around 4.0 $m^3\ sec^{-1}$ and, the average maximum around 66.0 $m^3\ sec^{-1}$ (Figure 22). These water volumes are large and fairly constant resulting in over 300 million $m^3\ yr^{-1}$ or 0.3 $km^3\ yr^{-1}$ of freshwater being delivered to the bay. This represents about 21.5% of the total volume of the bay.

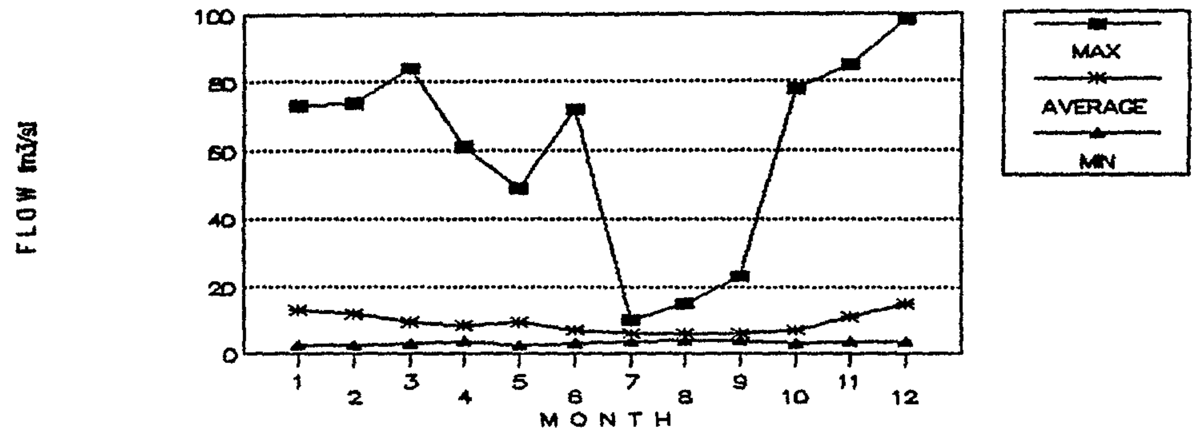


Figure 22 - Monthly discharge volumes of the Jadro River

The capacity of the Pantana spring has not been determined precisely, since the spring is located exactly at sea level, resulting in the outflow being immediately mixed with the sea. The average spring flow is estimated to be 6 $m^3\ sec^{-1}$, the minimum 0.5 $m^3\ sec^{-1}$ and the maximum 20 $m^3\ sec^{-1}$.

To the south of Split in the Stobrec area, there is a small river, the Zrnovnica which flows into the Brac Channel. Its spring is 5 km upstream in the village of Zrnovnica and in summer this river almost dries up, whereas in winter its discharge reaches around 5.0 $m^3\ sec^{-1}$. At its estuary the river forms a small delta covering an area of 2 km^2.

The quantity and quality of the water in these springs are influenced by man's activities in the catchment areas. The greatest influence is exerted by the regulation of the Cetina River which flows along the boundary of the River Jadro catchment. It has been noted, that the construction of reservoirs and regulation of the Cetina River led to increased discharge from the Jadro Spring, particularly at times of low flow. The complex geological structure of the area (karst) makes it difficult to estimate all quantities, so that it was not possible to obtain reliable data on this source of water to the Jadro.

A major feature of the fresh water regime in the area is the significant fluctuation during the year, in relation to the wet and dry seasons. Around 70% of all freshwater inflow into the bay occurs during the wet winter period, when the evapotranspiration losses are least significant. In this period the influence of fresh water upon the marine ecosystem is the greatest. In the summer period, when the evapotranspiration losses are significant and inflows low, the influence of fresh water on the aquatic environment of the bay is practically negligible.

It should also be noted that during the summer months, a high proportion of the total fresh water flowing into the bay is urban waste water, around 1.8 $m^3 sec^{-1}$ in summer and, an average of 1.32 $m^3 sec^{-1}$ throughout the year). This outflow is most important in the eastern and northern parts of the bay where the estuary of the Jadro River and other important fresh water springs are located and where urbanization and industry are most concentrated. Approximately the same volumes are released directly into the Brac Channel from the eastern part of the Split peninsula.

According to past investigations, the outflow of fresh water from the bay takes place directly in the surface water layer. These outflows are greatest in winter and almost negligible in summer since inflow is low at this time and since the bulk of evaporation occurs from the surface sea layer.

The main direction of the fresh water flow is from east to west (southwest) and the flow is directly influenced by the wind so that it is very changeable. After leaving the bay the fresh water flows westward, along the coast of Ciovo island.

In order to analyze the situation in the bay and to compute the water budget it is necessary to know all the inflows and outflows from the region including the water quality and quantity, and the variations in these values in time and space. Unfortunately, the available data are inadequate for further analysis. Despite these problems an attempt is made to estimate the future influence of climate changes on the water budget using existing data and without additional, new or special investigations having been carried out.

The springs which give rise to the Jadro and Zrnovnica rivers and the Pantana spring are all very important for the hydrology of the study area, however their watershed area is outside the area covered by the scenarios of climate change. Hence the influences of future climatological changes on their characteristics cannot be evaluated.

Main climatological and other changes used as input data

Scenarios of temperature and precipitation for the Kastela Bay region developed by the Climatic Research Unit of the University of East Anglia (Guo *et al.*, 1992) and detailed in Chapter 1.3. provide values for local changes in temperature and precipitation for the years 2030, 2050 and 2100 in relation to global climatic change. Table 15 lists the seasonal temperatures expected under these scenarios.

TABLE 15

Seasonal mean air temperatures (°C) for Split-Marjan under conditions of global warming

	Present	2030		2050		2100	
		min.	max	min	max	min	max
Annual	16.0	17.44	17.62	17 2	18.7	17.6	20.5
Winter	8.3	9.92	10.1	9.65	11.3	10.1	13.3
Spring	14.3	15.75	15.92	15.5	17.0	15.9	18.8
Summer	24.4	26.02	26.2	25.75	27.4	26.2	29.4
Autumn	16.9	18.34	18.7	18.1	19.9	18.5	21.9

In addition it may be expected that extreme conditions will be greater, the intensity of rainfall will be greater, that wind speed will increase and that the following rises in sea level may occur:

2030	2050	2100
+18 cm (+/- 12 cm)	+38 cm (+/- 14 cm)	+65 cm (+/- 35 cm)

2.3.2 Influence of climatic changes on water resources

The scenarios of future changes suggest an increase in total annual precipitation, with increases in all seasons except autumn. Precipitation increases will occur during the period from December to August, and decreases in the period from September to November. At the same time the temperature will increase from between 1.2 and 5.0 degrees during each month in the year.

The extent of these changes is greater for the longer time horizons, thus the changes expected by 2030 are relatively small. Three elements of these climate changes will influence local water resources: increasing temperature; increasing annual precipitation; and, sea level rise.

The increases in precipitation and temperature will result in greater relative humidity due to increased evaporation from the bay and from the soil (Figure 23). An increase in temperature of 1 °C would result in increased evaporation of around 10% and tend to make precipitation more uniform throughout the year. Increased humidity will result in an increase in the water contained in the biological section of the hydrological cycle. The actual significance of these changes is difficult to establish particularly if one takes into account the fact that the characteristics of this region have been significantly altered by intensive urbanization and rapid development. These changes will certainly exert greater influence on the characteristics of the hydrological cycle than will global climatological changes.

The way in which these changes will be reflected in the water resources of the Kastela Bay region is very difficult to predict since it is not possible to quantify future evaporation and evapotranspiration. The absolute monthly increase in precipitation could be significant and could greatly influence the water regime of the region. At the same time, however the temperature increase will result in increased losses in all stages of the hydrological cycle (Figure 24).

On balance it is concluded that the water regime will not be significantly changed and that the capacity and other characteristics of the water resources will not be altered as a consequence of global climatic changes. A decrease in the surface flow could be expected, as a consequence of the increased evapotranspiration, however, these changes will not be significant since the terrain is karst, vegetation cover is low and there is high infiltration. This conclusion is particularly valid in the case of the scenario for 2030 when expected changes are small. For the 2100 scenario this conclusion is less strong because changes in precipitation and temperature are greater. Nevertheless there is some confidence in the conclusion that water balance will not be significantly changed.

The difficulty in predicting changes to water balance in the area is due to the lack of quantitative data and to the uncertainty of predictions concerning future changes to the biological systems, particularly changes resulting from human interference including urbanization of the land surface (Margeta, 1991).

An increase in sea level of between 18 and 65 cm will influence fresh water resources since it will result in intrusion of salt water upwards and landward. This will have an effect on coastal aquifers, coastal springs and river estuaries (Figure 25).

The groundwater level in the coastal region will be raised to a level comparable to that of the raised sea level and intrusion of saline water will occur further inland. This will result in changes in aquifer capacity and flooding of low-lying areas which will have strong impacts on coastal development and construction.

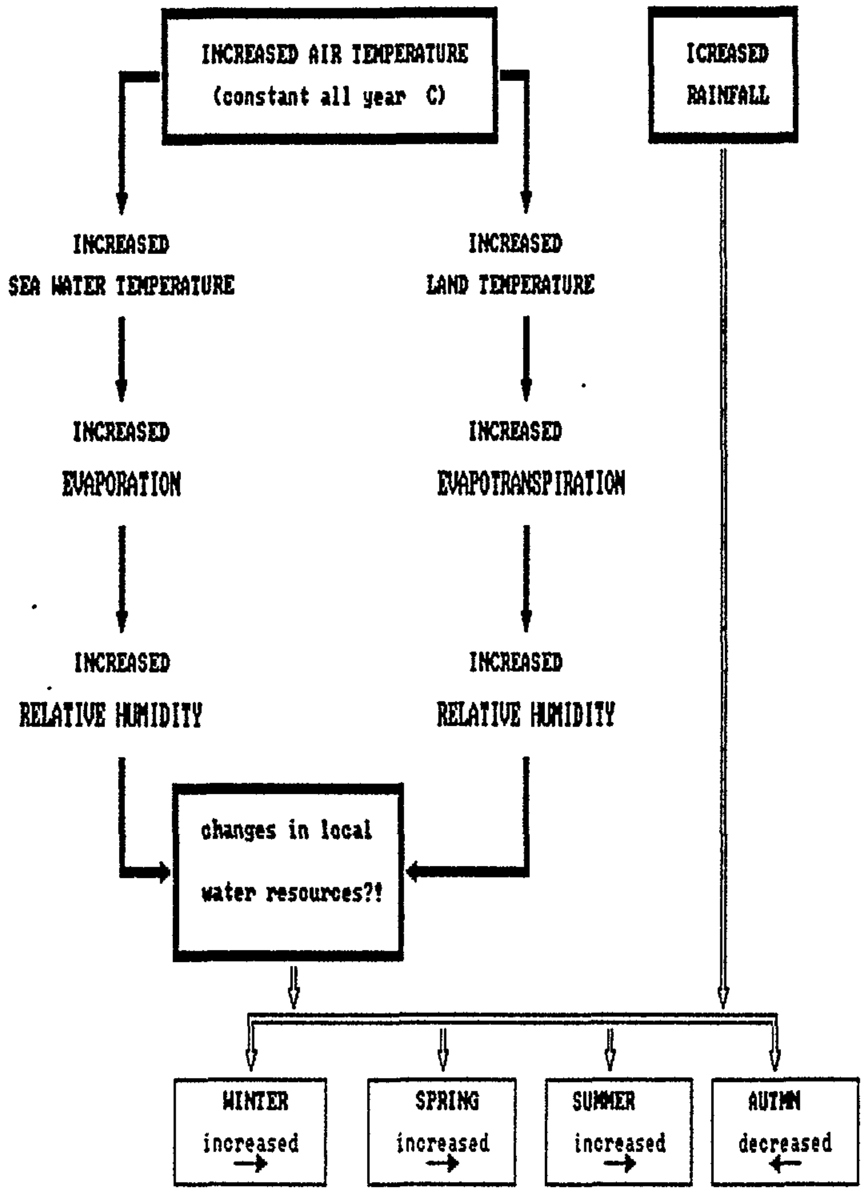


Figure 23 - Influence of raised temperatures and higher rainfall on the local hydrological cycle

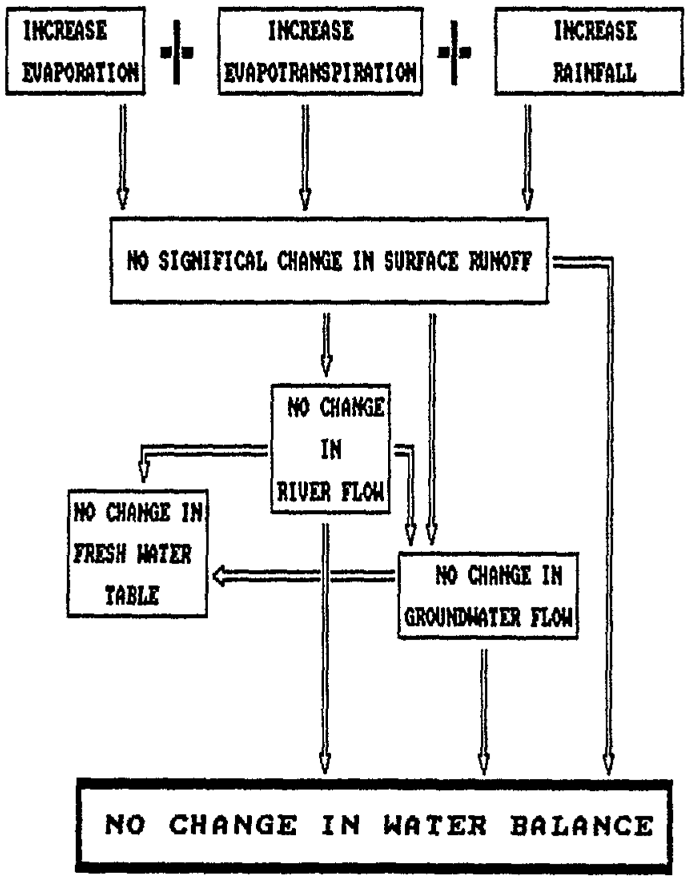


Figure 24 - Schematic diagram of possible changes in water resources in the Kastela Bay area

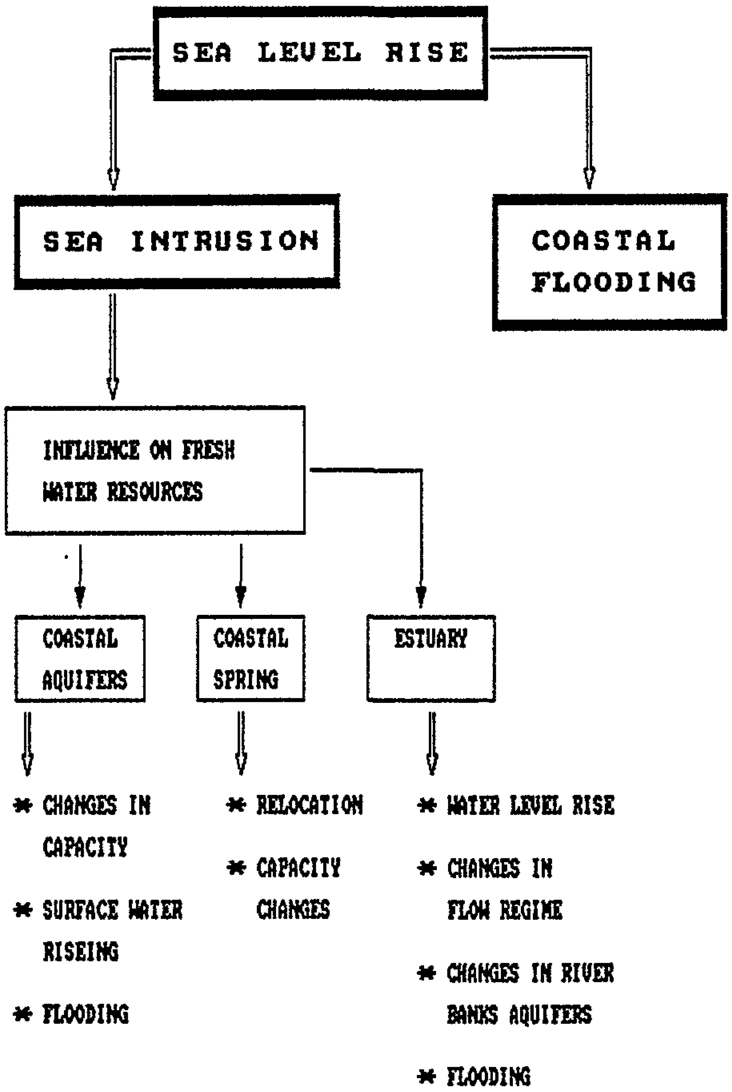


Figure 25 - Diagrammatic representation of sea level rise impacts on local water resources in the Kastela Bay area

Problems arising from increased sea level will be particularly significant in the estuaries of the Jadro and Zrnovnica Rivers. Estuaries will suffer saline intrusion further inland resulting in increased water levels in the river and river bank aquifers and in groundwater in the coastal zone. As a consequence flooding of the estuary and upstream areas and changes in river flow regimes may be expected. These changes will not cause major impacts in the Jadro River estuary, since it is already regulated and has artificial banks. Plans are currently being developed for similar regulation of the Zrnovnica River estuary.

Any rise in sea level could lead to changes in the location and volume of groundwater outflows particularly in the case of Pantana spring, the outflow of which is already influence by sea level. Such changes are however, unlikely to affect the largest springs (Jadro and Zrnovnica) which are located in rocky terrain at elevations in excess of 20 m asl.

A rise in mean sea level would lead to an increase in the discharge volume through the Brac Channel, resulting in possible increased flushing of the bay. Since the shores of the opening between the bay and the channel are relatively steep, a rise in sea level of 40 cm, would not significantly increase the surface area (around 0.3%) of the 1.8 km wide channel. Changes to flushing will probably therefore not be significant.

The configuration of the shoreline will not be changed, since it is mainly rocky, hence no increase in shoreline erosion or other morphological processes is anticipated. The coastal region is relatively enclosed, such that physical influences of the sea on the land are not significant at the present time.

No significant changes in water quality are expected to result from the global and climatological changes. Changes in water quality could result from changes in the quality of the atmospheric water or from pollution of the air and soil, rather than from anticipated increases in precipitation and temperature. Changes in the quality of storm run-off will directly influence the quality of water resources, particularly water quality in the Jadro and Zrnovnica rivers. The catchment area of these rivers is located in karst geological structures, with well developed direct surface inflows into the groundwater, rapid infiltration and a low capacity for self purification. Pollution will result from saline water intrusion, upward and landward especially in low level areas which will be flooded.

All negative impacts resulting from level rise will be increased the higher the sea level rise. The scenario for 2030 suggests a possible sea level rise of between 6 and 30 cm, which would not cause major problems and changes in water resources. This is not the case with the sea level rise of between 30 and 100 cm, suggested under the scenario for 2100. These changes in sea level would have major negative impacts on water resources in the Kastela Bay area.

Changes in air temperature will result in temperature changes in surface water bodies. Future air temperatures may rise by up to 3.5 °C, and it can be expected that changes in water temperature will be less than half of these values. In this area the majority of water resources are contained in groundwater which is less sensitive to changes in the air temperature than surface water. The same applies to the water of the Jadro River, since the river is only 10 km long. The greatest changes can be expected in sea surface temperatures since changes in deeper layers will mainly reflect global changes in water temperatures over a wider area.

Increases in freshwater temperature will result in a reduction in the oxygen saturation in water bodies and speed up decomposition of organic matter as well as biological and chemical processes, with ecological consequences.

2.3.3 Socio economic consequences of the change in the water resources

The projected changes in water resource characteristics will influence the socio-economic characteristics of the region.

Sea level rise is a constant process that has occurred over the last century as a result of which many old buildings and historic sites have been flooded. With increased sea level rise and flooding, directly by the sea and indirectly by changes in groundwater level, will be intensified (Figure 26). Other changes in water resources will not have significant impacts in the socio-economic sector.

Sea level rise will result in flooding of estuaries, natural and artificial coastlines. Estuaries will experience increased frequency of bank overtopping and upstream flooding will occur in the Jadro and Zrnovnica rivers. Flooding along natural coastlines will not be important since the coast is largely steep and rocky so effects would be minor, occurring in the coastal belt 0.5 to 1.0 m wide. Only 30 % of the coastline within the study area is natural, most is developed or artificial. The most important effects will occur along such coastlines and will include impacts on coastal services such as transport, loading and unloading of ships, tourism infrastructure, construction, buildings and other permanent structures.

No impacts on the drinking water supply are anticipated since the characteristics of the Jadro Spring will not be changed.

A rise in coastal groundwater levels will result in an increase in the capacity of existing wells and an improvement in the efficiency of the old and new ones. Wells are used exclusively for the irrigation of the relatively small agricultural areas.

A rise in groundwater levels in the coastal zone will lead to negative impacts, particularly in increasing the effects of buoyancy on all structures influenced by groundwater. This will increase their potential instability, and through increased wetting result in more rapid degradation and destruction. These effects will occur in all structures located in the coastal region or inland where a rise in groundwater levels can influence their foundations. Since the greater part of the coastal zone is urbanised and, since it includes the most attractive items of cultural heritage, these effects will have significant consequences. Many of the historic buildings are already at very low elevations due to past sea level rise and will require additional measures to ensure their continued protection.

Special attention should be paid to the cellars of Diocletian's Palace in Split, which date from the III century A.C., and to the historic centre of Trogir, located on a small island, around 1.2 m above present sea level. The cellars of Diocletian's Palace are at an even lower level. Consequently, rising sea level represents a great threat to these cultural monuments which are recorded as part of the world's cultural heritage.

The sewerage system will also be subject to negative impacts since rising sea level and groundwater will lead to a greater infiltration of groundwater into the system, resulting in decreased capacity and increased pumping and maintenance costs. These impacts may be particularly important in the case of faecal and waste water treatment facilities if seawater infiltrates into them. Raised sea level will also result in decreased discharge capacity of all the outfalls, in the intrusion of the sea water leading to the possibility of upstream sewage flooding. Since the coastal zone is mainly urbanized these effects will be highly significant. Sewerage pipes, water supply pipes, electricity power lines and other underground services could be flooded by sea water resulting in increased corrosion of pipes and cables.

These potential impacts are equally applicable to the area of the estuaries of the Jadro and Zrnovnica Rivers, which have not been urbanized to date. The areas involved are quite narrow extending in a belt along the river, around 1 km inland for the 2030 scenario, and 5 km for the 2100 scenario.

The intensity of the negative consequences increases with expected increases in mean sea level. If the changes in the sea level are small, around 20 cm, then the consequences will be minimal, but if the increase is greater, around 40 to 60 cm, then the consequences could be very significant and should be taken into account in advance. A sea level rise of 100 cm would be catastrophic for the region.

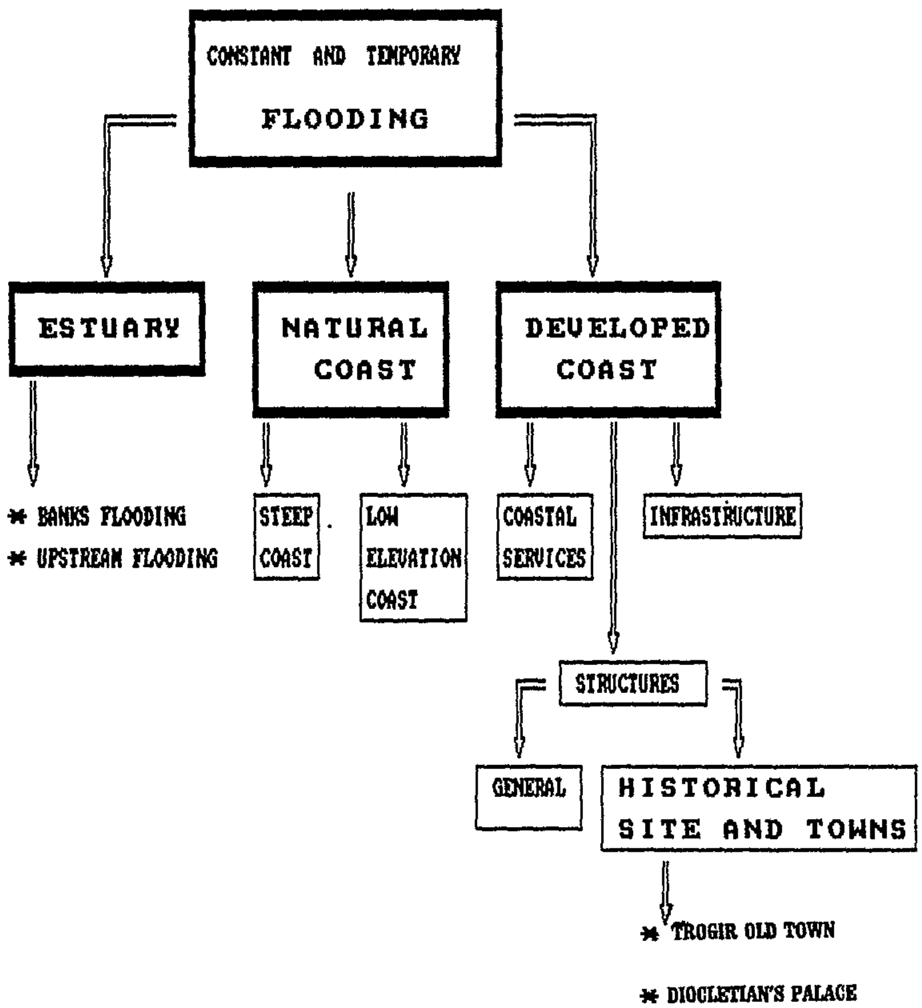


Figure 26 - Flooding effects on freshwater sources

With a sea level rise of 0.2 m flooding will affect all the coastal zone but direct inundation would affect 10 ha around the Pantana spring; about 5 ha of the Jadro river estuary; 10 ha of the Zrnovnica estuary; and some 10 ha in various other locations. A sea level rise of more than 0.5 m would inundate more than double these areas and would include some very important additional areas such as: the old town of Trogir; the shipyard; the western part of Split city port; marinas; some 25 km of the coastline of Kastela Bay to 15 m inland; 5 km of coast in the Trogir area; the old centre of Split; the railway station and industrial zone in Dujmovaca (20 ha) including the PVC factory and hotel Lav; low-lying areas in Solin; and many other smaller locations.

In addition to the gradual increase in sea level temporary extreme flooding events will affect larger areas than before. These episodic flooding events have strong negative impacts because of higher levels of flooding and difficulties in their prediction. Consequently, it is important to monitor the development of these expected changes in order to carry out the required mitigation actions in advance. The future conditions should be considered and anticipated through regulatory activities in order to prevent the negative impacts in the region of the river estuaries and in the coastal zone.

No significant ecological changes to the freshwater habitats of this region are expected. The Jadro River is only 10 km long and has no special ecological importance and the Zrnovnica river even less so. More significant changes in the environmental characteristics of these water bodies can be expected as a consequence of changes in the quality of storm water run-off and through the influence of pollution of the air, land and underground water bodies.

It should be noted that the Kastela Bay area is highly urbanized. Further urbanization of this region together with the development of other activities will have a greater effect on the water quality and quantity than will climatic changes. These characteristics of human use of the region will make it difficult to distinguish the potential environmental changes caused by climatic factors from those caused by other sources of change.

2.4 Atmosphere

2.4.1 Present state

To define the degree of pollution of the atmosphere in the Kastela Bay area, data on concentrations of settling particles, airborne particles, sulphur dioxide and smoke are presented and analyzed. These parameters have been monitored continuously since 1975 at a number of locations in the area (Figure 27). Air quality is determined from monthly and daily means or from short-term ,usually 24-hour long measurements. In Table 16 upper permissible limits (UPL) of four relevant air pollutants are given for comparison with the data for Kastela Bay.

TABLE 16

Upper Permissible Limits of air Pollutants

POLLUTANT	UPL (mean)	UPI (in interval)	Time interval
SETTLING PARTICLE (mg m^{-2} day^{-1})	450	800	30 days
AIRBORNE PARTICLE ($\mu g\ m^{-3}$)	110	300	24 hours
SO_2 ($\mu g\ m^{-3}$)	60	150	24 hours
SMOKE ($\mu g\ m^{-3}$)	60	160	24 hours

UPL = upper permissible limit of mean values.
UPI = upper permissible limit in time intervals.

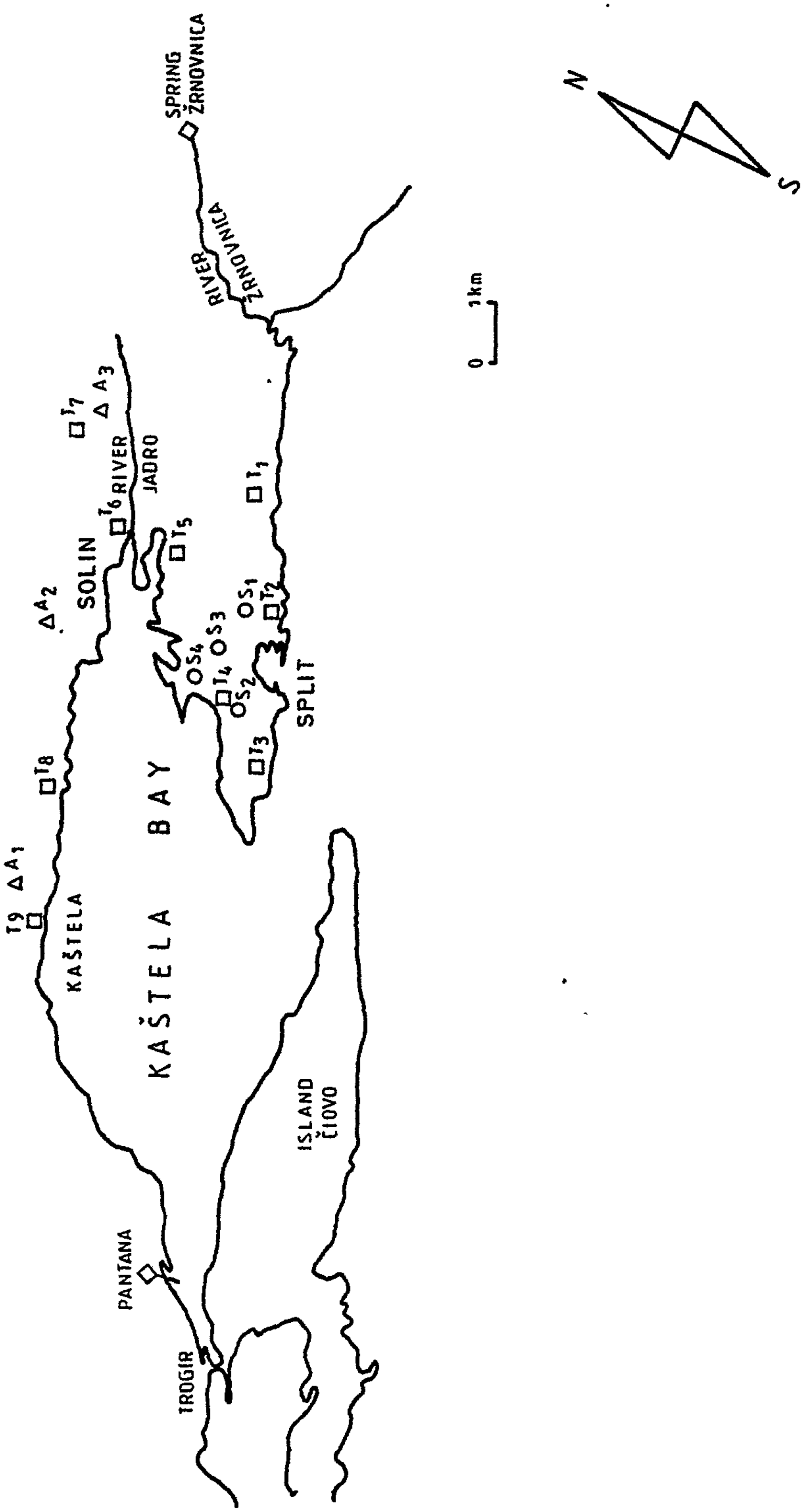


Figure 27 - Location of Monitoring stations for:
- sulphur dioxide and smoke measurements (stations denoted by circles and "S");
- settling particle concentrations (stations denoted by squares and "T");
- airborne particle concentrations (stations denoted by triangles and "A")

Sulphur dioxide and smoke

Long-term changes in smoke and sulphur dioxide are presented in Figures 28 and 29 respectively. Yearly means were calculated for the period from April 1 to March 31 for four measurement stations. Mean annual values of sulphur dioxide are highly variable from year to year (Figure 29) and differ greatly from station to station. They range from 16.4 to 53 $\mu g\ m^{-3}$ while the average value for the entire area is 29.9 $\mu g\ m^{-3}$ with a standard deviations of 8.1 $\mu g\ m^{-3}$ (Table 17). Maximum daily concentrations were recorded in the center of the city where the traffic is most dense. Maximum daily concentrations reached as high as 367 $\mu g\ m^{-3}$ during the winter (Tomic, 1988) due to anticyclonic weather patterns which result in strong thermal inversions preventing vertical mixing. Sulphur dioxide concentrations are generally higher in winter months (Tomic and Grbec, 1989) due to higher emissions combined with higher frequency of anticyclonic calm weather conditions.

Mean yearly smoke concentrations were within the range 13.7 to 51 $\mu g\ m^{-3}$ (Figure 28) and are below the upper permissible level except in the case of station S4 which is next to the street with heaviest traffic. The average value for the entire area is 37.7 $\mu g\ m^{-3}$ with a standard deviation of 7.5 $\mu g\ m^{-3}$ (Table 17). Annual records show a strong seasonal signal with maximum levels in December and January (Tomic and Grbec, 1989) due to higher emissions associated with heating houses.

TABLE 17

Mean annual concentrations (C); standard deviations (STD); and, maximum annual concentrations (Cmax) of sulphur dioxide and smoke

	SO_2 ($\mu g\ m^{-3}$)			Smoke ($\mu g\ m^{-3}$)		
Station	**C**	**STD**	**C max**	**C**	**STD**	**C max**
S1	23.2	5.5	250	19.7	4.3	131
S2	30.0	8.0	180	22.0	4.9	135
S3	29.7	10.3	367	38.9	7.0	293
S4	36.5	8.6	222	70.2	13.8	366
Mean	29.9	8.1	367	37.7	7.5	366

Settling particles

Monitoring stations for settling particle concentrations are distributed in the Split area and along the coast as shown in Figure 27. Concentrations of settling particles in the Kastela Bay area for some years are more than three times the upper permissible limits. In the Split area the ratio between the yearly mean concentrations and upper permissible limits are somewhat smaller since the main sources of settling particles, the cement industry is situated in the Kastela area.

Maximum daily concentrations of settling particles have an average value in the Kastela area of 2622 2 mg m^{-2} a day and vary within the range from 1495 to 4604 mg m^{-2} a day. The permissible limit is 800 mg m^{-2} a day. The large range is mainly due to variations in the intensity of emission sources. The fact that variations in the Split area are similar to those in Kastela area suggests that diffusion and transport by wind are very important in redistributing the settling particles.

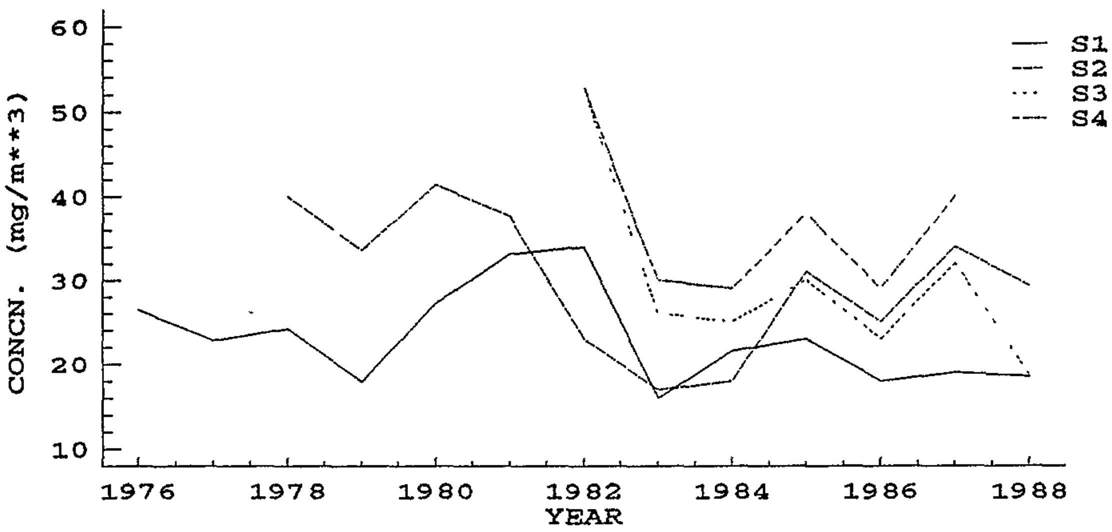


Figure 28 - Average annual smoke concentrations for four measurement locations

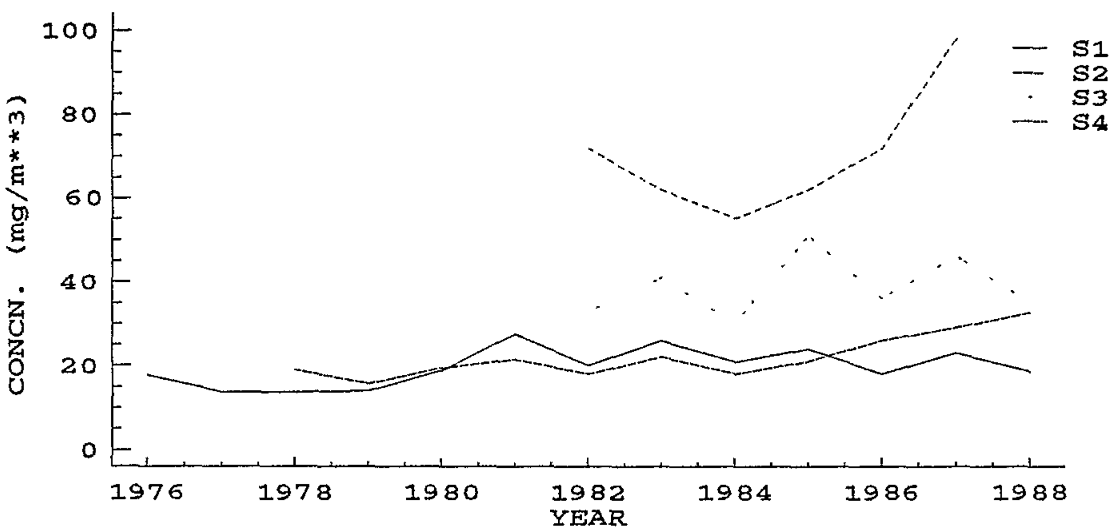


Figure 29 - Average annual sulphur dioxide concentrations for four measurement locations

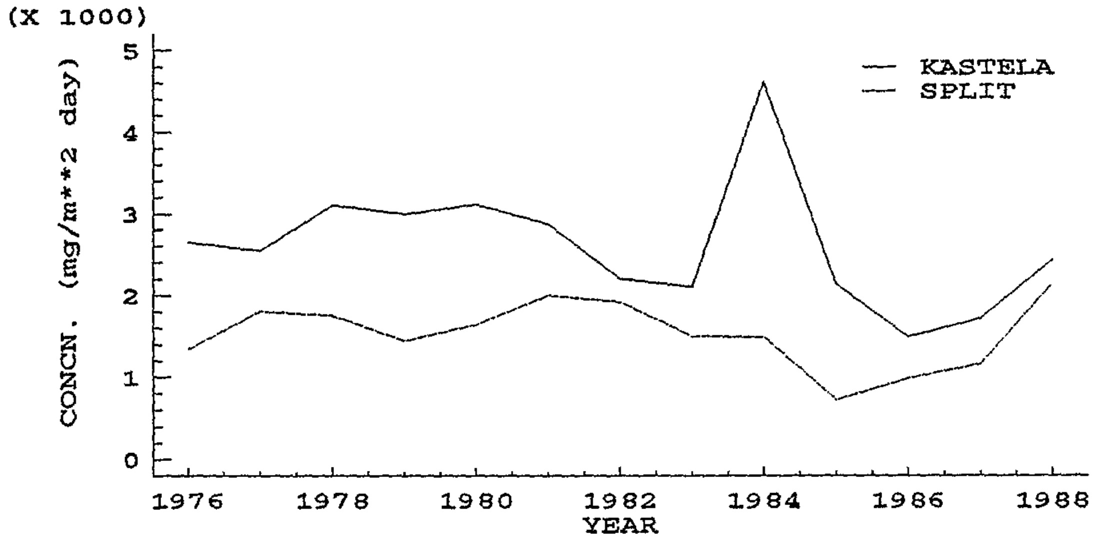


Figure 30 - Yearly maxima of settling particle concentrations for the Split and Kastela areas

Figure 31 - The ratio of annual mean settling particle concentrations (C) and upper permissible limits (UPL) for the Split and Kastela areas

Yearly maximum values of settling particle concentrations (Table 18) and the ratio between the annual means and maxima and the upper permissible limits are shown in Figures 30 and 31. It is not known to what extent inter-annual variability is due to variations in the emission intensity or to variations of climate conditions. The absolute maximum of settling particle concentrations in the area of Kastela is related to a strong increase in emissions. It is interesting that this maximum does not occur in the area of Split.

TABLE 18

Mean (C) and maximum (Cmax) annual concentrations of settling particles; and the ratios between annual mean and UPL (C/UPL) and maximum annual concentrations and UPl (Cmax/UPl) for the areas of Kastela and downtown Split

	KASTELA AREA				SPLIT AREA			
	C ($mg\ m^{-2}\ day^{-1}$)	Cmax ($mg\ m^{-2}\ day^{-1}$)	C/UPL	Cmax/UPL	C ($mg\ m^{-2}\ day^{-1}$)	Cmax ($mg\ m^{-2}\ day^{-1}$)	C/UPL	Cmax/UPL
1976	1125	2618	2.50	3.27	795	1341	1.77	1.68
1977	1426	2549	3.17	3.19	729	1809	1.62	2.26
1978	1578	3109	3.51	3.89	815	1752	1.81	2.19
1979	1380	3000	3.07	3.75	585	1447	1.30	1.81
1980	831	3117	1.85	3.90	521	1642	1.16	2.05
1981	737	2869	1.64	3.59	557	1999	1.24	2.50
1982	864	2207	1.92	2.76	613	1916	1.36	2.39
1983	850	2100	1.89	2.62	420	1500	.93	1.87
1984	1265	4604	2.81	5.75	491	1491	1.09	1.86
1985	724	2132	1.61	2.66	361	720	.80	.90
1986	923	1495	2.05	1.87	585	983	1.30	1.23
1987	980	1714	2.18	2.14	686	1157	1.52	1.45
1988	751	2431	1.67	3.04	534	2145	1.19	2.68
MEAN	1033.4	2611.2			591.7	1530.9		

Airborne particles

Airborne particle concentrations have been continuously monitored since 1979 and sampling has been undertaken for a period of 15 to 20 days in each season, at the three locations indicated in Figure 27.

Average and maximum annual values of airborne particles are presented in Table 19 and in Figures 32 and 33. They are higher than the upper permissible limits in both the Kastela and Split areas. In the Kastela area values are between 78 and 172% higher than the upper permissible limits, and maximum yearly values are often higher than 1000 μg m^{-3}.

Values for the station A2 which is closest to the city centre are slightly lower but still between 45 and 129% higher than the upper permissible limits. Yearly maximum concentrations are around 1000 μg m^{-3}. The third monitoring station (A3) displays the lowest values for airborne particle concentrations which are however, still larger than the upper permissible limit by between 58 and 94%.

Daily variations in the airborne particle concentrations are very large. They are highest at locations which are closest to the sources and weakest in the downtown area.

Maximum airborne particle concentrations in excess of 1000 μg m^{-3} were recorded in the Kastela area during cold, anticyclonic weather, in winter and during calm stable weather in summer. Concentrations are much lower under windy conditions. In the downtown areas airborne particle concentrations display maxima during the synoptic NE wind conditions.

TABLE 19

Annual mean (C) and maximum values (Cmax) of airborne particle concentrations and the ratio between annual mean concentration and upper permissible limits (C/UPL) for three sampling stations

YEAR	Station A1			Station A2			Station A3		
	C (μg m^{-3})	Cmax (μg m^{-3})	C/UPL	C (μg m^{-3})	Cmax (μg m^{-3})	C/UPL	C (μg m^{-3})	Cmax (μg m^{-3})	C/UPL
1979/81	195.6	1103.4	1.78	173.7	1089.0	1.58	190.9	410.9	1.74
1981/82	222.3	532.0	2.02	204.3	732.9	1.86	213.3	441.7	1.94
1982/83	234.0	532.8	2.13	186.0	454.9	1.69	192.4	383.9	1.75
1984/85	285.0	1721.0	2.59	159.2	402.5	1.45	205.4	457.8	1.87
1985/86	299.0	696 8	2.72	251.9	603.8	2.29	173.7	403.5	1.58

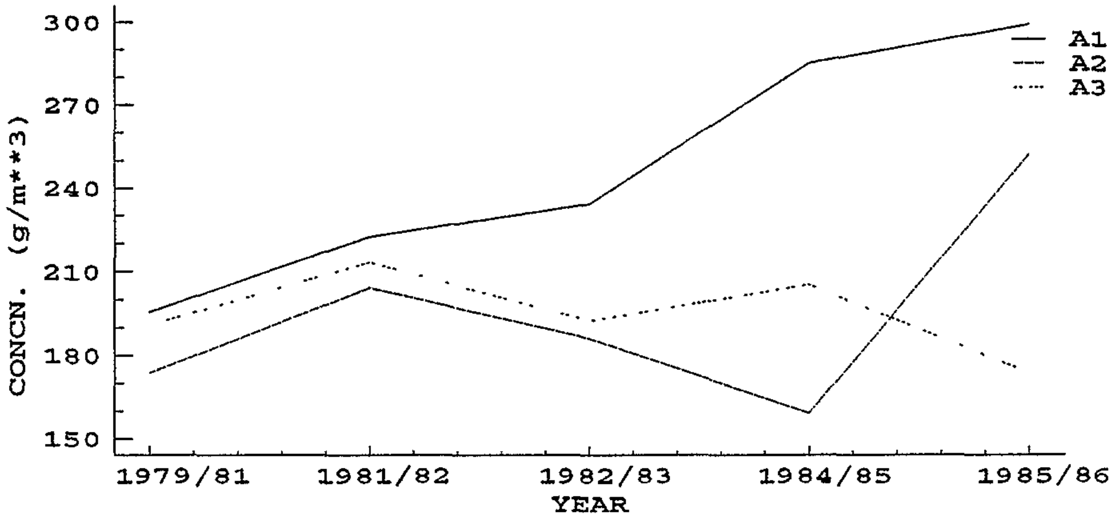


Figure 32 - Annual mean values of airborne particle concentrations for the three monitoring stations

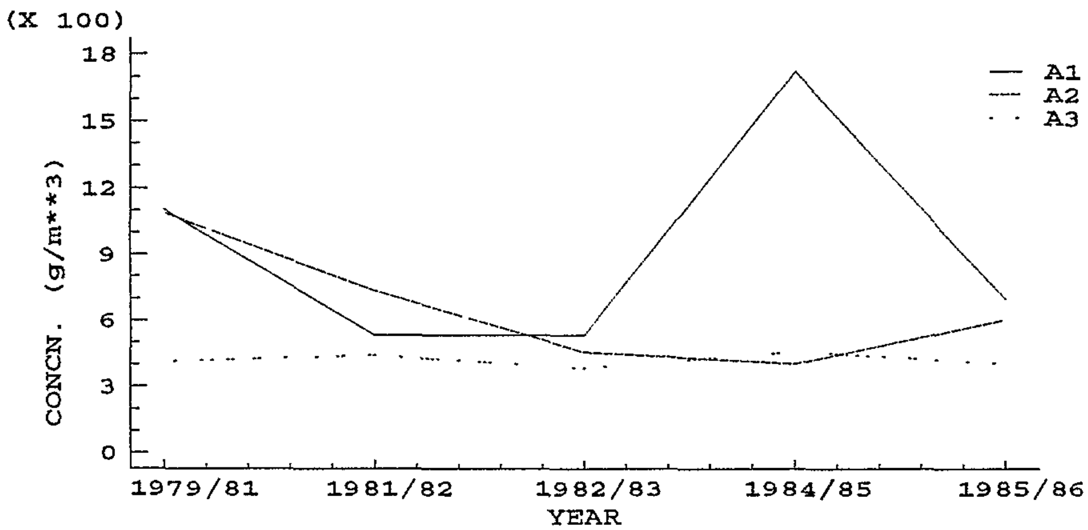


Figure 33 - Annual maximum airborne particle concentrations for the three monitoring stations

2.4.2 Expected climatic changes and air quality

Sulphur dioxide, smoke and airborne particle concentrations depend on the wind field. The stronger the wind, the lower the concentrations in the area where the sources of these pollutants are located. In contrast the concentration of settling particles depends to an unknown extent on rainfall. It can therefore be concluded that a decrease in the frequency of passing synoptic perturbations over the area would result in an increase in the concentrations of all the air pollutants, considered in this analysis. An increase in the frequency of mid-latitude cyclones would however result in a decrease in air pollution in the study area. An increase in winter temperature would result in a reduction in the frequency of occurrence of thermal inversions, which in turn would help to increase vertical mixing and reduce the concentration of air pollutants.

2.5 Natural Ecosystems

2.5.1 Terrestrial Ecosystems

2.5.1.1 Past trends and present situation

The initial, post-pleistocene vegetation cover consisted mainly of evergreen elements dominated by holm oak (*Quercus ilex* L.) woodland. The Kozjak mountain ridge and higher slopes of Mosor were covered by evergreen and deciduous vegetation, dominated by *Quercus pubescens* Willd. and *Carpinus orientalis* Mill. as a result of temperature differences between the coastal zone and the montane areas. From a biogeographic perspective, the Kastela Bay area belongs to the Mediterranean region of the holarctic floral Realm.

The entire coastal area of Kastela Bay, surrounded by the Kozjak and Mosor mountains and their slopes, and encompassing the area from the shoreline to the highest ridges, belongs to the Adriatic Province of the Mediterranean region. Two natural vegetation formations, in distinct geographical zones can be distinguished on the basis of the structure of the natural vegetation (Horvatic, 1963; Ilijanic, 1984):

- the eu-mediterranean or evergreen zone; and
- the sub-mediterranean or deciduous zone.

The eu-mediterranean includes the coastal area with its primary vegetation at lower altitude including the elements of holm oak woods and shrubs which form a separate association, the *Orno-Quercetum ilicis*, not found at higher altitudes (Figure 34).

The woods and shrubs of the coastal zone and mountain massif are not uniform in their composition. Apart from the typical formations dominated by holm oak woods in the eastern part of Sucurac grove; there are formations dominated by the strawberry tree, *Arbutus unedo* L. which is very important to the west of the Sucurac grove and close to the small church of St. George is a formation composed of *Carpinus orientalis* Mill., *Quercus pubescens* L., *Fraxinus ornus* L and *Ostria carpinifolia*. Scop. Holm oak woods also occur on the sheer rocks below the ridge of Kozjak due to favourable microclimatic conditions. There is no woodland of holm oak above Kastel Gomilica, except for isolated patches on shear rock faces since the development of primary evergreen vegetation has been prevented by forest fires which have been rather frequent in recent times.

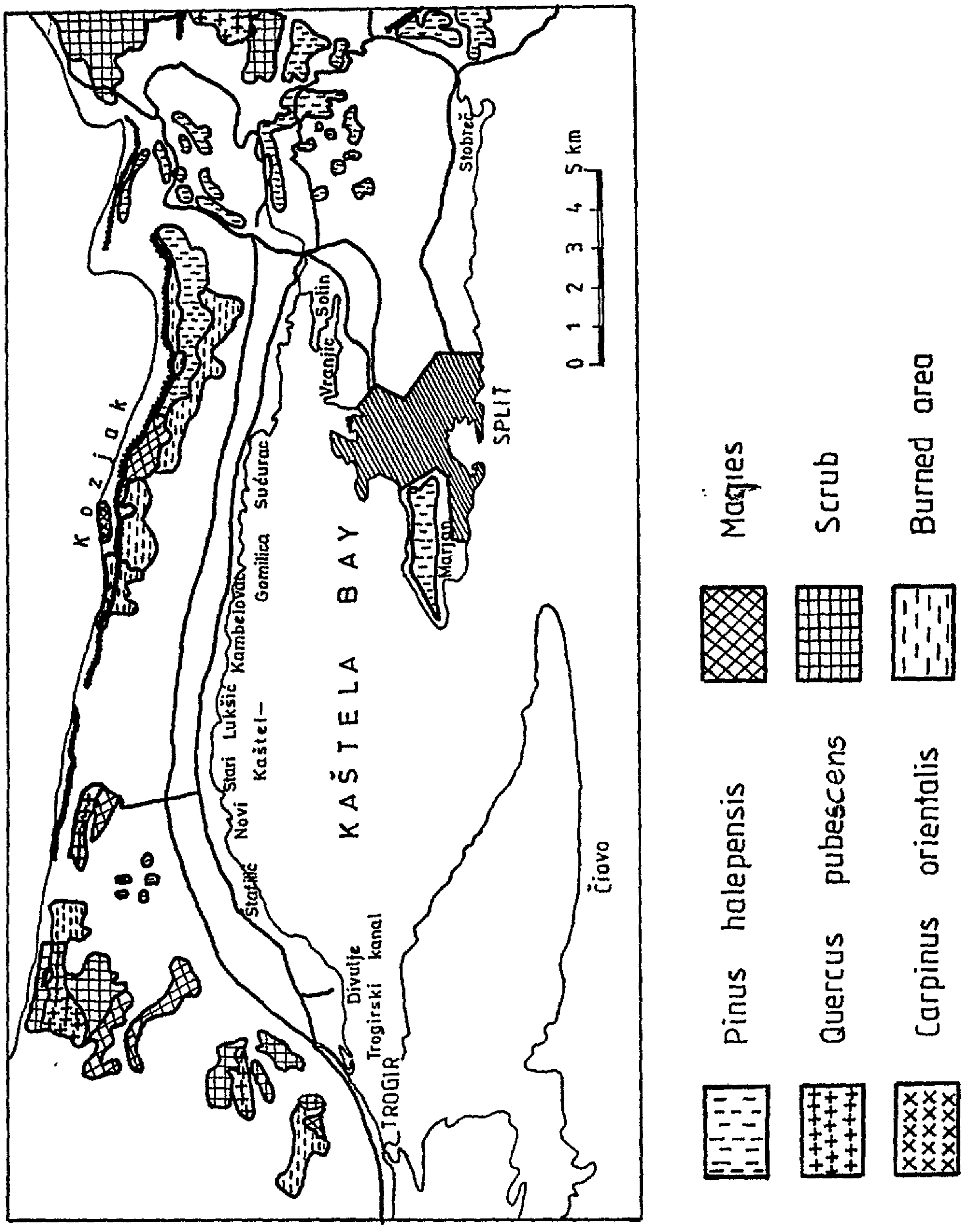


Figure 34 - Vegetation cover of the Kastela Bay area

Long-term and frequently careless exploitation of woodland has led to changes in vegetation cover in the Kastela area, such that the primary vegetation of evergreen woods has been considerably degraded or has completely disappeared. Most of the area is covered by degraded vegetation of early successional stages. Weedy plants and ruderal vegetation dominate the inhabited coastal areas.

Less degraded areas of the evergreen vegetation belt covered with low, open and light copses, pine-tree woods, and plantations of pine on the slope of Kozjak and smaller hills form the other areas of woodland vegetation in the Kastela Bay area. Pine woods cover significant areas in the eastern part of the Solin basin and are dominated by the species *Pinus halepensis* (Mill.) while Marjan hill is the largest area of pine forest habitat in this region. In addition to *Pinus halepensis; Cupressus semprevirens, Thuja orientalis,* and *Cedrus atlantica* also occur here. Other native trees include *Pistacia lentiscus, Pistacia terebinthus, Phillyrea media, Juniperus oxycedrus,* and *Spartium juncem* together with some other Mediterranean plant species.

Very degraded areas within the evergreen vegetation belt occur from the western part of Kastel Gomilica to Trogir; areas where the forest and shrub vegetation has completely disappeared, and bare rocky ground remains. In this area vegetation communities belong to the classes of eu-mediterranean and sub-mediterranean dry grassland and rocky areas dominated by the Brachypodio-Chrysopogonetea association.

The vegetation of areas of lower elevation forms a separate class of eu-mediterranean grasslands and rocky areas: the Cymbopogo-Brachypoddietalia formation and within it the association Cymbopogo-Brachypodion, dominated by *Brachypodium ramosum* (L.) and *Cympogon hirtus* (L.) is the most important.

The recognition of vegetation types in the area of Kastela Bay provides a basis for the distinction between ecological biotopes within a broader and considerably degraded forest climax that grades into the agricultural land of the central and lower sections of the Kastela Bay area. The Kastela agricultural area stretches from the southern side of the Kozjak mountains and includes the pine forest and rocky ground biotopes at higher elevations. The coastal plain lying between the 100 m contour and the shore can be divided into the following biotopes: settlements; cultivated land; marshes and coastal wetlands; and, pine wood stands on areas of low elevation such as the Marjan hill. The non-avian vertebrate fauna of these biotopes is listed in Tables 20 and 21.

Until recently the marshes in the vicinity of Rika pond; the estuary of the Pantana spring, near Trogir; and, the marshy mouth of the Zrnovnica River near Stobrec were rich habitats for birds. Very little marshland remains near the Jadro River, some marshy ground remains on the right bank of the Zrnovnica River along its lower reaches and in the estuary, where marsh plants can be found along the river banks and in irrigation canals. The banks of the upper Zrnovnica river are overgrown by willows - *Salix alba* L. and often also by elm, *Ulmus foliacea* Gilb.

TABLE 20

Distribution of amphibians and reptiles in the biotopes of Kastela Bay

SPECIES	BIOTOPE					
	Pine woods	Scrub & copses	Settlements	Cultivated areas	Marshes	Pine woods on low hills
Bufo viridis	+	-	+	+	+	+
Bufo bufo	+	-	+	+	+	+
Hyla arborea	-	-	-	+	+	-
Rana ridibunda	-	-	-	-	+	-
Rana dalmatina	-	-	-	+	-	-
Lacerta muralis	+	+	+	+	+	+
Lacerta viridis	-	-	-	+	+	+
Hemidactylus turcicus	-	-	+	+	-	-
Ophisarus apodus	+	-	-	+	-	-
Elaphe situla	+	-	-	+	-	+
Elaphe longissima	-	-	-	+	+	-
Natrix natrix	-	-	-	+	+	-
Telescopus fallax	-	-	-	+	-	-
Coluber naiadum	-	-	-	+	-	+
Coluber gemonensis	-	-	-	+	-	-
Vipera ammodytes	-	+	-	-	-	-
Malpoion monspesularus insignatus	-	-	-	+	-	+
Testudo hermanni	-	-	+	+	-	-
Emys orbicularis	-	-	-	-	+	-

TABLE 21

Distribution of mammals in the biotopes of Kastela Bay

SPECIES	BIOTOPE				
	Pine woods	Scrub & copses	Cultivated areas	Marshes	Pine woods on low hills
Rhinolophus hipposideros	+	+	-	-	-
Rhinolophus euryale	-	-	-	+	-
Rhinolophus ferrum-equinum	+	+	-	+	-
Plecotus auritus	+	+	+	+	+
Pipistrellus pipistrellus	+	+	-	+	-
Pipistrellus savii	-	-	+	-	-
Pipistrellus kuhlii	-	-	-	-	+
Myotis myotis	+	+	-	-	-
Vespertilio serotinus	-	-	+	-	+
Nyctalus maximus	-	-	-	+	-
Nyctalus leisleri	-	-	-	+	-
Leuconoe cappacinii	-	-	-	+	-
Selysius emarginatus	-	-	-	+	-
Miniopterus schreibersii	-	-	-	+	-
Erinaceus europaeus	-	-	+	-	+
Suncus etruscus	-	-	+	-	+
Lepus europaeus	+	+	+	-	+
Oryctolagus cuniculus	-	-	-	-	+
Glis glis	+	-	+	-	+
Vulpes vulpes melanogaster	+	+	+	-	+
Martes foina	+	+	+	-	+
Mustela vulgaris	-	-	+	+	+

This short review of the ecosystems and their biotopes in the area of Kastela Bay provides the basis for their future study and was compiled from available literature and personal observations.

2.5.1.2 Effects of fire on the Kastela Bay ecosystems

Forest fires are particularly frequent in the vicinity of solid waste dumps near Split and Trogir. Fires may also be caused by careless burning of weeds near habitation throughout the Kastela area. Fires are frequent in spring and autumn and most frequent in summer when self-combustion may be one of the causes. Fire sites on steep terrain tend to result in soil erosion by subsequent wind or rain and its removal to lower, plains areas leaving degraded rocky ground. The only way to protect such sites is through planned and systematic reforestation. Although burnt areas may recover naturally, this is a long process, affected by a variety of natural and anthropogenic factors.

Burnt areas are often ecologically and topographically suitable for the development of particular plants of which wild asparagus (*Aspargus acutifolius* L.) should be mentioned. This species is abundant on burn sites in the vicinity of Trogir and on the steep slopes of the Labin saddle. Since this plant is useful for food (its young sprouts) it may be frequently found in Split and Trogir vegetable markets in early spring.

Burnt sites on the plains or gently sloping areas are frequently transformed into rich farmlands where natural vegetation is replaced by new cultivated crop plants. Burnt areas in the plains, if not cultivated, rapidly revert to natural vegetation passing through grasslands, to shrub and woodland complexes, which may reach a climax stage, depending on their location.

2.5.1.3 Impact of expected climatic change

The study area is already highly impacted by different human activities and these influences are more important for the terrestrial ecosystems than the expected climatic changes. Climatic changes may affect the natural vegetation such that sub-mediterranean vegetation could form the climax for the whole area. Significant effects of expected climatic changes on animal life are not expected.

2.5.2 Freshwater ecosystems

2.5.2.1 Past trends and present situation

Two springs give rise to rivers in the study area, the Jadro and the Zrnovnica. The latter flows east of the town of Split for 4 km from its source in the slopes of the Mosor Mountain, before discharging into the Brac Channel near Stobrec. At its estuary the stream forms a small delta covering an area of 2 km^2.

The Jadro also has its source on the slopes of the Mosor mountain at 27 m above the sea level. The upper 4.6 km of its length follows a natural channel and the river enters the eastern part of Kastela Bay at Solin. The origins of both rivers are connected with the Cetina River through a system of underground channels and the Cetina river enters the Brac Channel some 20 km east of the town of Split.

Both the Zrnovnica and Jadro rivers are typical karst springs, the water flow of which is highly dependent on precipitation in their immediate hinterland. Annual average flow of the Jadro river is around 9.5 m^3 sec^{-1}; with a minimum of 4.0 m^3 sec^{-1} and a maximum of up to 66.0 m^3 sec^{-1}. Water flow is lowest during summer months and highest during late autumn, following the precipitation regime. The flow of the Zrnovnica is much lower, during the summer its bed is almost dry, and in winter the average flow is 5 m^3 sec^{-1}.

Water temperature at the Jadro source is practically constant all year round. Measurements carried out in 1978/79 showed variation of not more than 0.7 °C (min 12.6 and maximum 13.3 °C). The water temperature varies along its length depending on season, in summer water temperature reaches 22 °C at the estuary where it is mixed with sea water. It is only slightly cooled during winter.

Oxygen saturation also varies with season along the length of the river. Saturation levels vary between 75 and 95% at the source. Oxygen in the water is consumed by microbial decomposition of organic matter, such that the water is undersaturated at its source. Saturation level increases along the river ranging between 95 and 120%. Along its length oxygen is taken up from the atmosphere and the water is also enriched by oxygen released by primary production. However, the river receives waste waters towards the middle of its course such that oxygen saturation is between 80 and 105% at the estuary. Data on the increase in Biological oxygen demand suggest pollution from the mid-point of its course to the estuary.

The biota of the Jadro has not been well studied, although the river is well known for its endemic trout species, *Salmothymus oktusirostus salonitana*, which has disappeared from the middle and lower sections of the river. Presumably, the culture of rainbow trout has contributed to its disappearance combined with pollution from the industrial plants constructed along the upper course of the river around the mid fifties and construction of illegal residential areas beginning in the sixties. At present the species is found only in the higher reaches of the river.

The Zrnovnica river has not yet been the subject of any scientific study. Trout is known to live in this small river and the estuary was a feeding ground for migratory birds some 20 years ago. The estuary has been devastated such that birds no longer stop there.

2.5.2.2 Possible impacts of anticipated climatic changes

Anticipated air temperature increases will not significantly increase the spring water temperature of either river. Along the river course water temperature will increase, but to a smaller extent than the air temperature increases. The impact of temperature increase on freshwater plants and animals is impossible to estimate, due to lack of information. The endemic trout species is unlikely to be affected since it lives in the upper part of the river Jadro, where the temperature increase will be not so marked.

A sea level rise of 50 cm will presumably cause significant changes to river estuaries. A large part of the Zrnovnica estuary will be flooded and sea water will penetrate deep into the Jadro River since its flow is low. Penetration of a saline wedge will occur around 500 m inland, which will change the biota of the river. Similar effects are expected at the mouth of the Zrnovnica river. A higher sea level rise of up to 100 cm by the year 2100 would completely change the present river estuaries since sea water will penetrate deeper into the river.

2.5.3 Marine Ecosystems

2.5.3.1 *Past trends and present situation*

Physical characteristic

The shape of the bay and the geology of the surrounding land indicate that the bay represents a submerged depression, made up of soft and poorly resistant flysh marl and sandstone. The bottom of the bay is covered by silt and fine sand sediments.

The most important freshwater source in Kastela Bay is the river Jadro, located in the eastern part of the bay, and having an average annual inflow rate of about 9.5 m^3 sec^{-1}. Along the northern coast of the island of Ciovo, are two underwater springs which release freshwater into the bay, mainly during the winter. There is also another strong water source west of Divulje, but it releases brackish water. A number of other brackish springs with much lower flows are to be found along the southern shore of the bay.

The physical characteristics of the bay in terms of the currents and distribution of temperature, salinity and density depend upon the characteristics of the wind field, the inflow of freshwater, the topography of the bay, and the influence of the open sea.

The effects of tidal oscillations are relatively weak and negligible due to the small amplitude of the oscillations of the sea surface (a few tens of centimetres) resulting in relatively weak horizontal currents. The same is true of the free oscillations of the sea level (seiches) which have a period of 60 min, and an amplitude which rarely exceeds 20 centimeters (Gacic *et al.*, 1989).

The temperature and the salinity of the sea water have been measured monthly since the late 1940's at a station located in the centre of the bay at standard oceanographic depths. In addition, sporadic measurements of these parameters are carried out in other parts of the bay. Table 22 shows the average monthly values of water temperature measured at the station in the centre of the bay over the period from 1965 to 1970.

TABLE 22

Monthly average water temperatures (° C) in Kastela Bay
(after Buljan and Zore-Armanda, 1966)

MONTH	DEPTH 0 m	DEPTH 10 m	DEPTH 20 m	DEPTH 30 m	DEPTH 35 m
01	10.80	12.04	13.77	13.50	13.70
02	10.76	11.22	11.43	11.82	12.00
03	11.49	11.49	11.44	11.77	11.95
04	14.06	13.44	12.03	12.79	12.76
05	17.51	15.40	14.72	14.10	13.84
06	22.09	19.16	16.58	15.13	14.76
07	22.71	19.68	15.92	14.62	14.35
08	24.49	21.97	17.26	15.23	15.01
09	22.41	21.65	20.89	18.33	16.96
10	20.15	20.62	20.75	20.04	19.88
11	17.29	17.76	18.37	18.52	18.55
12	13.19	13.75	14.85	15.20	15.37

These temperature data show a cooling of the sea surface during the period from November to February. The surface temperature is lower than that of the deeper layers during this period. The surface temperature is at a minimum in February and at a maximum in August. The water column is most homogeneous in March, but in April the existence of a thermocline can already be detected in the upper layers. In October the thermocline almost disappears due to cooling of the sea surface and the vertical mixing generated by the wind. Similar temperature variations have been recorded in the Brac and Split Channels.

Table 23 presents data on the average of temperature, salinity and density for three sections of the bay: eastern, A; central, B; and western, C. It is evident from these data that salinity exceeds 38 °/oo in the bottom layer of the central part of the bay during the summer season. This reflects the influence of cooler and more saline waters from the Split channel, which enter the bay through the bottom layers in the summer months and possibly induce local upwelling.

During the summer season the lowest salinity is found at the surface of the eastern section of the bay, while in spring low salinity water is found in the west. This reflects the impact of freshwater inflow from the Jadro river and submarine springs. As a rule, the influence of the freshwater inflow is not apparent at depths below 10 meters.

TABLE 23

Seasonal average temperature (°C), salinity (g/kg) and density (σ_t) for three zones of the Bay (A = Eastern, B = Central, C = Western) covering the period 1934-1974 (after Zore-Armanda, 1980)

PARAMETER	DEPTH	ZONE	WINTER	SPRING	SUMMER	AUTUMN	ANNUAL MEAN
TEMPERATURE °C	0	A	11.20	19.53	22.42	16.70	17.46
		B	11.86	17.78	23.93	16.55	17.28
		C	11.54	17.53	22.47	15.93	16.86
	10	A	11.64	15.87	19.78	17.54	16.20
		B	12.00	15.56	20.44	17.16	16.31
		C	11.57	16.34	20.59	16.02	16.13
	20	A	11.88	14.47	17.38	15.51	14.81
		B	12.47	14.62	17.40	17.47	15.49
		C	11.90	15.48	18.65	16.75	15.69
	35	B	12.80	13.83	15.32	17.48	14.85
	30	C	11.96	15.45	18.49	16.65	15.64
SALINITY °/oo	0	A	34.76	34.89	33.90	35.72	34.43
		B	35.21	34.37	36.67	35.96	35.55
		C	35.20	32.75	35.55	35.57	34.28
	10	A	36.54	36.85	37.48	36.71	36.90
		B	36 26	36.54	37.33	37.10	36.81
		C	36.42	36.46	37.44	37.03	36.84
	20	A	36.84	37.38	37.79	37.22	36.93
		B	37.17	37.32	37.75	37.69	37.48
		C	36.83	37.03	37.83	37.39	37.27
	35	B	37.52	37.76	38.15	38.00	37.86
	30	C	36.65	37.16	37 84	37.25	37.25
DENSITY σ_t	0	A	27.30	24.15	24.87	25.95	25.17
		B	26.92	24 86	25.08	26.53	25.85
		C	26.75	23.53	24.49	26.25	24.88
	10	A	27.92	27.35	26.70	26.66	27.16
		B	27.67	26.86	26.56	27.17	27.09
		C	27.71	26.78	26.49	27.17	27.04
	20	A	28.17	27.66	27.29	26.92	27.53
		B	28.17	27.81	27.54	27.47	27.75
		C	27.96	27.43	27.26	27.34	27.50
	35	B	28.48	28.32	28.24	27.79	28.19
	30	C	27.75	27.55	27.44	27.38	27.53

Some studies have show that the northern component of the wind stress correlates well with the surface layer salinity changes which occur simultaneously over the entire bay area. An increase in the north wind component results in a drop in surface salinity, demonstrating that the northwind component enhances the spread of river water. An increase in the north wind component is associated with temperature decrease in the entire water column. The combined cooling and lower salinity causes surface water to sink. In contrast water temperature variations in the bay are not affected by variations in the northeast wind component.

The surface water of the central part of the bay is under the direct influence of the Split channel. The eastern portion of the bay is separated from the rest by a quazi-stationary front in the field of mass. The less dense water, which is probably less saline as well, leaves the bay along the coast of the island of Ciovo.

The temperature minimum of the deeper water layers in the central part of the bay during the summer has been explained in terms of upwelling generated by the wind, suggesting that transport from the Split channel into the bay predominates in the bottom layer.

In the surface layer of Kastela Bay, a number of residual circulation types both cyclonic, anticyclonic, and a combination of the two can be seen at different times. The type of circulation is dependent on many factors, but primarily on the wind. The southwest wind generates incoming currents in the surface layer while the northeast wind generates outgoing currents. At the same time the surface circulation patterns in the bay are anticyclonic and cyclonic with respect to the two winds. It has been shown that under the direct influence of a wind with a component perpendicular to the shore, the response of the current field can be described by a two-layer model. In this case the surface current is in the direction of the wind. About 70% of the variation in the current field of the bay results directly from the effect of the wind. Under stratified conditions the water flow shows large lateral changes in the inlet, with the water entering the bay on one side and leaving it on the opposite side. When the water column is vertically homogenous,the exchange is predominantly baroclinic with the surface flow 180 degrees out of phase with respect to bottom flow. The barotopic-like flow (vertically homogenous) is not correlated with local wind field and can be induced by non-local forcing through the bay inlet.

The flushing time in the bay has been calculated on the basis of salinity changes and current meter data, and is estimated at one month for the entire bay. Movement of water masses in the Brac and Split channels is mainly westward, and forms part of the general current pattern of the Adriatic (Tudor *et al.*, 1991).

Surface currents are under wind influence, especially during the summer season. Therefore, "maestral" the predominant summer wind generates eastward currents in a surface layer, while the "bora" (wind from the north) generates southward currents.

Biological characteristics of the bay

Phytoplankton community

In the phytoplankton community of the bay diatoms are the dominant group. Their contribution to total phytoplankton density ranges from 70 to 99%. About 70 pelagic, diatom species are found in samples taken during the course of a year. 39 diatom species were common in the period between 1962 and 1970, but this number fell to 25 species subsequently. The phytoplankton community during the early period was characterized by a larger number of *Chaetoceros* species, but later the phytoplankton community was dominated by *Skeletonma costatum, Nityschia seriata* and *Leptocylindrus danicus*. The species *S. costatum* was first recorded in the bay in 1968, and over the next few years it became a dominant species. Together with some species of the genera *Nitzschia* and *Leptocylindrus* it determines the seasonal variations in the phytoplankton community. At the same time, the species *Chaetoceros dadayi* and *Chaetoceros. tetrastichon* disappeared from the area while the abundance of the genus *Chaetoceros* generally decreased.

During the summer season the phytoplankton community in the eastern section differs remarkably from that of the rest of the bay. In the east the relative contributions of diatom and dinoflagelate species were 1% and 94%, respectively, while in the central part of the bay diatom species formed 65% and the dinoflagelate species 6%, of the phytoplankton (Gacic *et al.*, 1989).

A study of red tide indicated that this phenomenon is induced by temperature. When temperature reaches the value of 20 °C, "red tides" start to develop, ceasing when sea water temperature drops below 20 °C (Marasovic, 1991). At the end of the summer of 1980, in the eastern part of the bay, there occurred for the first time, a strong "red tide" (Marasovic and Vukadin 1982). The cause was a monospecific bloom of the dinoflagelate species *Gonyaulax polyhedra*, a typical "red tide" organism which appeared in enormous quantities. Over the last few years "red tides" caused by the species *G. polyhedra* have been a regular summer occurrence, and depending on the meteorological conditions have on occasion been accompanied by mass mortalities of marine organisms.

The density of the phytoplankton population varies throughout the year. During the spring season phytoplankton density is the highest, falling to a minimum in summer. Increasing again during the fall-winter season. Since 1968 a significant increase in the phytoplankton density was observed during the summer season.

Kastela Bay is very productive basin. Due to a sewage discharge, primary production in the last two decades has almost doubled in the central part of the bay. Between 1970 and 1984 it increased from 150 to 235 g C m^{-2} yr^{-1} (Figure 35).

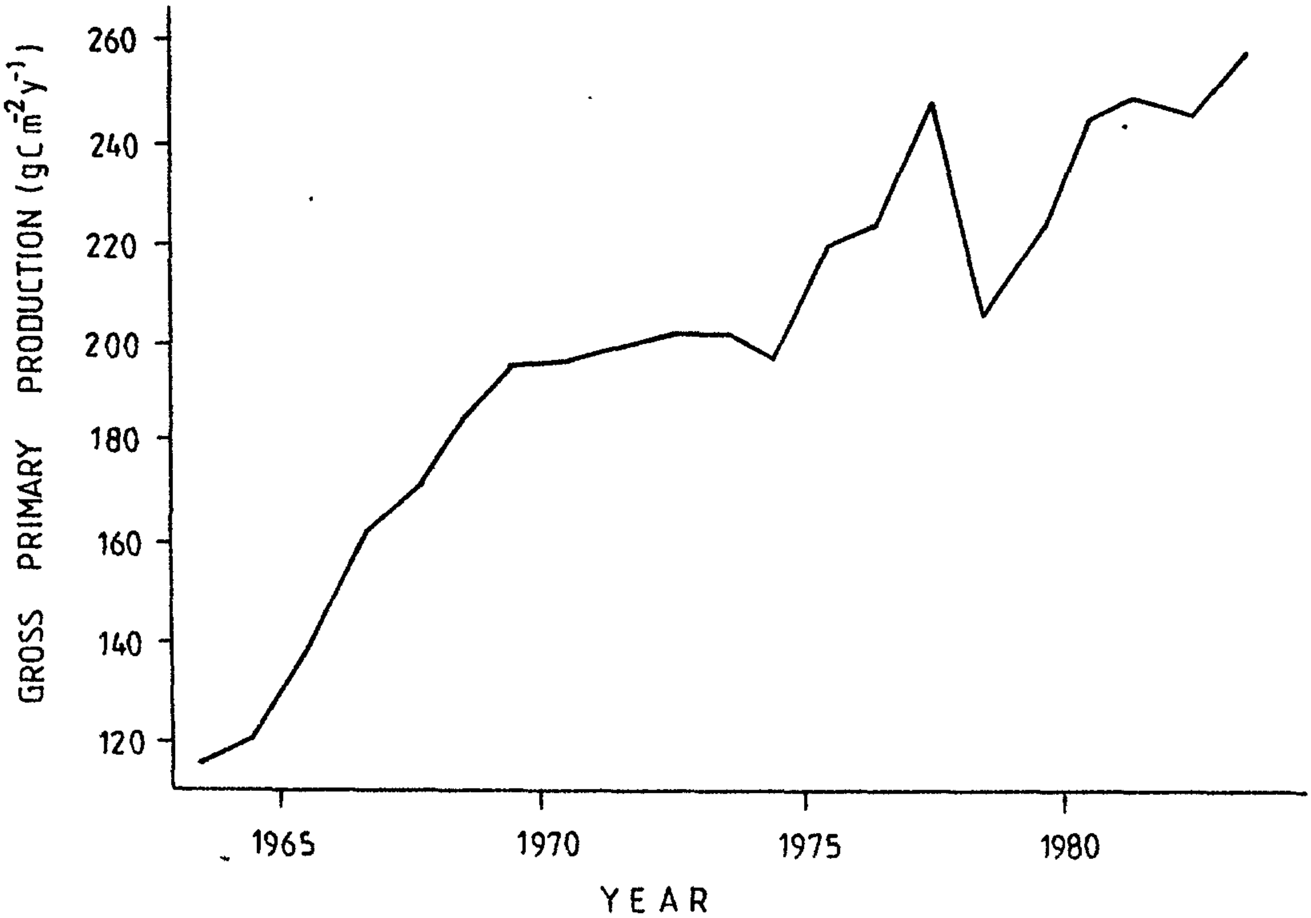


Figure 35 - Changes in the gross primary production in Kastela Bay
(after Pucher-Petkovic and Marasovic, 1988)

Zooplankton community

According to long-term studies begun in 1956, the average biomass values of zooplankton show a spring-summer maximum and a winter minimum. Copepods are the most numerous group of zooplankton, and are present throughout the year, unlike some other groups which appear only periodically or are few in number. The copepods form 70% and sometimes even 99% of the total zooplankton in the bay.

The results of a long-term study on the composition of the zooplankton in the central part of the bay indicate that the proportion of copepods has remained unchanged. However, the relative contribution of different species has changed. Some of those species which were numerous in the bay fifty years ago, are found in very small numbers today. At the same time the relative contribution of the species *Acartia clausi* has increased. According to some data the relative abundance of this copepod is much higher in regions which are under the influence of pollution. At a station in the eastern part of the bay *Acartia clausi* reaches 93% percent of total copepod community (Gacic *et al.*, 1989).

Bacterioplankton

Monitoring of the distribution of bacteria, their relative contribution to the total plankton community and their biomass in the central part of the bay has been undertaken since 1968. Special attention has been given to the heterotrophic bacteria which play a major role in the decomposition of organic matter.

The density of total bacteria and the heterotrophic group is larger by an order of magnitude in the bay than in the open sea. The average density of heterotrophic bacteria in the bay ranges between 208 and 1100 CFU ml^{-1} over the year and a large inter-annual variation is apparent. Seasonal changes in the density of heterotrophic bacteria show a summer maximum and a winter minimum. The number of bacteria in the summer reaches three times the winter values.

The results of long-term studies of the density of heterotrophic bacteria indicate a trend towards a slight increase in density. The horizontal distribution of heterotrophic bacteria in the bay is not uniform, the concentrations being one order of magnitude greater in the east then in other parts of the bay (Gacic *et al.*, 1989).

Benthos

The benthic communities have been severely affected by pollution and significant changes have occurred at the species and community level.

Red algae (*Rhodophyta*) are the predominant algal species in the area, but brown algae (*Phaeophyta*) and green algae (*Chlorophyta*) are also present. The number and biomass of each algal group depends on the pollution of the sea.

In polluted areas (eastern and northern part of the bay and in the vicinity of the city harbour) the number of species is reduced, and some nitrophilic species are present. In less polluted and unpolluted areas the number of species is much higher, and the presence of nitrophilic species was not detected (Table 24) (Tudor *et al.*, 1991).

Sea-grass meadows (*Posidonia oceanica* and *Cymodocea nalose*) are present in the clear unpolluted areas of the channels.

TABLE 24

Number of algal species in the three major algal groups at different locations in the Brac and Split channels

	Vicinity of the city harbour	Stobrec	Ciovo Island	Brac
Rhodophyta	59	87	97	107
Phaeophyta	10	27	26	39
Chlorophyta	17	22	18	23
Total	86	136	141	169

The results of studies of the zoobenthos indicate the impacts of pollution on the benthic communities (Table 25) while the numbers of species are higher in unpolluted areas and they are reduced in very polluted areas (Tudor *et al.*, 1991).

TABLE 25

Number of species of bottom fauna at different location in the Brac and Split channels

	Vicinity of the City harbour	Stobrec	Ciovo Island	Brac Island
Porifera	8	7	22	20
Cnidaria	5	3	6	7
Annelida	5	5	5	5
Arthropoda	9	8	13	12
Mollusca	37	44	49	40
Testaculata	1	1	1	1
Echinodermata	7	6	14	8
Tunicata	4	1	2	4
TOTAL	76	75	112	96

Eutrophication of the bay

The eutrophication level of Kastela Bay can be described in terms of the following parameters: dissolved oxygen, transparency and nutrients, for which data have been collected over a long period.

Oxygen

Data on oxygen content are frequently used for assessing eutrophication levels in aquatic ecosystem. During periods of strong stratification of the water column oxygen content increases in the surface layer, accompanied by a decrease of oxygen in the bottom layers. In extreme cases, the bottom layers become completely deoxygenated and hydrogen sulphide appears.

The oxygen content in the central station of Kastela Bay has been monitored since 1953 (Buljan and Zore-Armanda, 1966) (Figure 36). Oxygen content in the bottom layers was somewhat lower than in the surface layers, during the early periods which can be considered normal for shallow oligotrophic seas. Two exceptions recorded in this period occurred in 1960, when extremely high levels of oxygen in both surface and bottom layers were recorded. The causes of these extreme values are not known. From the early 70's on, there has been a noticeable increase in the oxygen content of surface waters. At the same time, there is a slight decrease in oxygen content of the bottom layer. The increase in the upper layer is explained in terms of stronger photosynthetic activity (Pucher-Petkovic and Marasovic, 1988) resulting from an increased discharge of nutrients into the sea. This is accompanied by an increase in biomass and for its decomposition in the bottom layers a higher amounts of oxygen is needed.

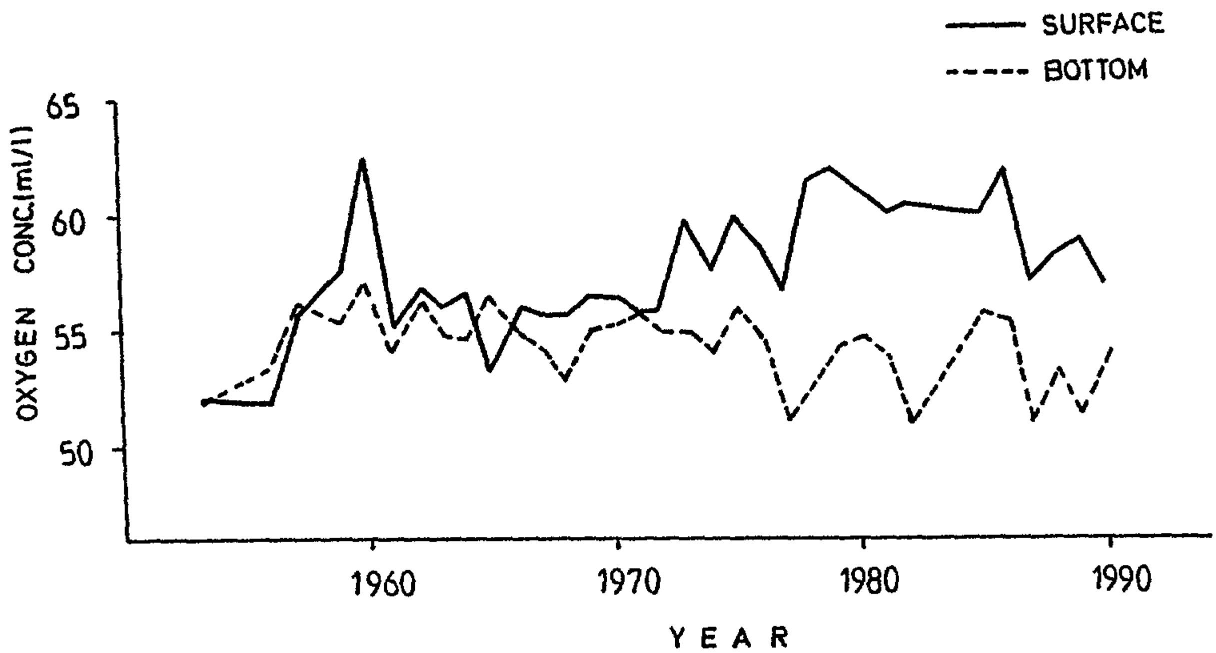


Figure 36 - Average annual values of dissolved oxygen in the surface and bottom layers at the central station in Kastela Bay

Occasional monitoring of oxygen content in particular in the eastern part of Kastela Bay where most municipal and industrial waste waters are discharged and the river Jadro also enters the bay, confirm the forgoing conclusions. In this part of the bay, in the summer, the water is stagnant and water exchange is considerably weaker than in the entire bay (Zore-Armanda *et al.*, 1976).

At the end off the "red tide" phenomenon in the eastern part of the bay oxygen values were very low, both in the bottom and in the surface layers returning rapidly to previous levels in surface waters (Marasovic and Vukadin, 1982) as indicated by the data in Table 26.

TABLE 26

Changes in Oxygen concentration during the occurrence of a "red tide" in the eastern section of Kastela Bay in 1980

DATE	DEPTH (m)	OXYGEN (ml l^{-1})
19 Sept. 1980	0	4.60
25 Sept. 1980	0 10 (sea bottom)	1.84 0.58
26 Sept. 1980	0 10	4.91 1.82

On the basis of available data on oxygen content, it is possible to conclude that eutrophication in Kastela Bay started in the early 70's and continues to occur. In the eastern part of the bay the level of eutrophication, due to its physical and chemical characteristics is much higher than in the central and probably also the western sections of the bay.

As dissolved oxygen concentrations between 3.7 and 5.6 ml l^{-1} are required to satisfy the needs of marine organisms, lower concentrations can cause adverse effects. It is believed that oxygen concentrations which persist below 3.5 ml l^{-1} for several hours, may not be damaging in ecosystems close to the shore (Sournia, 1973). The lower lethal limit for the majority of marine organisms is 0.9 ml l^{-1}.

Data from the eastern part of the bay show that oxygen levels were below the lethal limit at certain times. It is not known, however, for how long these concentrations persisted nor how large was the area were the oxygen content dropped below the lethal limit. Nevertheless, it may be presumed that with present pollution trends, the areas affected by such deoxygenation can only get larger and their duration longer.

Transparency

Sea water transparency, generally measured by means of a Secchi disc, is a parameter which can be used for studying the eutrophication process since under eutrophic conditions the depth of light penetration declines as a consequence of light scattering by plankton.

The light penetration to deeper layers is reduced as eutrophication becomes more intense, however, reduced transparency can also be caused by the presence of suspended particles of inorganic origin. In coastal waters, reduced transparencies frequently occur near river mouths, or following heavy rainfall when runoff water carries large quantities of suspended matter to the sea.

Measurements of sea water transparency at Kastela Bay central station date back to 1953. Mean annual values are shown in Figure 37 (Buljan and Zore-Armanda, 1966; 1979). Individual Secchi disc values vary considerably as do the annual averages, especially during the first part of the measurement period. An explanation for this variability can be found in the impact of the overall suspended matter reaching the sea through runoff via the river Jadro. However, the data clearly show a small but statistically significant decrease in transparency over a period of 25 years. This decline in transparency may be attributed to increasing eutrophication in Kastela Bay due to pollution.

Transparency in the eastern part of the bay is lower than in the centre. This reflects the fact that the eastern part of the bay receives the bulk of municipal and industrial waste waters. Transparency is significantly reduced at stations closer to pollution sources. This decrease in transparency can be partly explained by the presence of suspended (inorganic) particles, but, predominantly results from increased phytoplankton density caused by increased nutrient inflow.

The increased inflow of nutrients to the eastern part of the bay which has a relatively small water mass compared to the whole bay and a longer flushing time, favours a rapid increase in phytoplankton biomass. The phytoplankton blooms in recent years and increased quantities of waste water released into this part of the bay lead us to conclude that reduced transparency with present values substantially lower than those recorded during the 1975-76 period, indicate increasing levels of eutrophication.

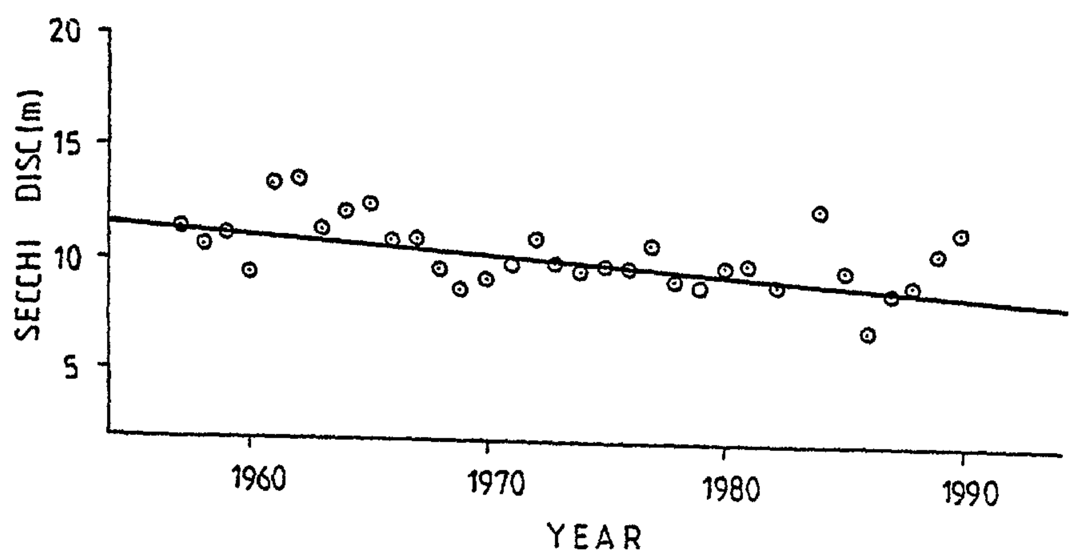


Figure 37 - Average annual values of transparency (secchi disc) in Kastela Bay

Nutrients

Although higher inflow of nutrients to the marine environment is the cause of eutrophication, the nutrient content of sea water is, generally speaking, not a reliable indicator of eutrophication or of pollution. The actual concentrations of nutrients in sea water are the result of a series of chemical and biological processes, which are interconnected and controlled by different factors. Changes occurring in these processes can significantly alter concentrations of nutrients in the water. Therefore, data on nutrients in the water are not necessarily an indicator of eutrophication.

Nutrient concentrations have been continually monitored at the central station in the bay since 1971 and the phosphate content has been observed since 1962 (Buljan and Zore-Armanda, 1966; 1979). The P-PO_4 concentration increased up to the beginning of the 70 s and then gradually decreased. N-NO_3 and N-NO_2 concentrations fell gradually over the entire period of measurement. The ratio of nitrogen and phosphorus salts is shown in Figure 38 (Pucher-Petkovic and Marasovic, 1988). This ratio declines reaching a value of 23, which is still above the optimal value for phytoplankton growth, but is significantly below the value determined for the open Central Adriatic. The reduced nitrogen phosphorus ratio confirms the fact that Kastela Bay receives large quantities of municipal waste water in which the nitrogen/phosphorus ratio is 5.

Studies of nutrient content in the eastern part of the bay were carried out during the 1975-76 period (Buljan *et al.*, 1976). Nitrate content in the surface layer at all the stations was above that of bottom water, and this is also true of the ammonia content. Nitrite content at all the stations was significantly higher in the bottom layer than at the surface. Phosphate concentration at all the stations was higher in the surface layers than in the bottom water. These data confirm the fact that municipal waste waters are an important source of nitrates and phosphates, released in large quantities into the study area. Lower surface salinities at these stations confirm this origin.

Unlike other nutrients, nitrites are created by bacterial decomposition of dead organisms on the sea bottom, and their concentration is higher in the bottom layer. They are subsequently transported to the upper layers of the water column by vertical mixing processes.

Nutrient Inputs to Kastela Bay

The inputs of nitrogen and phosphorous to Kastela Bay are shown in Figure 39.

Atmospheric Input

The input of phosphorus from the atmosphere is insignificant. It is estimated that the input from the atmosphere is somewhere between 1 and 2% of the total input to sea water, or some 5 mg m^{-2} yr^{-1} (SCOPE, 1976). In coastal waters, particularly those close to large industrial centres input can be higher. Rain contains on average 0.08 mg l^{-1} of phosphorus which, considering the mean annual quantity of rainfall in this area of 837 mm means that some 4 t of phosphorus reach the bay annually via the atmosphere.

The atmospheric input of nitrogen compounds is more important, especially near large urban areas where nitrogen oxides in the air occur in high concentrations. Similarly in proximity to agricultural land, ammonia inputs may be greater due to evaporation from highly fertilized areas (Stirn, 1988). The average amount of nitrogen in rainwater is 0.7 mg l^{-1}, and therefore the annual input of nitrogen into Kastela Bay is about 36 t in various forms.

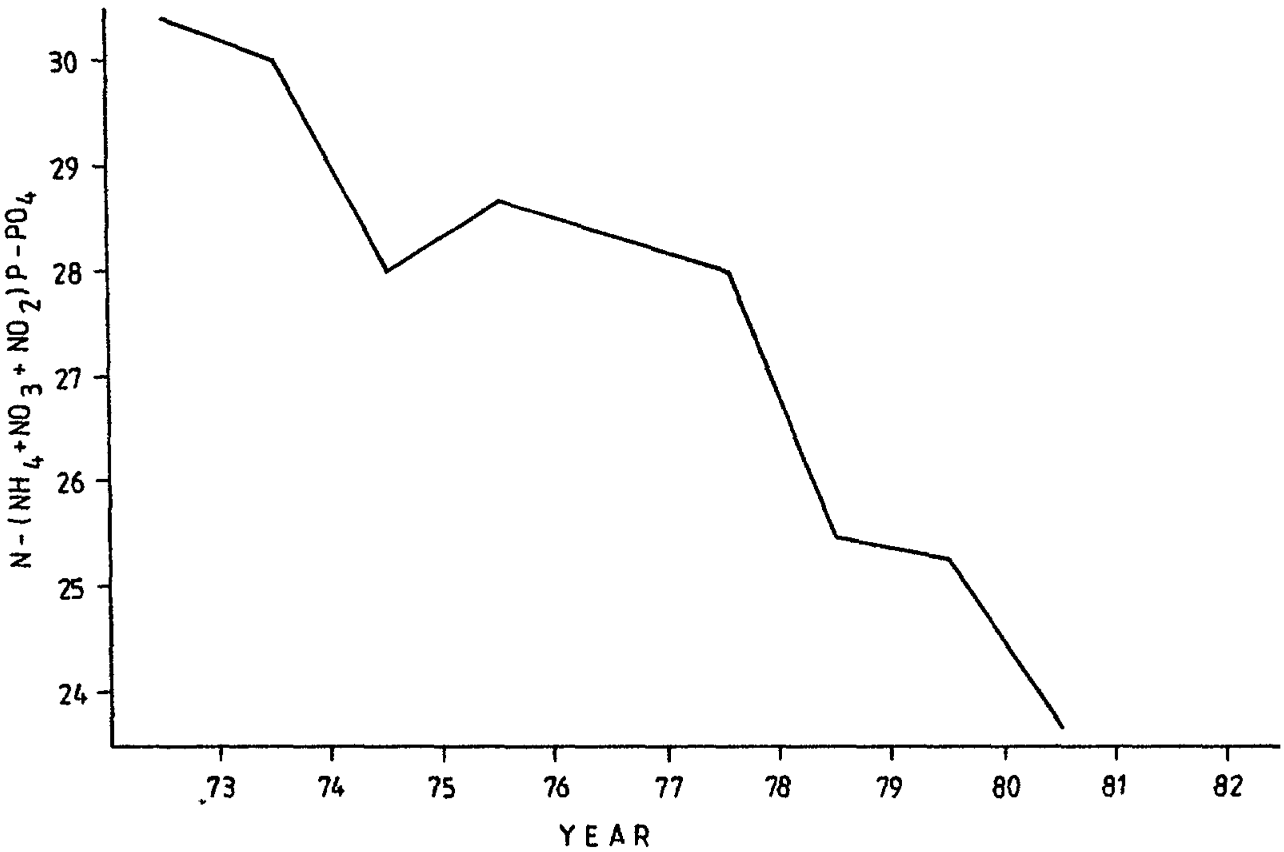


Figure 38 - 5-year running mean of the ratio of nitrogen to phosphorous in Kastela Bay for the period 1973-80 (after Pucher-Petkovic and Marasovic, 1988)

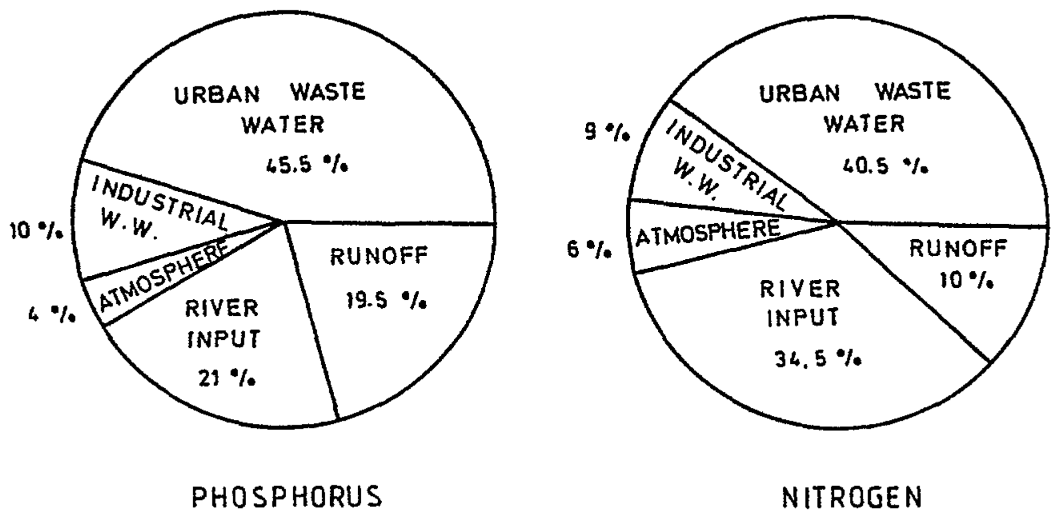


Figure 39 - Main sources of nitrogen and phosphorous reaching Kastela Bay

Input by River and Runoff

The average annual inflow from the Jadro river is 2.39 x 10^8 m^3. The mean annual nutrient content of the water is of 0.4 mg l^{-1} of total nitrogen l^{-1}, and 0.17mg l^{-1} of phosphate phosphorus (Smolcic *et al.*, 1980). The river Jadro consequently carries to the bay, 100 t of nitrogen in various compounds, and 40 t of phosphorus in the form of phosphates, annually. Situated in the northwest part of the bay lies the Pantana stream, and in the southwest there are two underwater springs. There are no available data for assessing the input of nutrients via these sources. It is also impossible to assess the volume of nutrients carried to the bay through runoff, in particular in the northwestern area, where large agricultural areas are located.

Municipal Waste Water

Municipal waste water contains domestic and industrial waste in addition to human faeces. The nutrient content in municipal waste depends on the level of water treatment as illustrated in Table 27 (Stirn, 1988).

TABLE 27

Nutrient levels in waste waters following different forms of treatment (Stirn, 1988)

Effluent	Nutrient concentration (mg l^{-1})			
	Total Nitrogen	Ammonia	NO_2 & NO_3	Total Phosphorus
Untreated	45	25	7	9
Primary Treatment	31	15	7	6
Secondary Treatment	25	2	13	6
Oxidation ponds	11	7	1	6
Phosphorus sedimentation	23	2	13	2

Municipal waste waters are released into Kastela Bay without treatment. The two main sewage outflows (Duje and Lora) lie to the east of the Split peninsula and release some 6.4 x 10^6 m^3 of waste water annually (Stambuk-Giljanovic, *et al.*, 1987). A number of smaller sewage systems are found in the northern part of the Split peninsula, and numerous smaller outfalls occur along the entire northern shore of Kastela Bay. The average contents of the waste water discharged into the sea by the two main sewage systems are shown in Table 28 (Stambuk-Giljanovic *et al.*, 1987).

TABLE 28

Inputs to Kastela Bay via the main sewer outfalls

		Lora	Duje
Flow	(m^3 yr^{-1})	3.3 x 10^6	3.1 x 10^6
Suspended matter	(mg l^{-1})	71	39
Total Nitrogen	(mg l^{-1})	36.3	12.3
Ammonia	(mg l^{-1})	21	8.5
Nitrite nitrogen	(mg l^{-1})	0.02	0.005
Nitrate nitrogen	(mg l^{-1})	0.1	0.045
Total Phosphorus	(mg l^{-1})	6	3.5

The total annual input of nitrogen and phosphorus discharged into the sea in different forms via these two sewage systems is estimated at 160 t of nitrogen and 31 t of phosphorus. If it is assumed that the mean content of the remaining waste water is similar to that of the two main waste water systems, then the total nitrogen and phosphorus inputs to the bay would equal 240 and 46 t respectively.

Industrial Waste Water

Nutrients can also be found in waste waters originating from certain industries such as food processing. On the extreme southeast side of the bay a separate outlet carries waste water from a brewery, a slaughterhouse and a dairy, into the sea. This waste water contains significant quantities of organic matter, estimated at a level of 3500 t yr^{-1} of chemical oxygen demand (COD) and 1500 t yr^{-1} of BOD_5. The total amount of nitrogen and phosphorus reaching the bay through discharge of industrial waste water is thus 53 and 10 t yr^{-1} respectively.

2.5.3.2 Possible impacts of the expected climatic changes

Estimates of the possible impacts of expected climatic change on the marine ecosystem of the area under study is not possible on the basis of the data available. Considerable changes have occurred in the last 30 years due to pollution, primarily from urban and industrial waste waters. It is therefore difficult to predict what will be the impacts of the expected climatic changes will have in the absence of scenarios for other sources of change. There are no such scenarios, and they would be difficult to produce given the number of unknown parameters.

It may be assumed that the present pollution by urban and industrial waste waters will be considerably reduced in a relatively short time if plans for sewage treatment facilities eventuate. However, there still remains the question of how long the negative impacts will continue following reduction in effluent discharges and how the ecosystem might respond.

Acting on the assumption that in the next 15 or so years, all urban and industrial waste waters which are now being discharged untreated, will be subject to primary treatment and discharged through submarine outfalls, one might suggest that the observed trends will continue for at least another 10 years and possibly longer.

Physico-chemical parameters are the primary determinants of the distribution of marine habitats, communities and ecosystems, and of ecological structures and processes. Changes to such parameters will therefore cause impacts on marine and coastal resources.

The global increase of temperature in the lower atmosphere will cause an increase in the open sea surface temperature although this change will not be as great as the increase in temperature of the lower atmosphere. Whether this will be the case in channels and semi-enclosed bays, is difficult to predict. Assuming that the sea surface temperature increase will be lower that of the air certain changes in the existing wind patterns are bound to occur, since there will be an increase in the temperature gradient between the sea and the land. This will intensify the air exchange between the sea and the land which will be reflected in the daily wind pattern in the summer season, as well as on a synoptic time scale of a few days.

The pattern of sea currents in Kastela Bay, as well as the exchange of sea water masses are mostly determined by the wind pattern. Unless a change occurred in the direction of prevailing winds, which is quite unlikely, there will be an increased flow of surface currents in the bay and the channels, combined with more intensive vertical mixing. As the distribution of salinity in the surface layer of Kastela Bay depends upon the inflow of fresh water from the Jadro river (which is also the case with the Cetina and Zrnovnica rivers in relation to the Brac Channel) and the wind pattern, it is realistic to assume that the fresh water will be spread over a larger area.

In oligotrophic seas, such as the Adriatic, primary production is limited by the availability of nutrients in the euphotic layer. The principal source of nutrients in Kastela Bay is the urban waste waters discharged into the surface layer. Once the sewerage system is constructed, the intensity of the primary production will be determined by the vertical mixing and nutrient input from the bottom layers. Unlike today, the expected inflow will be considerably lower in the future which will, in turn largely decrease primary production in the bay but not in the channels where primary production will probably increase due to the temperature rise and more intensive vertical mixing induced by stronger winds and a higher inflow of nutrients.

The predicted temperature increase of surface waters and changes in vertical and horizontal circulation would have impacts on marine life. However, marine organisms, as a whole, have genetic and behavioral flexibility, allowing them to adapt to constantly changing environmental conditions (Odum, 1986). This property is a basis for the relative stability of zoogeographic patterns under the conditions of natural climate variations.

Studies of the "red tide" phenomenon in the bay show that it appears when the temperature of the sea water exceeds 20 °C, and disappears after the sea water cools below 20 °C. If the assumption that the red tide phenomenon results from the large inflow of nutrients via waste waters into the surface layers of the eastern part of the bay is correct, and if it is also correct that only temperatures higher than 20 °C trigger the appearance of the phenomenon, then it would be expected that by stopping the inflow of nutrients the red tide phenomenon should cease to occur. There is still, however, a slight possibility of the phenomenon continuing, although less conspicuously and earlier in the year, depending on how early the sea water warms to 20 °C.

Although a change in the primary production is likely to happen, it is impossible to predict how this may be reflected in the food chain, and particularly on the economically important fish species. There is no information which would allow predictions of the possible nature and extent of changes in the phytoplankton and zooplankton populations as a consequence of sea temperature increase. One impact of increased water temperature in the Mediterranean may be to accelerate the penetration of Lessepsian migrants from the Eastern to the Western basin and possible to bring some species to the Adriatic and the Kastela Bay area. Penetration of Lessepsian migrants to Kastela Bay may affect local communities in various way which are very difficult to define and predict.

The impact of climate change on economically important fish species in the study area is impossible to predict on the basis of available knowledge. The biological cycle of important demersal species is not fully known, in particular the factors affecting their spawning. Thus it is impossible to predict whether and to what extent expected climate changes may influence the fish stocks.

Sardines spawn in cool waters of the mid Adriatic. Fingerlings come to the coastal waters in spring, together with full-grown fish, and stay there until the beginning of winter. This behaviour pattern will not be significantly influenced by the sea surface temperature increase which may only cause sardines to stay longer in the coastal waters. Whether the increased sea surface temperature will have an impact on spawning is difficult to predict, since there are no relevant data which allow predictions along these lines.

Changes in the ecosystem expected to occur under the influence of climate change will probably have some impact on the behaviour of sardines, but it is not possible at present to state with confidence what such changes may be. The population of *Sardinella aurita* in this area may increase, and this may have negative impacts on sardine stocks.

2.6 Managed Ecosystems

2.6.1 Agriculture

2.6.1.1 Past trends and present situation

Due to the proximity of the sea and to the favourable transport and climatic conditions of the area it was populated a long time ago and agriculture has a long tradition in the area. Among the crops which were grown in ancient times and which still occupy a high proportion of cultivated land are vines, olives and cereals. Dryland farming was and still is the predominant practice in cultivated areas.

In the post-war period of farm abandonment and depopulation of villages, the population pressure on the coastal zone, especially along the shore itself, has increased. Added to this the process of industrialization and the rapid development of tourism, have led to conflicting demands for different land use. The problem of urban expansion onto the most fertile soils is a major issue in this area, but is also, a phenomenon common to many Adriatic and Mediterranean coastal areas. As the total arable land in the area is scarce, urban expansion tends to cause serious conflict between different users. Increasing pressures for housing development and tourism have led to a critical situation in the agricultural sector.

Of the total cultivated area only a small proportion is currently irrigated. The main irrigated crops include citrus, kiwi and a wide variety of vegetables and flowers, produced in controlled environments (greenhouses) and in the open. The contribution of controlled environmental production to annual agricultural output is very important. Such intensive agricultural production is located on the most productive soils in the western part of Kastela Bay, near Trogir, to the east of Split.

Private ownership is the predominant feature of land tenure in Kastela Bay and the thousands of small and fragmented agricultural holdings pose a major technical obstacle to agricultural development - second only to the problem of water scarcity.

2.6.1.2 Possible consequences of expected climatic changes for agriculture

Cultivation of plants relies on two different media, the soil and the atmosphere, which provide necessary nutrients, water, light, energy and gases for plant growth and nutrition.

The most important consequences of climatic change for agricultural production will result from higher potential evapotranspiration, primarily due to higher air and land surface temperatures. The increased rate of potential evapotranspiration and loss of soil moisture would be of considerable importance for agriculture. An increased plant water deficit during the growing season would lead to a significant decrease in agricultural yields and potential. Citrus and kiwi fruit are already impossible to grow without irrigation so that problems with these crops can be expected in the future since water is scarce in this area.

Reduction in average levels of soil moisture as a result of higher rates of evapotranspiration could increase the number of days with minimum threshold of water availability for given crops. Similarly, the number of very hot days, which can cause damaging heat stress to temperate crops could increase significantly as a result of a 2 to 3 °C increase in mean annual temperatures. Increase in summer precipitation will be insufficient to compensate for increases in evapotranspiration losses under higher temperature which will reduce crop-water availability.

The unfavourable distribution of rainfall and low soil humidity in the period of the most intensive plant growth (May- September) is at present the principal limiting factor to agricultural production. The best adapted plants are those of traditional culture: vines, olive, fig, sour and sweet cherry. The cultivation of even these plants is threatened by insufficient soil moisture due to the long period of summer dryness. The expected increase in evapotranspiration and resulting water deficit will cause further reduction in yields of these crops. These climatic limits to agriculture, in combination with soil constraints (particularly shallowness of terraced mineral soils), means that the potential base for rain-fed agriculture is quite limited. Solutions need to be developed through proper selection of culture and management systems, aimed at those crops best suited to the new climate.

Increases in temperature can be expected to lengthen the growing season. Since soil moisture is abundant and temperatures are already favourable in the autumn and winter period, growing winter vegetables should be promoted, especially since economically these are more profitable than traditional crops. The existing intensive flower cultivation should be further stimulated and improved.

Such an orientation requires a greater use of agricultural chemicals (fertilizers and pesticides), which may have adverse affects on the soils, the general environment and human health. At the same time, increasing coastal populations and airborne particles from heavy industrial activity contribute to soil contamination. Intensive and often uncontrolled use of fertilizers and pesticides has resulted in the accumulation of harmful substances in the soils. In order to prevent chemical degradation, it is important to reduce and control the use of agricultural chemicals.

Warming may reduce yield potential of current cereal production because higher temperatures encourage more rapid maturation and shorten the period of grain development. An important effect of warming will be a reduction in winter chilling. A 1 °C rise in temperature would reduce effective winter chilling (vernalisation) by between 10 and 30%, thus contributing to a poleward shift of temperate crops (Salinger, 1989). Continuous monitoring is required in order to obtain a better understanding of the impacts of expected climatic changes on agriculture.

2.6.2 <u>Fisheries</u>

2.6.2.1 Past trends and present situation

The areas of Kastela Bay and the Brac and Split channels are not significant from a commercial fishery viewpoint, even though people living in this area has been engaged in subsistence fishing from the time of earliest settlement.

Pollution of Kastela Bay over the past decade has resulted in prohibition of any fishing activity. Fishing is allowed only in the Brac and Split channels and even there closed seasons are operated from time to time. There is no official fishery statistics for the catches in this area.

Quantities of demersal fish are low and quality considerably lower than some 30 years ago. This has been primarily ascribed to overfishing and pollution by urban and industrial effluents. Quantities of demersal fish both in the bay and in the channels have been assessed at about 600 kg km^{-2}. Hake (*Merluccius merluccius*) and striped mullet (*Mullus barbatus*) are most common in the channels, making up 45% and 14% of catches respectively. The quantities of hake (*Merluccius merluccius*), striped mullet (*Mullus barbatus*), picarel (*Smaris vulgaris*) and sea bream (*Diplodus annularis*), in the bay are almost the same each contributin about 10% (Gacic *et al.*, 1989) to the total catch.

Studies of the feeding habits of hake (*Merluccius merluccius*) from Kastela Bay showed that this semi-pelagic species feeds on pelagic species (sardine and anchovy) so that its seasonal migrations follow those of the two prey species.

In contrast to hake, the feeding habits of typical benthic fish species, such as striped mullet (*Mullus barbatus*), and pandora (*Pagellus erythrinus*) show intensified feeding in summer when the sea water is warmer. Their food consists mainly of Polychaeta (40%), Lamelibranchiata (up to 20%) and decapod Crustacea (about 14%).

The small pelagic fish catch of sardine and anchovy in this area has varied around 1500 t yr^{-1} of which, between 300 and 500 t have been caught in the bay. Anchovy makes up 5-6% of the total catch (Kacic, pers. comm.). Sardine migrates to this area from the open sea in spring and remains here until late autumn. Sardine juveniles and fish of one or two years of age are found together.

Some 15 years ago *Sardinella aurita* was first caught in this area. This species normally inhabits the southern Mediterranean along the north African coast, but is now known to reproduce in the Adriatic. Quantities of this fish have been assessed at about 1% of those of sardine (*Sardina pilchardus*) (Kacic, pers. comm). The reason for the extension of the range of this species into the Adriatic is not known although it has been suggested that it was due to changes in the freshwater regime of the Nile delta following construction of the Aswan Dam.

Up to some 30 years ago, the catch of mackerel in the bay area and in the channels, was significant. However, they disappeared suddenly returning in small numbers in 1991. The future status of these stocks cannot be predicted, nor can their sudden disappearance and return be accounted for.

2.6.2.2 Possible impacts of anticipated climatic changes

Significant changes in demersal fish stocks over the past two decades are due both to overfishing and marine pollution. It is to be expected that these two factors will continue to be crucial in the future. Pollution lead to eutrophication which is particularly pronounced in the bay where summer algal blooms occur ever more frequently followed by mass mortalities of marine organisms. It is unlikely that anticipated climatic changes (temperature increase, sea level rise and precipitation increase) will directly affect fish stocks before the year 2030. The extent of the predicted changes is insignificant such that it is reasonably certain that marine ecosystems will not suffer significant changes.

The anticipated global temperature increase of 1.8 °C by 2030, is unlikely to cause an increase in sea water temperature in excess of 1.5 °C, and on the basis of present knowledge, it cannot be predicted whether such a temperature increase will result in any changes in fish stocks. Anticipated changes in precipitation are not expected to cause significant change in fresh water runoff and hence no significant changes to salinity are anticipated. Although the greatest increase in precipitation (34.2 %) is predicted for the summer season, in absolute terms this represents only 45 mm of rainfall. It is impossible to predict whether salinity will change due to increased evaporation.

Predicted sea level rise for the year 2050 (up to 52 cm) and for year 2100 (up to 100 cm) are unlikely to impact commercially important fish species, but the impact of temperature increases by these dates could be significant. Temperature increases of up to 2.3 °C (in the year 2050) and up to 3.5 °C (in the year 2100) will raise sea water temperatures by at least 1.5 °C and 2.5 °C, respectively. In addition to the impacts of such temperature increases on the physical characteristics of sea water, such increases will very probably affect commercially important fish species. The migration pattern of pelagic fishes (sardine and anchovy), as well as their spawning areas could be changed. Under conditions of increased temperature small pelagic fishes would remain for longer in coastal waters. Changes in the migration patterns of small pelagic fishes will in turn affect semi-pelagic fish such as hake.

The original range of *Sardinella aurita* is the southern Mediterranean, where sea water temperature is higher than in the northern Mediterranean. Sea water temperature increases in the Adriatic, in general, may favour this species in the Adriatic. This may in turn affect other small pelagic fishes in various ways which are difficult to define and predict.

It is well known that wind affects primary production, by accelerating vertical nutrient transport from bottom to surface layers. Diatoms dominate the phytoplankton of the bay (70-99%) and are significant food sources for other organisms in the food chain. They easily sink due to their density and are retained at the surface by vertical flow. However, the effect of climatic changes on the wind regime and consequently on vertical mixing in the surface layer, is still unknown.

2.6.3 Aquaculture

2.6.3.1 Past trends and present situation

There are no marine fish farms, nor plans for their construction in the study area due to the heavy sea water pollution. The Institute of Oceanography and Fisheries in Split maintains an experimental hatchery for sea bass and gilthead sea bream with a capacity of up to 300,000 fish fry.

Californian trout is cultured in two fish farms, one in the Jadro River and the other at the mouth of the Pantana stream. These two farms operate together with the hatchery in the Jadro River rearing fish to one year of age. Thereafter, fish are cultured at Pantana up to commercial size. Total annual production is 400 t.

The total area of the fish farm at Pantana is 2.5 hectares with a pond area of 1.2 hectares. The Pantana spring is at sea level so its water flow cannot be determined with certainty. Average water flow was estimated to be 6 m^3 sec^{-1}, minimum 0.5 m^3 sec^{-1} and maximum 20 m^3 sec^{-1}. Since the spring is at sea level and not far inland, fresh water is mixed with the sea water at the spring itself. Water salinity therefore ranges from 2 to 20 $^{\circ}/_{oo}$. Salinity is highest in summer when freshwater flow is reduced. Apart from seasonal salinity variations there are also daily fluctuations due to tides. Temperature is constant, around 13 °C.

Ten years of experience of fish farming under conditions of significantly varying salinity, even during the day, has shown no adverse effects. Moreover, some beneficial effects have been recorded: fish seem to mature later, which affects their growth and consequently reduces food consumption; fresh water parasites cannot survive in salt water, so that the farmed population is healthier than in fresh water; and finally these fish are well known for their special flavour which makes them more expensive than fish from any other farm in Croatia.

The fish hatchery in the Jadro River is upstream from the town of Solin, near the middle of the Jadro River's course. Total pond area is about 1 hectare. The Jadro River is a typical karst river with average annual water flow of 9.5 m^3 sec^{-1}, average minimum flow 4.0 m^3 sec^{-1}, and average maximum flow 66.0 m^3 sec^{-1}. Water temperature varies in ponds from 12.0 to 15.5 °C with lowest temperatures occurring in December and January and highest in July and August.

2.6.3.2 Impact of anticipated climatic changes

Anticipated air temperature rises of about 1.8 ° C, by the year 2030 and 2.3 ° C, by the year 2050 will not significantly affect the present temperature regime of the Jadro River and Pantana spring. Therefore it is likely that no direct impacts on present aquaculture will occur. The anticipated sea level rise may adversely affect the Pantana farm. Since the farm is on an alluvial plain, at a very low elevation, part of the farm may be flooded. Sea level rise will significantly affect the spring itself. Since Pantana spring is already at sea level, it is already affected by the sea such that significant daily salinity variations occur. A rise in sea level will increase the salinity in the spring area. It is also quite probable that the ponds will be flooded, which will mean significant salinity increase up to values approaching that of sea water.

It is very unlikely that the Jadro River hatchery will be affected by the anticipated climatic changes. The natural flow of the Jadro river will not be significantly changed by anticipated changes in precipitation. Water temperature is unlikely to be significantly altered.

In conclusion it may be stated that the anticipated temperature increase of 3.5 ° C by the year 2100 will not significantly affect aquaculture activities either on the Jadro river or at Pantana spring, however a sea level rise up to 100 cm would endanger the Pantana farm. The indirect implications of anticipated climatic changes cannot be estimated. Aquaculture is an activity the development of which will be affected by a series of factors not directly related to climatic changes. The implications of other factors will greatly exceed those of anticipated climatic changes.

Appropriate protection of the terrain and ponds from sea level rise would protect the Pantana farm. Experimental rearing of sea bass under present conditions has shown very good results and it might be expected that sea bass could be reared under conditions of higher salinity at the Pantana farm.

2.6.4 Sylviculture

In the study area there are no exploitable forests.

2.7 Industry and Energy

2.7.1 Industry

2.7.1.1 Past trends and present situation

The industrial zone of the study area is situated along the eastern part of the bay, in the boundary area of the municipalities of Split, Solin and Kastela. Almost all industries are concentrated there along with the cargo port and oil terminal.

This high concentration of industries is due to two principal reasons. The first is purely technical and for example, the cement factories, of total annual capacity around 2 million tons, were erected adjacent to the raw material deposits. The second reason relates to the communist ideological desire to create an artificial working class in addition to the agricultural and service sectors. Hence, a vinyl chloride factory was built in a predominantly agricultural area immediately after World War II.

The area of the bay occupies less than 2% of Croatian territory but was inhabited by 5.9% of the Croatian population in 1988. The industrial and service sectors occupy an area of about 4.5 km^2, some 0.5% of the total bay area. The shipyard, chemical industry, production and processing of PVC, cement works, metal production (steel and ferroalloys), cloth-making and footwear, food, spirits, soft drinks and beer production are the most important industrial activities in this area. The number of employees in the different industries in 1990 is given in Table 29.

TABLE 29

Numbers of employees by industrial sector

INDUSTRY	No of employees
Food	3,000
Chemical	3,200
Cement	3,600
Shipyard	11,000
Metallurgy	2,000
Clothing & Footwear	6,400
Other	9,300
TOTAL	38,500

The industry of the area is basically heavy industry (cement, chemical, metallurgy) characterized by high investment and high flows of raw materials and merchandise and high energy consumption. The great proportion of manpower is employed in the processing sector (shipyard, cloth-making) and much of the production machinery (30 to 50%) is out-dated and worn out. Most of the workforce lives in the area of the bay, less than 10% comes daily from the hinterland.

Energy consumption by industry is particularly high with annual consumption amounting to about 516,000 MWh of electrical energy, around 274,000 t of coal, 72,000 t of oil and 10,000 t of other liquid fuels. There is a trend towards the introduction of liquefied gas. The cement and metal industries are the largest energy consumers and over the past ten years the cement works have replaced oil with coal in furnaces. The metal industry consumes exclusively electrical energy.

Industries are, for the most part, export oriented. The total production of the shipyard has been exported, as is much of the output from the ferroalloy factory. A significant proportion of cement production is also exported.

2.7.1.2 Impact of anticipated climatic change

The existing industry is of a kind that should be significantly restructured irrespective of climatic changes. In the first place, the basic heavy industry is the largest energy consumer and at the same time a significant source of environmental pollution and should be replaced with light industry, services, agriculture and tourism.

Temperature increase may favour the consumption of soft drinks and consequently increase the demand on existing industries producing soft drinks and beer. However, since considerable quantities of soft drinks are consumed by tourists during the summer season the final demand will depend on the development of tourism in this area. Expected local climatic changes will have implications for the cloth-making and foot wear industries. An increased demand for summer clothes and footwear of natural materials is to be expected.

A search for new production programmes will presumably be affected by increased demand for air-conditioning which in turn may encourage the production of air-conditioning equipment in this area.

2.7.2 Energy

2.7.2.1 Past trends and present situation

Energy demands in the bay area are largely met through consumption of electricity, coal, oil and liquefied gas. Sectorial energy consumption is shown in the Table 30.

TABLE 30

Energy consumption by source and sector in the Kastela Bay area

Sector	Electricity (Mwh yr^{-1})	Coal (t yr^{-1})	Oil (t yr^{-1})	Liquid gas (t yr^{-1})
Domestic	360,000	1,700	14,500	5,000
Industry	516,000	274,000	72,000	10,000
Transport	-	-	90,000	-
Other	150,000	50,000	12,000	2,000
TOTAL	1,026,000	325,700	188,500	17,000

Residential demands are largely met through electricity and, to some extent, from liquefied gas (Figure 40). This sector is partly forced to utilize these energy sources, since apartment buildings built between the sixties and eighties have no chimneys. Some of these apartment buildings have central heating systems which burn exclusively oil. A section of the population living in family houses on the outskirts of Split and in Solin and Kastela consume wood, and, to a lesser extent, coal for heating.

Industrial consumption of different types of energy is illustrated in Figure 41. The cement industry used oil in rotary kilns up to the eighties, but following the rise in oil prices after 1974 they were forced to replace oil by coal powder. Nowadays oil supplies are less than 10% of energy demand in this industry the rest being met by coal. The chemical industry utilizes coal in part, whereas all other industries are almost exclusively electricity consumers.

Local public transportation uses oil exclusively. Around the mid-sixties attempts were made to develop a tram system although the project was abandoned despite the construction of a six kilometer wire network. Railways still use oil although electrification of the railways has been planned.

Electricity used in this area is mainly produced by local hydro power plants. About 60% of electricity in the Republic of Croatia is supplied by hydro power plants, the remainder by thermal plants burning coal, oil and gas, and one nuclear power plant.

2.7.2.2 Impact of anticipated climatic changes

The potential direct and indirect impacts of anticipated climatic changes are presented only qualitatively, due to the lack of relevant quantitative data. Some possible impacts of individual climatic parameters on energy demand, the energy supply system, and on energy policy and society are shown in Figure 42 (Tegart *et al.*, 1990).

Whereas the changes in electric energy consumption will exclusively result from local climatic changes, changes in the energy supply system may be, to a considerable extent, affected both by local changes, and by overall national demands which will have implications for energy policy and society. Therefore, it would be quite impossible to anticipate any changes in energy policy without taking into account overall national circumstances.

The expected temperature rise will shorten the period when indoor heating is required which will release a defined quantity of energy. Ordinarily, the period of heating in this area lasts from the beginning of November to mid April. Some German assessments (Tegart *et al.*, 1990) show that temperature increase will result in a 13% reduction in energy demand. The same study, however, shows that a reduction of 45% may be attained in newly built houses using building materials of good isolation properties and appropriate construction. The temperature increase alone will reduce heating energy demand by 15 to 20%.

Temperature rise will, however, increase energy demand for air-conditioning in summer. Present energy demand for air-conditioning is almost negligible in comparison to the demand for heating energy, hence it may be assumed that the increase in energy demand for air-conditioning will be considerably lower than the reduction in demand for heating energy. As a consequence the total energy demand will be reduced. Some changes in energy sources are likely to occur, which will be affected by other factors such as recurrent and relative capital costs.

Climatic changes, both direct and indirect, will not significantly affect energy consumption in the industrial sector. Energy consumption in the transportation sector will follow national and world trends, since there are no peculiarities in this area which would suggest local deviations.

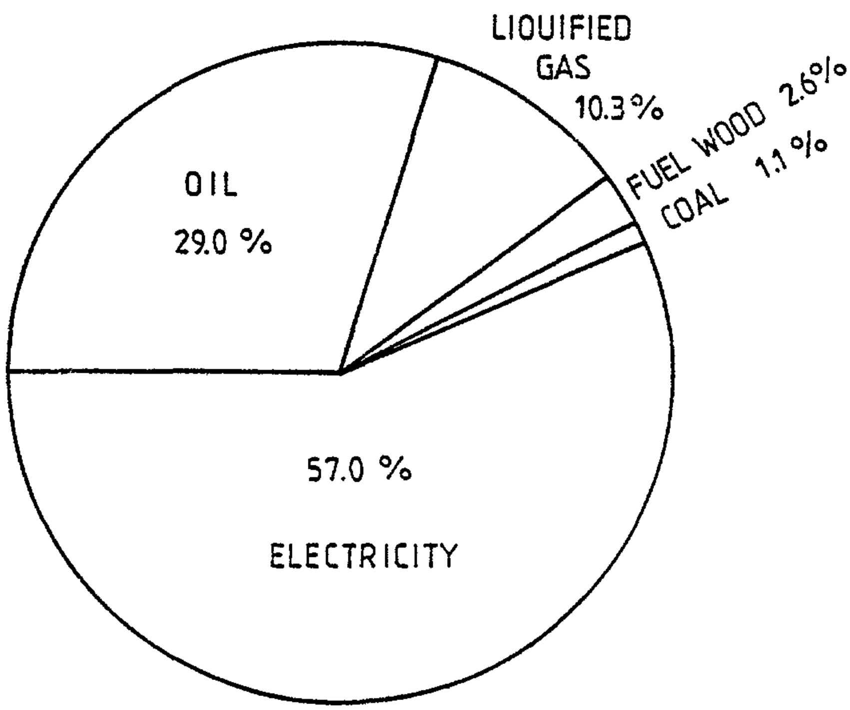


Figure 40 - Percentage of different types of energy consumed in the domestic sector

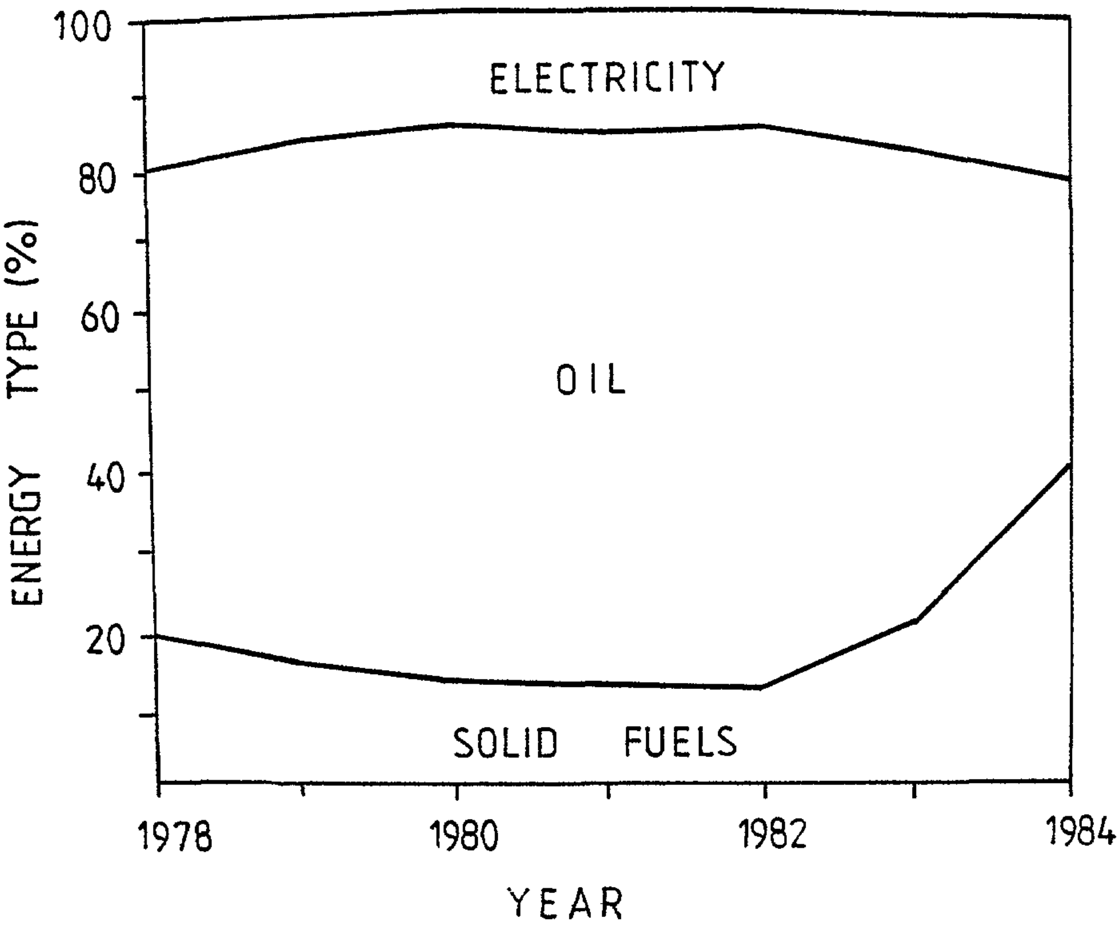


Figure 41 - Percentage of different types of energy consumed by the industrial sector

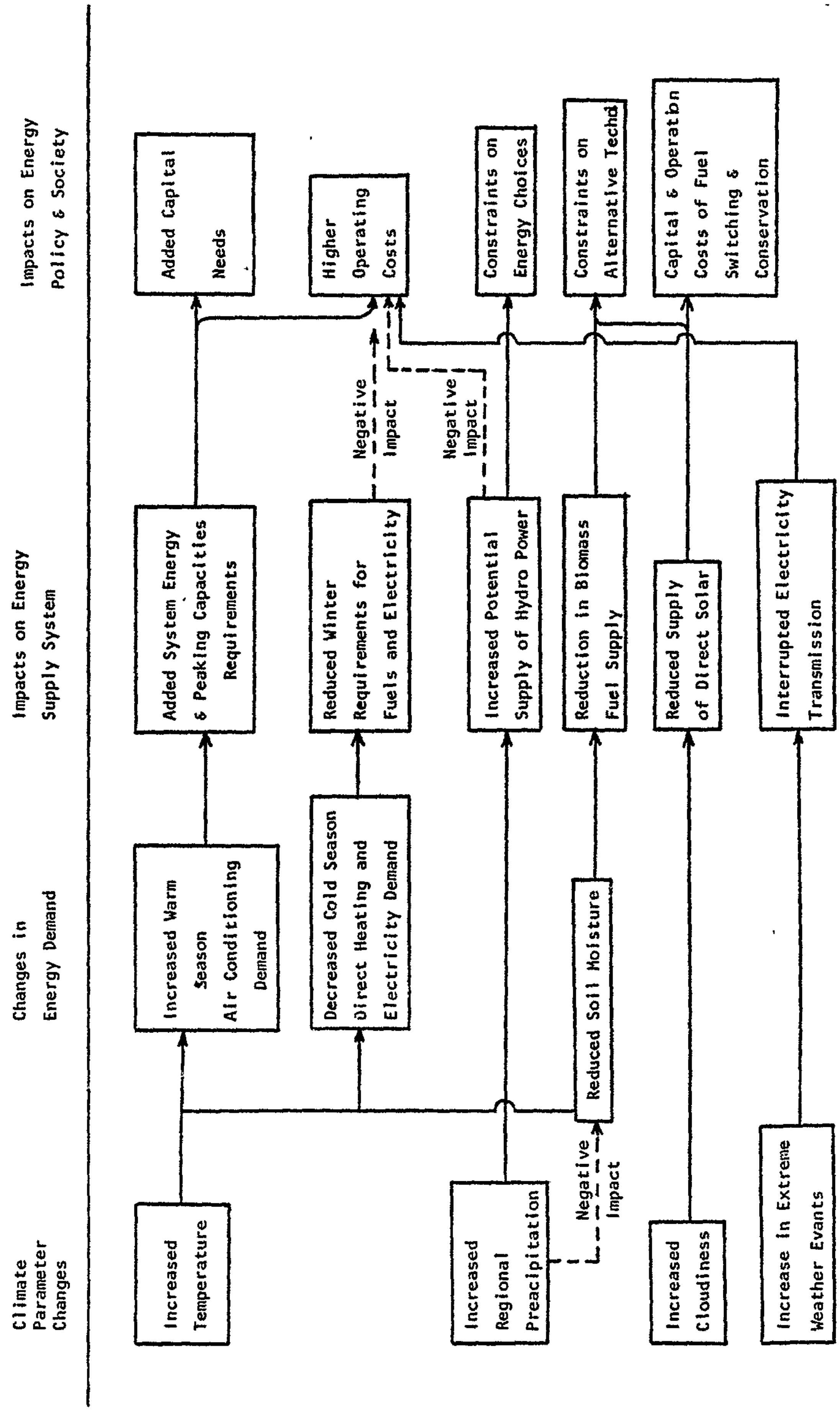


Figure 42 - Some possible impacts of individual climatic parameters on energy demand, the energy supply system, and on energy policy and society (Tegart *et al.*, 1990)

2.8 Tourism

2.8.1 Past trends and present situation

Generally speaking, tourism in the Kastela Bay region, particularly in the coastal area, is not a major economic activity, although the existence of large potential for tourism places this area among the most attractive destinations in Croatia.

Apart from a mild Mediterranean climate, central geographic location in Dalmatia, and favourable natural conditions, the large number of historic and cultural monuments such as Diocletian's Palace and the old city centres of Split, Trogir, and Kastela, have a potentially important, but as yet insufficiently recognized value for tourist development.

At present, coastal, summer tourism is the main pattern of tourist development in the area. Basic tourist facilities are located in the vicinity of Split along the narrow coastal belt which is under strong pressures in terms of spatial limitations. The land of the coastal belt, within 700-800 meters of the shore is almost completely occupied by settlements and domestic dwellings. The industrial zones are characterized by wide heterogeneity of basic industry and occupancy of a disproportionate area of land in relation to its needs.

As housing, industry and other urban activities have tended to spread onto valuable sites, mostly along the coastline, they have diminished the opportunities for the construction of large tourist complexes. It should be noted that valuable coastal sites in the vicinity of Split as well as the beaches of Kastela Bay allocated for future tourist development have been considerably reduced in extent in recent years due to demands from other sectors.

In addition to over-exploitation of some natural resources, industrialization and urbanization in Kastela Bay has given rise to numerous ecological problems resulting in stagnation of the tourist sector as a consequence of the decrease in the general quality of life in the area. According to available data the number of domestic and international tourists declined significantly between the 1960s and 1980s. At present an average of 1.5-1.8 million domestic and international tourists per year spend their vacation in the Kastela Bay region (Table 31). However, the majority spend only a few days in transit waiting for connections to the Adriatic islands.

TABLE 31

Registered domestic and foreign visitors in 1989

	Visitors			Overnight stays		
	Domestic	Foreign	Total	Domestic	Foreign	Total
Split	121,500	118,700	240,300	504,200	418,500	929,700
Kastela	27,100	22,200	49,300	162,700	184,500	347,200
Solin	-	-	-	-	-	-
Trogir	35,100	61,700	96,800	166,700	455,500	622,200
TOTAL	183,700	202,600	386,300	833,600	1058,500	1892,100

Generally speaking, tourist accommodation capacity in the region is relatively small considering the potential. In 1989 the bed capacity was around 25700 of which 6500 were in hotels, tourist residences and apartments and the remaining 19200 in camps, private and other accommodation. Although increased in the period between 1965 and 1989, the present accommodation is still insufficient, in proportion to the area (Table 32).

TABLE 32

Registered bed capacities by class of accommodation, 1965 to 1989

	Bed capacity by class				
	Hotels & Tourist Residences	Seaside resorts	Camps	Private	Total
1965	2592	6614	-	5079	14285
1980	3770	5738	1910	10320	21843
1989	6879	4510	2100	12000	25489

Considering the above information it may be concluded that tourism is only a small part of the economy of the Kastela Bay region and is critically constrained by the existing environmental problems. At present, this activity contributes around 4% of the region's total gross domestic product and only 5% to overall employment. According to the main objectives of future development this sector is considered to be one of the most important sectors to which considerable attention should be given. In terms of land use this would mean that vacant or partially built up sites along the coast will be primarily reserved for future tourist development.

2.8.2 Impact of anticipated climatic changes

It is generally recognized that the changing climate conditions and particularly the predicted sea level rise will not have a significant impact on the development of tourism since it will not result in the loss of sites or land considered as suitable for tourist development. The majority of such sites are located very close to the shore, but on relatively high land of elevation around 4m which will be unaffected by a predicted 1m rise in sea level.

In addition the rugged and steep slope of the coast and the erosion resistant substrate of the shoreline means that beach erosion is unlikely. It is anticipated however that future sea level rise will cause the disappearance of small and narrow sandy beaches below the new water line. This will not be a very serious problem since these beaches make up less than 2% of the entire shore line of the Kastela Bay region.

Apart from the direct effects of a sea level rise, a relatively serious problem may be the intrusion of salt water into ground water and the elevation of water tables leading to deterioration of the cultural and historic heritage which is located close to the shoreline or practically on it (Diocletian's Palace, Trogir, and the old centres of settlements such as Kastela). This process will not be the product of the sea level rise alone, but might be accelerated by rising sea level.

It is also expected that the increase in temperature will extend the summer weather conditions and hence extend the tourist season.

2.9 Transport and services

2.9.1 Past trends and present situation

The study area represents a very important traffic crossing point on the Adriatic coast. The roads running along the coast and those leading inland towards Bosnia and central Croatia meet here. Split is the terminal station for two railway networks, from Zagreb and from Vinkovci. The passenger port is the single connecting point for the mid-dalmatian islands with the mainland as well as with other Adriatic towns (Dubrovnik, Bari, Pescara). During the summer there is a liner connection to Venice (Italy) and Corfu, Patras and Igoumenitsa (Greece).

With the exception of heavy traffic in the northwestern bay all other important traffic points are located in the eastern part.

Split airport is about 6 km from Trogir and was constructed on an alluvial plain, about one kilometer inland and about 5 m above sea level. Intensive agriculture was developed there prior to the construction of the airport at the end of sixties. The size of the airport and its equipment make it suitable for all aircraft types to land and take-off. Meteorological conditions are very good: fog is very rare and does not remain long. The airport is protected from winds such that landing is possible under all wind conditions with the exception of storm winds from the south which result in the airport being closed on average once a year.

The old town port is now the passenger port, receiving ferries that connect the mid-Dalmatian islands of Brac, Solta, Vis, Hvar, Korcula and Lastovo with the mainland, as well as trans-Adriatic and long distance passenger liners. A long breakwater stretching east-west protects this port from winds and waves and from most weather conditions. Only short, strong southwest wind events may threaten the safety of ships in the middle of the port. Entering and leaving the port is safe under any meteorological conditions. The port receives passenger liners up to 4000 DWT, but tugs are needed for safe entrance of the bigger liners.

The railway station was built at the beginning of this century and is adjacent to the passenger harbour. There is a bus station for long-distance buses located between the passenger harbour and the railway station. Air terminal and bus stop for urban lines are also in the vicinity. The high concentration of traffic in a relatively narrow area causes a lot of difficulties and traffic jams occur, particularly during the tourist season. The existing access road is very narrow and inappropriate for the present traffic load. At the same time parking places are inadequate to satisfy traffic demands.

The cargo port is in the eastern section of Kastela Bay. It was built at the end of the fifties and in the early sixties prior to which the old town port had served as both the passenger and cargo port. This port is safe under any weather conditions and can receive ships with 10 m maximum draught. In addition to this central cargo port, the ferroalloy factory in Dugi Rat, the two cement works in Kastel Sucurac and Solin, the oil terminal in Solin and the Jugovinil factory have small ports for their own use in transporting raw materials and products. Both the main cargo port and these smaller ports with the exception of that at Dugi Rat are linked to the main railway.

About 2.7 million t of goods are transported to and from this area by maritime transport. Cement, produced here, makes up the bulk of these goods. Even though the capacity of the cargo port exceeds local demand, the volume of goods cannot be increased due to inadequate traffic connections with inland areas. Rail transportation is fairly expensive owing to the steep terrain through which the railways pass. Inadequate roads make road transport difficult. Annual road transport of goods amounts to 3.8 million t and the railroad transport to 3.1 million t.

Local public transportation is exclusively by bus and around 17 million passengers are carried by local bus transport annually. Long-distance transportation is significantly higher during summer when a large number of domestic and foreign tourists come to this area and to the islands. Long-distance road transport carries up to 3 million people during the year. A similar number of passengers are transported by the railway and, rail passenger numbers also increase in summer due mainly to the arrival of domestic tourists to the mid-Dalmatian area and islands.

About 1.2 million passengers are transported by plane to Split annually and again the summer increase is due to direct international flights bringing foreign tourists.

2.9.2 Possible impacts of climatic changes

There are no data available which would make the quantification of the possible impacts of climatic changes on the transport systems of the area feasible. Potential direct and indirect impacts are therefore considered qualitatively.

Split airport will not be directly affected by the anticipated rise in sea level. It may, however, be transferred from its present location since vibrations produced during take-off, are seriously threatening the historic monuments of Trogir, particularly the cathedral.

Meteorological effects have not, up to now been important for the operation of the airport. Higher air temperatures and lower air pressures could be critical during take-off, however, the maximal expected increase of 3.5 °C would not significantly alter the present situation. It is difficult to forecast whether temperature increase and heavier precipitation might cause fog or low cloud, which could affect airport operations. It is assumed that no significant changes will occur, even if climatic changes were to affect the prevailing winds. At present only hurricane force winds from the south, a side wind in relation to the runway are potentially dangerous. It seems unlikely that the frequency of such winds would increase under conditions of climatic change.

Most passengers arriving at the airport are foreign holiday makers. Since a temperature increase may prolong the tourist season, this would result in an increase in such passenger traffic. However, the expected temperature increase in Central and North Europe could make central European lakes and the Baltic Sea more attractive holiday destinations resulting in a loss of tourists in the Mediterranean.

Climatic changes will have no significant implications for the operation of port facilities. A possible rise in sea level of up to half a metre would not endanger ships approaching or using the port facilities, and present quay height is sufficient to prevent flooding. The existing breakwater offers good shelter from winds and waves, even sea conditions which might be expected under future conditions of higher sea level and intensified winds. The northwestern section of the port may face problems in the future since the coastal level is so low that even today, during strong south and southwesterly wind conditions, waves flood the quay. A future sea level increase of 50 cm would flood this area of the port.

Anticipated climatic changes will not directly affect maritime transportation but indirect impacts are expected as in the case of air traffic. Changes to cargo traffic are possible but these will be more strongly affected by economic and other factors, including the development of transportation linkages inland via railways and roads. The existing railway and road infrastructure will not be directly affected by climatic changes. The volume of traffic is also unlikely to be directly affected by anticipated climatic changes although, inland temperature increases may reduce snow quantities and facilitate the movement of railway traffic in winter.

Increases in precipitation, occurring as a larger number of rainy days, particularly in spring and summer, will result in an increase in the number of traffic accidents. At the beginning of rainy periods the thin film of oil on the road surface when mixed with water, makes them extremely slippery. Existing data show that the number of accidents is higher at the beginning of rains after long dry periods.

Indirect impacts of climatic changes on railway and road traffic will depend on national economic and other measures undertaken in compliance with the international agreements for the reduction of emissions of greenhouse gases. These effects would not be of a purely local character, since they will be determined by national plans and policies.

2.10 Sanitation

2.10.1 Present situation and expected effects of climatic changes

The Jadro spring has been used as a source of fresh water since the third century and its use will continue in the future. The spring originates 27 m above mean sea level and the capacity of the water supply system is 2.5 m^3 sec^{-1}. The water supply network has been in existence since the third century, however most of it was installed after the second world war. The system is generally in good condition and the water from the Jadro spring is of good quality requiring only chlorination as water treatment.

The sewerage system of the region consists of several networks: Split, which is the largest; Solin; Kastela; and, Trogir. The systems are partly separated but partly combined with storm water drainage and there are no treatment plants, all sewage and storm water being directly discharged to the sea. Most of the outfalls are about 50 m from coast, but there are also two longer submarine outfalls. The result of this situation is pollution of the near-shore waters, such that most of the coastal sea water is not suitable for swimming. A new sewerage system in the region is partially completed and partly under construction and includes treatment plants and long submarine outfalls. Once completed this will guarantee good quality coastal waters.

Solid waste has been collected and disposed of on the single land-fill site located outside the town of Split and at a distance of around 2 kilometers from the coast.

The expected climatic changes may influence sanitation in the region. Ecological changes in the watershed area of the Jadro spring as a consequence of climate changes, combined with human activities will alter water quality so that additional water treatment will be necessary.

Sea level rise may result in corrosion of the water supply pipes and as result sea water intrusion could occur with consequent temporary contamination and losses from the system.

Changes in the pattern and intensity of rainfall will severely tax the existing storm water drainage system and the frequency and level of flooding will increase. Sea level rise will reduce the discharge capacity of the sewerage and storm water systems resulting in upstream flooding. Similar negative effects will result from sea water intrusion in the sewerage network under conditions of coastal flooding. Increased risks of flooding of the storm water and sewerage systems will increase the health risks from contaminated flood water.

Increased temperatures will speed up the rate of anaerobic decomposition of the organic mater in the sewage system leading to dangerous levels of methane build-up and risks of explosions. Similar effects will occur on the solid waste disposal site. Increased rainfall will increase leaching of the landfill site with possible pollution of the ground water.

Increased temperature will affect the treatment processes in the waste water treatment plant with possible consequences for effluent quality.

As a result of increased temperature we can expect an increase in all decomposition processes in the environment with accompanying side effects. Higher temperatures will have negative impacts on the sanitation of the urban environment affecting food storage and processing as well as food waste storage, collection, transfer and disposal. This means that sanitary problems and health risks will be increased in houses, the food industry, and service sectors.

It is difficult to predict the magnitude of these effects but they will generally be greater the greater the changes.

2.11 Population and settlement pattern

2.11.1 Past trends and present situation

2.11.1.1 Population growth

The area of the Kastela Bay coastal region is a small segment of the wider Split region. The boundaries of the study area are almost the same as the administrative borders defining the four coastal municipalities of Trogir, Kastela, Solin, Split. Although comparatively small in area (less than 2% of Croatian territory) the total population of approximately 284.8 thousand in 1991, represented 5.6% of the total population of Croatia (Table 33).

TABLE 33

Size of the population and population change between 1948 and 1991
(Source: Statistical abstract for Croatia, 1988. Figures for 1991 are mid-year estimates)

	1948	1953	1961	1971	1981	1991
Pop'n (000's)	114.6	127.8	151.9	203.5	255.7	284.8
% of Pop'n of Croatia*	3.03	3.25	3.65	4.6	5.56	
Growth rate in Kastela Bay (%)	2.18	2.15	2.9	2.28	2.31	1.08
Growth rate in Croatia (%)	0.81	0.69	0.62	0.39	0.59	

* The area of the Bay represents 1.98% of the total area of the Republic of Croatia.

A continuing increase in total population in the region has been a demographic feature in the recent past. As shown in Table 33, the total population increased 2.5 times in the period between 1948 and 1991. Rapid population growth was particularly apparent in the thirty three year period between 1953 and 1981. During that time the region's population grew from approximately 114 thousand to 255 thousand - an average annual growth rate of 2.31% . It is important to note that this growth rate was much higher than the national population growth rate of 0.59% over the same period.

The rapid growth, as well as the difference in growth rates between the Kastela Bay region and the whole of Croatia can be attributed to the net rural to urban migration which was typical for this period of intensive industrialization and urbanization in the country as a whole.

Table 33 shows that the region has been experiencing a slightly slower, and decreasing rate of population growth over the last ten-year period 1981-1991. The notable differences in growth rates between the 1948-1971 and 1981-1991 periods suggests that the process of population growth in the region is gradually declining.

The overall increase in total population has been influenced by positive values of both components of growth, namely migration and natural population increase. It should be noted that the process of demographic mobility (migration) has been more important than the natural population growth. Table 34 indicates that the net in-migration rates throughout the twenty year period 1961-1981 were continuously higher then the rates of natural population increase. In other words, inter-regional and intra-regional migration have been the major causes of rapid population growth in this region.

In contrast, the moderate and slightly falling rate of natural population growth, is indicative of the demographic transition process in which birth rates drop considerably (mainly due to changed family and social-economic attitudes, as well as to higher rates of industrialization and urbanization) while death rates continue to be steady and relatively low.

TABLE 34

Intensity of migration flows during twenty-year period 1961-1981

	1961-1971	1971-1981
Population size at first census (in 000's)	151.9	203.5
Natural Population increase (in 000's)	18.3	24.8
Population size at second census (in 000's)	203.5	255.7
Immigration (in 000's)	33.1	27.4
Average annual growth rate (%) due to natural increase	1.03	1.08
Percentage of total population growth	36.69	47.56
Average annual migration rate (%)	1.87	1.19
Percentage of total population growth rate	64.31	52.44

2.11.1.2 Distribution of population

A growing concentration of people and activities in coastal areas and increasing disparity between the coast and inland areas has been the main characteristics of past development patterns. At present over 90 % of the total population (267,700) of the region is concentrated in the narrow coastal belt, as a consequence of favourable natural conditions, a long urban tradition and development policies including construction of large industrial plants which have favoured the coastal cities.

Data showing the distribution of population (Table 35), and the growth rates for coastal and inland areas indicate that a typical "developed, urban agglomeration - undeveloped, rural hinterland" disparity is found in this region.

TABLE 35

Distribution of population (in '000) over the region
(1991 figures are mid-year estimates, figures for coastal zone include islands)

	1948	1961	1971	1981	1991	1991/1948
Coastal population	86.3	125.2	179.9	237.8	267.7	310
Inland population	28.3	26.7	23.6	17.9	17.1	60
Total	114.6	151.9	203.5	255.7	284.8	248
Coastal population (%)	75.3	82.4	88.4	93.0	94.0	
Inland population (%)	24.7	17.5	11.6	7.0	6.0	

The concentration of population in the narrow coastal belt may be attributed to the growth of the urban centres of Split, Solin, Kastela and Trogir. Assuming that the rates of natural population growth in these cities and their urban surroundings are slightly lower than those in rural hinterland areas, then the very high increase of coastal cities throughout the 1948-1981 period is the effect of in-migration flows (Approximately 65-70% of total population growth).

The largest portion of this influx comes from the hinterland, where the population has shown a continuing decline in total number over the past 30 years. The hinterland of the Kastela Bay region is characterized by a comparative scarcity of natural resources, lower level of economic development and transport isolation. These are the major "push" factors of intra-regional migrations which have been augmented by "pull" factors such as the attraction of the coastal area for living and greater employment opportunities in developed urban centres along the coast.

Apart from the intra-regional migration processes, migrants from other undeveloped, inland parts of Dalmatia and further away, have also moved to the coastal cities under the influence of the "pull' factors of job opportunities, possibilities for investments and better living conditions.

As a consequence of a high population growth rate, the narrow coastal belt, has become one of the most densely populated areas of Croatia (Table 36) with numerous environmental problems. The town of Split, as the economic centre of Dalmatia, and its surrounding settlements form a relatively highly urbanized, coastal agglomeration. Construction is concentrated along the narrow coastal strip, with almost all available coastal flatland developed to support local inhabitants. Land for agricultural production, as well as for recreational purposes has been reduced considerably in the last twenty-year period as a result of this industrialization and urbanization.

Due to the absence of appropriate measures based on the principles of sustainable development, increased congestion of the narrow coastal belt has resulted in the saturation of a number of sectors (primarily tourism) and a decrease in the general quality of life. Conflicts between different land uses are quite substantial, since agricultural, housing and polluted industrial areas, as well as tourist and other recreational facilities are located in a relatively small and confined space, between the sea and inland mountain ranges. The flat or gently sloped land which is built up or occupied by various settlements and infrastructure, as well as the over exploitation of the available natural resources indicates that the whole coastal belt is approaching the limits of growth and development.

The scope of this report does not encompass the determination of optimal population density for the area. However, the possibility must be taken into account that this area will become overpopulated if past trends continue.

TABLE 36

Population densities and distribution in the Kastela Bay Region (Figures for the coastal zone include islands)

	Area (km^2)	**Population density** (km^{-2})		
		1948	**1991**	**1991/1948**
Coastal zone	359	240	745	310
Hinterland	798	35	21	60
Kastela Bay Region	1157	99	246	248

2.11.2 Scenarios of future population changes

The principal objective of this section is to provide theoretical projections for the population of Kastela Bay by the year 2030, as well as to consider some basic parameters resulting from these projections.

2.11.2.1 Present trends scenario

This scenario (Table 37) is based on a persistence of the existing processes which are deemed powerful enough to influence the future development of population, as well as on the hypothesis that no measures of global development policy will be applied. This option has the following main characteristics:

- the relatively high rates of past population growth persist;
- population continues to concentrate in the coastal belt;
- the proportion of the population in the hinterland continues to decrease (Table 38);
- a continuously high immigration pressure on the coastal belt persists; and,
- state of environment of the coastal area continues to deteriorate.

TABLE 37

Population projection (in 000s) for the year 2030 based on present trends
(CBR = crude birth rate: CDR = crude death rate)

	1991	2001	2015	2025	2030
Total	284.8	337.4	431.2	505.0	545.4
Male	140.3	169.2	218.8	256.7	277.1
Female	144.5	168.2	212.4	248.3	268.3

Annual rates of change	1991-1996	1996-2001	2001-2006	2006-2011	2011-2016	2016-2021	2021-2031
CBR per 1000	15.9	15.7	15.2	14.7	14.8	14.5	14.7
CDR per 1000	8.6	8.6	8.6	9.0	9.2	9.3	9.3
Rate of natural increase (%)	0.7	0.7	0.7	0.6	0.6	0.5	0.5
Growth rate (%)	1.7	1.7	1.7	1.6	1.6	1.6	1.6

TABLE 38

Regional population breakdown (in '000) by area to the year 2030

Year	Coastal area	Hinterland
1991	267.7	17.1
2001	311.8	25.6
2011	376.1	21.6
2025	485.2	19.7
2030	527.1	18.3

2.11.2.2 Moderate growth scenario

Bearing in mind the increased congestion of the coastal strip as well as prevailing social-economic conditions in the other parts of the region, a "moderate" option of the future population growth has been developed (Table 39). This option anticipates a gradual change in the existing trends. It is based on the effects of implemented policy measures which may result in a decrease in population growth rate and in a somewhat different distribution of pópulation within the region. The aim of this option is to provide insights into what might be expected by the year 2030. This "moderate growth" option has the following characteristics:

- a decreased population growth rate based on the current decline in the growth rate over the 1981-1991 period;
- creation of a development axis in the hinterland of the region comprised of small urban centres intended to bring about a re-distribution of population and lessen the pressure on the coastal area; and
- gradual decrease in migration within the region owing to opportunities being opened up through the development of neighboring regions;

As far as the vital components of the population is concerned this option is based on the following assumptions:

- under the influence of the active population policy measures the fertility rate, which is at present considerably reduced (less than two children per mother), will slightly increase particularly during the later decades of the projected period; and
- on the other hand, life expectancy at birth (nowadays close to 70 years), will remain unchanged.

TABLE 39

Population projection (in 000 for the year 2030) - moderate growth scenario

	1991	2001	2015	2025	2030
Total	284.8	318.9	364.1	394.3	404.2
Male	140.3	158.7	182.7	198.4	203.8
Female	144.5	160.2	181.4	195.9	200.4
Age 0-14	59.5	64.9	74.7	83.6	88.1
Age 15-64	198.6	214.7	236.5	245.7	253.1
Age 65+	26.6	39.3	52.9	64.9	63.0

Annual rates of change	1991-1996	1996-2001	2001-2006	2006-2011	2011-2016	2016-2021	2021-2030
CBR per 1000	15.0	14.6	14.2	14.2	14.4	14.7	15.0
CDR per 1000	8.7	8.8	9.1	9.8	10.2	10.4	11.5
Rate of natural increase (%)	0.6	0.6	0.5	0.4	0.4	0.4	0.3
Growth rate (%)	1.2	1.1	1.0	0.9	0.8	0.8	0.6

As indicated in Table 39 the "moderate growth" scenario is based on moderate and slightly decreasing growth rates which are lower than those of the 1953-1981 period. As a consequence the resulting population figures in 2030 are far more acceptable than those which might be expected if the existing trends continue.

The spatial distribution of population must not be disregarded. Based on the crude subdivision into two topographic entities, differing considerably in the nature of their socio-economic development (the coastal and hinterland area), the population could reach the distribution shown in Table 40.

On the basis of these moderate growth assumptions the proportion of the coastal population would slightly decrease compared to the population of the hinterland area. Such a re-distribution would stem from the implementation of development policies which favour and stimulate decentralization within the region. Such a policy might prevent the population drain from inland areas and consequently alleviate population pressures on the coast.

TABLE 40

Regional population breakdown (in '000) by area under a scenario of moderate growth

	Coastal		Hinterland	
Year	No in 000's	%	No in 000's	%
1991	267.7	94	17.1	6
2001	296.0	93	22.3	7
2011	318.0	91	31.6	9
2025	347.0	88	47.3	12
2031	351.0	87	53.2	13

2.11.3 Impact of expected climate changes on human demographic and settlement patterns

Generally speaking, it is not anticipated that the expected climatic changes would have significant effects on the populations growth, since the time scale on which the changes are expected to occur, will enable the human population to adapt to them (Coastal Zone '91). The values of expected climatic changes in the Kastela Bay region show that the area will still remain within the limits normally taken as suitable for human habitation.

However, a predicted rise in temperature is likely to increase personal discomfort and affect the use of air conditioning units which will necessitate the use of more energy to maintain levels of comfortable temperature within buildings.

From the perspective of population growth and distribution over the Kastela Bay region the indirect consequences of climate changes are likely to be more important. These effects include the implications of sea level rise on future development in the low-lands of the region, which may in turn, have profound impacts on the distribution of the human population. It should be noted that a sea level rise of ca 30 cm by the year 2030 would be of some, but not formidable consequences. The main impacts will be financial and economic necessitating investment in some shore protection measures including the maintenance of drainage and sewerage systems which are likely to have slightly increased maintenance costs.

The expected climate change and particularly the predicted sea level rise which might occur by the end of the next century would be quite different in terms of possible consequences in the Kastela Bay region. Assuming a relative sea level rise of 100 cm by the year 2100, the major impacts on the area may be briefly outlined as follows:

- permanent coastal inundation (area around Pantana spring and the Zrnovnica River), as well as flooding which can be expected to occur particularly along the narrow low-lying areas where the coastal profile is flat or gently sloping and with the barrier elevation less then 2 meters above existing mean sea level. This will not only affect parts of existing residential areas and valuable cultural heritage adjacent to the shore, but will also increase the vulnerability of development in those areas. The loss of unprotected low-lying land can be expected unless adequate protective measures are taken. In order to prevent such problems, existing sea walls and other artificial coastal protection structures will have to be elevated. However, it should be pointed out that this option is costly, primarily consisting of engineering work to erect physical barriers against sea level rise;

- equally important is the fact that the sea level rise could cause intrusion of saline water upstream into the rivers Jadro and Zrnovnica, decreasing the drop and flow of those rivers. This will necessitate re-assessment of the implications of high water levels for flood control, as well as to adopting measures which will protect the vulnerable areas which are not expected to be extensive;

- the sea level rise may also cause intrusion of saline water into ground water and a rise in the level of the water table. These changes may alter the quality of agricultural land adjacent to the water table and alter the habitats and biota. Within the Kastela Bay region this will not be a serious problem since the most valuable agricultural land is located either on high land or relatively far enough away to be naturally protected from sea level rise; and

- the expected sea level rise in Kastela Bay is bound to have adverse impacts on storm water drainage, sewerage disposal and other infrastructure facilities in the urban area which are likely to have increased maintenance coast. Due to problems concerning the rise in water level and penetration of the sea into the coastal zone, improved infrastructure facilities and drainage for the population of low-lying areas will be necessary. At present the implications of future sea level rise are not taken into consideration either in master plans for development, or, in various capital projects involving the sewerage and water supply systems of Kastela Bay.

3. SYNTHESIS OF FINDINGS

3.1 Past trends and present situation

3.1.1 Climate conditions

Three decades of meteorological monitoring (atmospheric pressure, air temperature, relative humidity, wind) and oceanographic data (sea level and sea surface temperature) show that mean monthly temperatures range from 7.6 °C in January to 25.5 °C in July. The annual mean maximum is 28.8 °C and the minimum 20.0 °C. Average annual precipitation is 820 mm with a minimum of 613 and maximum of 1101 mm.

In general these data display no significant trends, although atmospheric pressure and relative humidity display an increase and decrease respectively. The present data are insufficient to determine whether these are trends, or merely a reflection of longer-term variability. Rainfall data from two localities within Kastela Bay demonstrate that existing differences over very short distances are greater than the changes predicted to occur as a consequence of global warming.

3.1.2 Lithosphere

The wide spatial variability in natural factors of soil formation (geology, geomorphology, hydrology and living organisms) combined with a long history of intense use by man has resulted in great variability in soil types and distribution in the area.

Geologically the Kastela Bay area is composed of marine limestones and dolomites, Palaeocene flysch sediments and quaternary sediments. In this area are found: lithosols, calco-melanosols, calco-cambisols and Terra Rosa soils on the mesozoic sediments; calcaric-regosols and calco-rendzinas on the flysch; and, anthropogenic soils. The basic factors limiting reforestation of the natural soils based on limestones are soil depth, low water retention capacity, slope and stoniness. Limiting factors for agricultural use of the anthropogenic soils are physiographic and lithological. The abandoned terrace soils are limited by low water retention capacity, physical degradation and erosion. The small plot size, fragmentation of holdings, slope and limited possibilities for use of agricultural machinery all limit production.

The arable, agricultural soils on typical Adriatic coastal flat lands are highly productive. However, a large proportion of these areas are densely populated and present trends are for further expansion of population and transformation to non-agricultural use. In other areas chemical degradation of the soils resulting from over-use of pesticides and fertilizers is a problem.

3.1.3 Hydrosphere

Kastela Bay is relatively well supplied with freshwater resources. The average annual precipitation is 820 mm. Seasonal variation is typical for the Mediterranean with a wet winter and dry summer. There are two rivers the Jadro and Zrnovnica with watershed areas extending outside the study area. These rivers are typical karst springs. As a result of the flysch formations a barrier runs parallel to the coast behind which is formed an inland aquifer, having a watershed area of 260 km^2 in the hinterland. The average annual discharge of the Jadro river is 9.5 m^3 sec^{-1} with an average summer minimum discharge of 4.0 m^3 sec^{-1} and an average winter maximum of 66 m^3 sec^{-1}. Similar variations in seasonal flows are shown by the Zrnovnica but the average annual flow is much lower, around 1 m^3 sec^{-1}.

The local aquifer for Kastela Bay is small and in contact with the sea. The annual discharge rate is 101 m^3 via diffuse seepage and submarine springs. The region is highly developed, such that the natural processes in Kastela Bay have less influence on the local water budget than do human activities. Sewerage outputs to the bay have more influence than natural local freshwater sources, particularly during the summer when sewage discharge is around 1.5 m^3 sec^{-1}.

3.1.3.1 Socio-economic consequences of changes in water resources

Sea level rise is an on-going process that has occurred over the last century as a result of which many old buildings and historic sites have been flooded. With increased sea level rise, flooding will be intensified both directly by the sea and indirectly by changes in water tables. Other changes in water resources will not have significant effects in the socio-economic sectors.

3.1.4 Atmosphere

At present some of the air pollutants exceed the upper permissible limits. The concentrations of settling particles exceed these by five times and airborne particles by a factor of two.

More than ten years of data on SO_2, smoke, settling and airborne particles are available which demonstrate that concentrations depend on the local sources, wind and thermal conditions. Wind contributes to the lowering of air pollution through dispersion. It was not possible to conclude whether the strong year to year variations are due to changes in the sources or to varying climatic conditions.

3.1.5 Natural Ecosystems

3.1.5.1 Terrestrial Ecosystems

The initial post pleistocene vegetation cover consisted mainly of evergreen forest, dominated by holm oak. The Kozjak mountain ridge and higher Mosor slopes were covered by sub-mediterranean deciduous forest. Present vegetation cover is almost entirely the result of a millennium of anthropogenic influence. The coastal plain has become almost completely covered with habitation, and agricultural areas. Steeper slopes and mountain sides support the remains of old groves, and secondary vegetation of scrub or have completely denuded surfaces.

3.1.5.2 Freshwater ecosystems

There are two rivers in the study area, the Jadro and Zrnovnica. Both are typical karst springs and their water flow depends on precipitation in the immediate hinterland. The minimum water flow has been increased by construction of several dams on the river Cetina indicating that there is a common system of underground channels connecting these systems.

Along their upper course (500 meters from their sources) the banks of both rivers are natural while for the remainder of their course the banks are artificial. Houses and industries have been built along the rivers which have become recipients of waste waters. Water quality decreases from source to river mouth.

The Jadro is famous for its endemic trout species which is endangered due to pollution in the lower reaches and poaching in the headwaters. The Zrnovnica estuary which was an important feeding ground for migratory birds some 20 years ago has been devastated and is no longer visited by birds.

3.1.5.3 Marine ecosystems

It is not possible to estimate the impacts of expected changes on the marine ecosystems of Kastela Bay despite the availability of some 50 years of data. This is due to the considerable changes which have occurred to primary productivity over the last 30 years as a consequence of pollution, primarily from urban and industrial waste water. Primary production in Kastela Bay has increased and the phytoplankton community has been changed. Red tides caused by blooms of dinoflagellate species have occurred since 1980 and this is now a regular phenomenon in summer when the water temperature exceeds 20 ° C. Changes in the zooplankton as well as bacterial populations have also been noted.

The benthic communities have been severely affected by pollution and significant changes have occurred at the species and community level with green algae dominating in a number of areas.

3.1.6 Managed Ecosystems

3.1.6.1 Agriculture

The total area covers around 16,000 ha of which: natural forest soils cover 450 ha; anthropogenic, mainly terraced soils cover 10,000 ha; 3,500 ha are abandoned terraced soils; and 1,900 ha has been deforested for urban development of Split, the airport and industrial developments in Kastela and Solin. The area between the coast and the steep slopes of the foothills (5,500 ha) are covered by high quality anthropogenic soils. The greater part of this area is heavily populated and current trends indicate a further expansion and transformation of valuable agricultural land to non-agricultural use including housing, industry and tourism.

Many of the present crops were grown in ancient times and include vines, olives and cereals. Dryland farming was and is the predominant practice in most areas. The main irrigated crops include citrus, kiwi and a wide variety of vegetables and flowers produced under controlled environments (greenhouses) and in the open.

Problems of agricultural development include: the private ownership of land in Kastela Bay resulting in small and fragmented agricultural holdings; water shortages; and low rainfall in the main growing season of May - September.

3.1.6.2 Fisheries

The area of Kastela Bay including the Brac and Split Channels are not very important from a commercial fisheries standpoint. Pollution of the bay over the past decades has resulted in prohibition of any fishing activity. Fishing is permitted only in the channels and then with closed seasons from time to time. Quantities of demersal fish are low and quality considerably impaired compared with 30 years ago when the catch was estimated at 600 kg km^{-2}. This decline has been primarily attributed to over-fishing and pollution by urban and industrial effluents. Small pelagic fish catch (sardines and anchovy) varies around 1500 t yr^{-1} of which between 300 and 500 tonnes are caught in the bay. Some 15 years ago *Sardinella aurita* was first captured in the bay. A normal inhabitant of waters off the North African coast catches of this species increase year by year.

3.1.6.3 Aquaculture

There are presently no marine fish farms nor plans for their construction in the area due to the current levels of pollution. Freshwater aquaculture (rainbow trout) farms are located at the Pantana delta and in the Jadro river. In the initial stages fish are cultured in the Jadro hatchery and then transferred to Pantana. Total annual production is around 400 tonnes.

3.1.6.4 Sylviculture

There is no forest on the study area.

3.1.7 Industry and Energy

Industry in the area includes: shipbuilding, chemical plants, cement works, steel production and production of alloys, cloth making, footwear and the beverage industries, and employs 38,500 people. The energy consumption for the area totals 1,026,000 MW yr^{-1} of electricity; 235,000 tonnes yr^{-1} of coal; 178,500 t yr^{-1} of fuel oil; and 17,000 t yr^{-1} of liquified gas.

3.1.8 Tourism

Tourism is not a major economic activity in Kastela Bay, although the area has high potential as one of the most attractive destinations in Croatia.

At present coastal tourism is the main pattern of tourist development in the region with tourist infrastructure located in a narrow coastal belt that is already under strong pressures for space. Practically all coastal land is developed, mostly by settlements and industry.

The capacity of tourist accommodation in the region is relatively small. At present there are around 25,700 beds of which 6,500 are in hotels and guest houses, the remaining 19,200 being in camps, private and other accommodation. The number of visitors has declined over the last twenty years. The average number of overnight stays over this period has been between 1.5 and 2 million.

3.1.9 Transport and services

The study area represents a very important traffic crossing point on the Adriatic coast. Roads run along the coast and inland, while the town of Split is the terminal station for two rail lines into the hinterland. The passenger port is the single connecting point for the mid-Adriatic islands to the mainland, as well as with other Adriatic towns in Croatia, Italy and Greece. Split airport is located towards the town of Trogir.

3.1.10 Sanitation

The Jadro has been used as a water supply since the third century and its use will continue in the future. The spring originates 27 m above mean sea level and the capacity of the water supply system is 2.5 m^3 sec^{-1}. The water is of good quality. The sewage system is incomplete, with some direct discharge to the river systems and all sewage presently passes to the sea without treatment. A single solid waste disposal site is located within the area at a distance of around 2 kilometers from the coast.

3.1.11 Population and settlement pattern

The Kastela Bay region has been experiencing intense population growth since the early 1950's. During the period 1953-1981 the regions population grew from 144,000 to 2,500,000 (2.31% per annum). This rapid growth can be attributed to a net rural to urban migration resulting from the process of industrialization and urbanization throughout Croatia.

Nowadays around 90% of the population (267,000 - 1991) is concentrated along a narrow coastal belt as a result of favourable natural conditions and past development policies which have favoured coastal settlements such as Split, Solin, Kastela and Trogir.

3.2 Expected effects and most vulnerable systems and activities

3.2.1 Climate conditions

The predicted increase in rainfall is smaller than existing spatial and inter-annual variations, thus changes in this parameter are not expected to result in significant overall effects. Predicted changes in temperature are also considered to have little effect. One of the important characteristics of the climate prevailing in the Adriatic is the passage of mid-latitude cyclones and anticyclonic conditions over the area. Climate conditions (wind, rainfall, air temperature) are thus determined as an average of all such events. It is important to know whether there will be any changes in the paths of cyclonic events due to climate change. Either a decrease or an increase in the frequency of these transient atmospheric perturbations could appreciably affect wind, rainfall and temperature, and present data are inadequate to answer this question.

3.2.2 Lithosphere

With the predicted increase in air temperature and a decrease in precipitation at least during the autumn it is anticipated that potential evapotranspiration will increase from 511 to 536 mm in the period May to September and that the soil moisture deficit will increase from 375 to 394 mm.

Physical degradation and soil erosion through increased strength of rainfall events will occur on steep slopes with impermeable flysch substrates. Total content and quality of soil humus will not change in these soils because the dominant form of humus is resistant to decomposition processes.

With the predicted rise in sea level, alluvial soils in the Jadro and Zrnovnica estuaries will be exposed to salinisation and rising ground water; saline marshlands near Pantana spring will be flooded. Higher sea level will not cause extensive coastal erosion since much of the coastline is already artificial.

Accumulation of nutrients and pesticides due to intensive use of fertilizers and deposition of airborne contaminants will continue to be a problem and may increase due to reduced leaching under the new climate conditions. Transfer of such contaminants to the sea through soil erosion is possible.

3.2.3 Hydrosphere

Three elements of climate change will influence local water resources; increasing temperature; increasing precipitation; and, sea level rise.

Increased air temperature will increase the sea surface temperature and hence enhance surface evaporation. On land, evapotranspiration will also increase and relative humidity is expected to increase throughout the year. It is not possible to predict accurately the effects of these changes on the water balance. Increased evaporation and evapotranspiration losses from the system and increased precipitation inputs may possibly balance resulting in no significant change to surface run-off. There will be no significant change in river and groundwater flows and the freshwater table.

Sea level rise will have a significant influence on local water resources resulting in movements of salt water upwards and landward. This will have an effect on coastal aquifers, coastal springs and river estuaries. Aquifers will change position and be reduced in capacity; coastal springs will be relocated at higher elevations and flow rates will be altered; estuaries will suffer saline intrusion further inland with consequent changes to river bank aquifers. In addition upward and landward movement of the sea will result in contamination of freshwater resources and flooding.

The expected effects on the biological community of hydrological changes are very difficult to predict because of the complexity of the interacting factors and the extent of human interference including urbanization and other activities on the land surface. The Jadro, Zrnovnica and Pantana are important freshwater resources for this area but their watershed is not unfortunately included in the area covered by the present study.

Socio-economic consequences of changes in water resources

Sea level rise will result in flooding of estuaries, natural and artificial coastlines. Estuaries will experience increased effects from bank overtopping and upstream flooding which will occur in the courses of the Jadro and Zrnovnica rivers. Flooding along natural coastlines will not be important since the coast is largely steep and rocky so effects are localized in the coastal belt 0.5-1 m wide. The strongest effects will be felt along developed coastlines and will include effects on coastal services, infrastructure and construction. Present coastal service infrastructure in low-lying areas will become unsuitable in the future.

Infrastructure such as sewers, water supply, electricity and other services could be flooded and corrosion of pipes and intrusion of seawater into pipes and sewage systems will occur.

With a rise in the water table the foundations and basements of coastal buildings will be flooded causing destabilisation of these structures. These effects will be particularly serious for the older buildings already at low elevations due to past sea level rise such as those in the old town of Trogir, the old centre of Kastela and Diocletian's Palace in Split.

Sea level rise will influence all water sewage discharge to the sea as a result of intrusion into the pipes causing changes to discharge rates and increases in water level in the sewage network with the possibility of upstream sewage flooding.

Sea level rise will result in salinisation of freshwater resources and indirectly change their availability. Pollution with effluents and increased water temperature will reduce the oxygen capacity since it will increase the speed of decomposition. Together with chemical pollution this will adversely affect biological processes. Unfortunately man-made pollution is a dominant factor in the area and will mask climatological effects.

A sea level rise of 30 cm would result in direct flooding of some 15 Ha around Pantana spring and 10 Ha each in the Jadro and Zrnovnica estuaries will be affected. In contrast a rise of 60 cm would flood: the shipyard; the western portion of the port of Split; the old centres of Split, Trogir and Kastela; all 6 existing marinas; and, a coastal belt of approximately 6 km length to a distance of 15m inland.

3.2.4 Atmosphere

The most important factor affecting air pollution in the Kastela Bay area is wind. Therefore any appreciable alteration to the wind regime will strongly alter air pollution levels, the possible increases in wind regime will lower the general level of air pollution. In contrast the thermal regime is less important in determining the level of air pollution.

3.2.5 Natural Ecosystems

3.2.5.1 Terrestrial Ecosystems

The study area is under high rates of impact from different human activities which are expected to continue to be more important than the impacts of future climate change and sea level rise.

The predicted climate changes may affect the natural vegetation, increasing the area of sub-mediterranean vegetation. Significant effects on animal life are not expected.

3.2.5.2 Freshwater ecosystems

The anticipated climate changes will not directly affect the Jadro and Zrnovnica rivers. Sea level rise will presumably cause significant changes in river estuaries. A large part of the Zrnovnica estuary will be flooded. Seawater will penetrate deep into the Jadro river since its lowest flows are very small and the saltwater wedge can be expected to intrude along the river bed to around 500 meters further inland. This will change the present freshwater ecosystem to a saline system and similar changes are expected in the mouth of the Zrnovnica.

3.2.5.3 Marine ecosystem

It may be assumed that the present pollution by urban and industrial waste waters will be considerably decreased in a comparatively short time through construction of an appropriate sewerage system for the collection, treatment and submarine disposal of domestic effluent.

The global increase in surface air temperature will cause an increase in the sea surface temperature although this may not be as great. These changes are likely to intensify the daily wind patterns of on-shore and off-shore winds in the summer season and on a synoptic time scale. This will intensify surface currents and increase vertical mixing in the bay and in the channels, decreasing the salinity gradient and increasing nutrient exchange between the bottom and surface waters.

Primary production will therefore be increased but this effect will be countered by the reduction in nutrient inputs from waste waters. Red tides will consequently be reduced in frequency. Although changes in primary production are likely to occur it is impossible to predict how these will be reflected further up the food chain and in particular affect the availability of important fish species.

3.2.6 <u>Managed Ecosystems</u>

3.2.6.1 Agriculture

The predicted increase in air temperature will be generally favourable for agricultural crop production extending the growing period. Decreased soil moisture will however further decrease the agricultural potential and the extent of this reduction will depend on the differing soil properties particularly the soil water retention capacity.

3.2.6.2 Fisheries

Over-fishing and pollution are two major factors which will continue to affect demersal fish stocks for the foreseeable future. It seems improbable that anticipated climate changes (increasing temperature and precipitation) will have any direct effect on fish stocks. The changes in primary production and phytoplankton population, as well as changes in the food chains could have some indirect effect, but it is impossible on the basis of present knowledge to predict these changes.

Pelagic species such as the sardines and anchovy could be affected by temperature increases, approaching coastal areas earlier in the year and remaining longer than under present conditions. This would lengthen the traditional fishing season which is based on the use of nets under artificial light on moon-less nights.

Changes in water mass circulation could also alter migration of some fish species but such impacts cannot be predicted at the present time.

3.2.6.3 Aquaculture

Anticipated temperature rise will not significantly affect the present temperature regime of the Jadro river and Pantana spring thus no direct impacts on present activities are anticipated. Temperature increase would have an indirect effect on the Jadro hatchery since higher temperature would accelerate decomposition of organic matter which will decrease oxygen concentration in the river water.

The anticipated sea level rise may adversely affect the Pantana hatchery since part of the area may be flooded. Sea level rise will significantly affect the spring itself and salinity will increase.

3.2.7 Industry and Energy

Existing industry should be re-structured regardless of expected climate changes since it is the greatest energy consumer in the area and at the same time a significant source of pollution within the bay. Industrial development should concentrate on light industry, the service sector, agriculture and tourism.

Temperature increase may favour the consumption of soft drinks and consequently increase demands for the products of the existing soft drink and beer industries. It is likely to affect cloth production and the footwear industry. Sea level rise is likely to directly affect the shipyards, chemical plants and the ferro-alloy plant.

The temperature increase will reduce the need for heating in winter but increase demand for air-conditioning in the summer hence changing the seasonal patterns of demand for different energy sources. The increased demand for air-conditioning may encourage the establishment of air-conditioning manufacture and servicing in the area.

3.2.8 Tourism

It is recognised that the changing climate conditions and particularly the impact of sea level rise will not have a major impact on tourism development in the region, since it will not result in the loss of sites or land considered as suitable tourist areas. In addition the rugged relief and erosion resistant substrate of the shore-line means that beach loss within the area in unlikely. However accelerated deterioration of coastal infrastructure will occur and improved drainage for the population of low-lying areas will be necessary.

The increase in temperature and changed weather conditions are unlikely to alter the level of human comfort. However the increase in temperature may extend the summer season which would be a positive benefit.

3.2.9 Transport and services

The airport will not be directly affected by the anticipated rise in sea level nor by the predicted meteorological changes. Anticipated climate changes may however indirectly affect transportation via measures that may be introduced to reduce the emission of greenhouse gases, although such measures would not be introduced at a local level.

Climate changes will have no significant implications for port facilities and navigation. Very serious problems will be created in the western part of the city harbour, where the level of the coast is very low. An increase of 50 cm in sea level would flood this part of the port. Sea level rise will also affect the existing railway in the city of Solin where railway tracks and the bridge crossing the Jadro river are located at low elevations.

Increases in precipitation, manifested as a larger number of rainy days, particularly in spring and summer, will cause an increase in the number of traffic accidents, particularly at the beginning of the rains when the thin film of oil and water makes the roads extremely slippery.

3.2.10 Sanitation

Expected climate changes may influence sanitation in the region through affecting water supply from Jadro spring. Sea level rise will influence the water supply network through corrosion from sea water intrusion into ground water. Corrosion problems in the sewage system may lead to contamination of ground and drinking water supplies. Changes in the pattern and intensity of rainfall will severely tax the existing storm water drainage system and flooding will increase. Increased risks of flooding of the sewerage system will increase the risks from contaminated flood water. The increased water levels in the sewage system will affect the operation of the system and future treatment plants. Increased temperature may speed up the rate of anaerobic decomposition in the sewage system leading to dangerous levels of methane build-up.

3.2.11 Population and settlement pattern

It is not anticipated that the expected climate changes will have any direct effect on human demographic characteristics such as life expectancy at birth, fertility or health. From the perspective of population growth and distribution the indirect consequences of climate change are likely to be more important. These effects include the implications of climate change and sea level rise for agricultural land use, coastal mariculture, infrastructure such as drainage systems and the maintenance of water supply and sewerage services which are likely to have increased maintenance cost.

4. SUGGESTIONS FOR ACTION TO AVOID, MITIGATE AND ADAPT TO THE ANTICIPATED EFFECTS OF CLIMATIC CHANGES

4.1 Climate Conditions

None

4.2 Lithosphere

On the Flysch terrain, re-cultivation of the anthropogenic terraced soils should be carried out only with adequate soil conservation actions. Soils should be protected from erosion by surface run-off and stream flows should be controlled.

4.3 Hydrosphere

The characteristics of the Kastela Bay area have been constantly modified by man and will continue to change in the future. Human influence is likely to be dominant except in the case of sea level rise effects. As a result it will be necessary to study changes in the macroeconomics of water resources.

Appropriate authorities should take into consideration these changes and through the planning process suggest appropriate administrative and construction measures to mitigate the impacts of vertical changes in water table and saline intrusion landward and up-river.

Possible strategies and tools for achieving flood hazard reduction are:

NON STRUCTURAL

A. *Modify susceptibility to flood damage and disruption*

1. Floodplain regulations, state and local:
   - zoning;
   - subdivision regulations;
   - building codes;
   - housing codes;
   - sanitary and well codes; and
   - other regulatory tools.
2. Development and redevelopment policies:
   - design and location of services and utilities;
   - land-right acquisition and coastal belt space use;
   - redevelopment and renewal; and
   - permanent evacuation.
3. Disaster preparedness and response planning especially for short term extreme sea level rise.
4. Flood prevention.
5. Flood forecasting and warning system.

B. Modify the impact of flooding on individuals and the community

1. Information and education.
2. Flood insurance.
3. Tax adjustments.
4. Flood emergency measures.
5. Post flood recovery.

STRUCTURAL

C. Modify flooding

1. Decrease level of flooding through:
   - Increasing the level of the coast;
   - Prevent sea intrusion landward;
   - Reduce water level inland; and
   - Levees and flood walls, etc.

D. Decrease susceptibility to flood damage

- keep water from structures and infrastructures;
- keep water out of structures;
- keep structures away from water; and
- use less sensitive materials and constructions, etc.

As may be seen different measures can be used for mitigating the negative effects on coastal services, infrastructure and structures, as well as generally on water resources. The best solution or combination of measures for this particular case is difficult to state without additional study. Evaluation of major policies and programmes and definition of the economic rationale for flood hazard mitigation have to include: research relating to warning and emergency response; improved data and information base; and, research relating to the effectiveness of mitigation/preparedness and recovery/restoration measures.

4.4 Atmosphere

Improve technology and use filters.

4.5 Natural Ecosystems

4.5.1 Terrestrial Ecosystems

The impact of climate changes on the terrestrial ecosystems cannot be avoided.

4.5.2 Freshwater Ecosystems

There is no reason to initiate any action to avoid or mitigate the expected negative impacts of climate change. Measures to eliminate all types of pollution (domestic and industrial waste water, run-off) of both rivers should be planned and implemented, in order to reduce oxygen depletion due to biodegradation of organic waste matter.

4.5.3 Marine ecosystems

Since the ecosystem is in urgent need of restoration no suggested actions to counter the impacts of climate change can be made. Construction of the proposed sewerage system would have beneficial effects on the marine ecosystems of the bay.

4.6 Managed Ecosystems

4.6.1 Agriculture

Agricultural development should be geared towards enhanced winter vegetable production. The suitability of the Kastela Bay area for different agricultural uses in the future should be fully evaluated. Control of the excessive use of fertilizers and pesticides should be enforced and the most appropriate crop varieties and systems of irrigation for future climate conditions should be identified.

4.6.2 Fisheries

On the basis of present knowledge it is impossible to suggest appropriate action.

4.6.3 Aquaculture

Reduction of pollution by organic matter of the Jadro River in order to reduce oxygen depletion. The area of the Pantana hatchery could be protected by embankment of the site. There is no information to suggest how the existing aquaculture could be adapted to the predicted changes.

4.7 Industry and energy

Predicted effects should be taken into account in the preparation of future development plans for the coastal region, particularly in terms of the future use of the areas where the chemical plant, cement works and ferro-alloy plant are presently located. The shipyards should undertake appropriate modification of their facilities to cope with the anticipated sea level rise.

4.8 Tourism

Adoption of an expected safe elevation for tourist establishments, industries, urbanization, drainage and sewage systems taking into account the scenarios of climate changes.

Development of educational programmes about coastal environments thus alerting the population, planners and decision makers to the possible consequences of climate changes and sea level rise and enabling them to be taken into account on an individual and collective basis.

4.9 Transport and services

The expected sea level rise should be taken into account in the planning of infrastructure along the coast. The necessary measures should be undertaken to protect the railway tracks in the Solin area.

4.10 Sanitation

Monitor changes in water quality of the Jadro water source and use appropriate water purification.

For the components of the water supply system and sewerage system affected by saltwater corrosion and intrusion, replacement with resistant materials and water proof joints will be necessary.

Sewerage systems should be better ventilated to reduced methane build-up.

All outflows should be designed and constructed in a manner appropriate for the new environmental conditions.

Some preconditions for future developments should be introduced. New design and construction criteria and regulations should be developed and adopted taking into account the conditions which will prevail under changing climate and sea level. All discharges to the watershed area of the Jadro river should be eliminated. New plans for the storm water system should be developed as well as new design criteria. This is especially necessary in the case of the storm water overflows.

All dead organic matter should be treated with more care in accordance with expected temperature levels. Sewerage wastes from the human environment should be properly treated, and new regulatory measures should be implemented.

Finally it is necessary to stress that sanitation problems can be analyzed and the negative effects avoided or mitigated only as an integral part of the other elements of the Kastela Bay environment, including socio-economic aspects of the problem.

4.11 Population and settlement pattern

Generally speaking, it is quite clear that the expected implications of climate change and sea level rise in Kastela Bay will neither cause large scale movements of population, nor, alter the general strategy of future socio-economic development in that area. However, in order to prevent or mitigate the possible hazards in Kastela Bay it is necessary to emphasize certain adaptive options which may have to be taken to reduce or limit the severity of the possible impacts. Those options can be summarized as follows:

- strengthen existing coastal protection systems in the Kastela Bay lowlands with the increased use of engineering solutions (sea-walls, breakwaters, etc.). Whenever physical protection of a site is not feasible, solutions may be sought through modification of existing structures. The climatic and the sea level rise implications should be taken into consideration in master (land use) plans for the area concerned;

- adoption of an expected safe elevation for industry, urbanization, drainage and sewerage systems which should take into consideration at least the moderate scenarios of climatic change and sea level rise; and

- prevent highly developed capital investment projects in the lowland costal area unless a detailed assessment of vulnerability of the Kastela Bay coastline to sea level rise is prepared.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The greenhouse effect is Man's most pressing environmental problems, one which presents major scientific challenges that span a wide range of disciplines.

Changes in global climate are likely to be dominated by the influence of global warming due to increasing concentration of carbon dioxide and other gases in the atmosphere, resulting from human activities.

The rise in mean sea level and global temperature are expected to be among the major consequences of the future climate change.

The expected temperature and precipitation changes for three time horizons (2030, 2050, 2100) in the Kastela Bay area were calculated using temperature and precipitation scenarios constructed by the Climatic Research Unit, University of East Anglia, based on General Circulation Models. The uncertainty of these scenarios is relatively high, especially for precipitation changes, since the models do not take account local orographic conditions.

One of the important aspects of the prevailing climate in the Adriatic is the passage of mid-latitude cyclones and anticyclonic conditions over the area. Climate conditions are thus determined as an average of such events. Either a decrease or an increase in the frequency of these transient atmospheric perturbations could appreciably affect winds, rainfall and temperature and the present data are inadequate to determine the direction of change.

Increased air temperature together with predicted precipitation changes will generally increase potential evapotranspiration during the summer season which will increase the soil moisture deficit.

Physical degradation and soil erosion by surface run-off due to increased storm rainfall will occur on steep slopes with impermeable flysch substrates.

Local water resources in the narrow coastal strip will be affected by sea level rise. Aquifers will change position and be reduced in capacity. Coastal springs will be relocated at higher elevations and flow rates to river bank aquifers will consequently be changed.

Sea level rise will increase the level of the water table which will affect foundations and basements of coastal historic buildings (Trogir, Kastela and Diocletian's Palace).

Existing sewage discharge outlets will be affected by the sea level rise. The sea water will intrude into pipes resulting in changes in discharge rates, increase of waste water level in the sewage network with a possibility of upstream sewage flooding.

Freshwater ecosystems in the lower reaches of the rivers Zrnovnica and Jadro will be affected by the sea level rise, which will alter their salinity regime.

Primary production in the marine ecosystem will be increased but this effect will be countered by a reduction in nutrient inputs from waste water. Red tides will consequently be reduced in frequency. Although changes in primary production are likely to occur it is impossible to predict how these will be reflected further up the food chain and in particular affect the availability of important fish species.

The predicted increase in air temperature will be generally favourable for agricultural crop production extending the growing period. Decreased soil moisture will however require additional water for irrigation.

Pelagic species could be affected by sea water increases, approaching coastal areas earlier and remaining longer than under present conditions. This would lengthen the traditional fishing season. Changes in water mass circulation could impact migration pattern of these fish species, but such impacts cannot be predicted due to lack of information.

The anticipated sea level rise may adversely affect the Pantana hatchery since the area may be flooded.

Existing industry should be re-structured regardless of the expected climate changes since it is the greatest energy consumer in the area and at the same time a significant source of pollution within the bay.

The temperature increase may favour consumption of soft drinks and beer, and affect cloth production and the footwear industry. Also, it will reduce the need for heating in winter but increase demand for air-conditioning in summer.

The temperature increase may extend the summer tourist season.

Sea level rise will affect the city harbour, the existing marinas and railway infrastructure in the city of Solin. Increase in precipitation, manifested as a higher number of rainy days, particularly in spring and summer, will cause an increase in the number of traffic accidents.

Sea level rise will influence the water supply network through corrosion from sea water intrusion into ground water. The increased water levels will affect the operation of the existing sewage system and future treatment plants.

5.2 The major impacts expected to result from anticipated climatic changes and recommended response measures

The major impacts expected from the predicted climate change are given below, together with suggestions for actions to cope with them:

- the rise in mean sea level over the next century would cause gradual and permanent inundation of the Pantana spring as well as areas around the Zrnovnica estuary. An increased frequency of episodic flooding of low-lying coastal areas up to 2 m altitude is likely to occur during the second half of the next century when the mean sea level is expected to exceed 50 cm;

- rising sea levels will result in intrusion of saline water into the estuaries of the rivers Jadro and Zrnovnica and into ground water resulting in river flooding and changes to local ecosystems;

- even a small rise in the water table, and increased ground water salinity will have negative impacts on coastal services and infrastructure with associated maintenance costs, as well as causing accelerated deterioration of valuable historic buildings; and

- the expected increase in temperature may increase domestic, industrial and agricultural water requirements and enhance aridity of the land.

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APPENDIX

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ANNEX

TEMPERATURE AND PRECIPITATION SCENARIOS FOR THE KASTELA BAY REGION

Report to the UNEP Co-ordinating Unit for the Mediterranean Action Plan

January 1992

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TEMPERATURE AND PRECIPITATION SCENARIOS FOR THE KASTELA BAY REGION

Report to the UNEP Co-ordinating Unit for the Mediterranean Action Plan

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SUMMARY

We have applied the methods developed by Kim et al. (1984) and Wigley et al. (1989) to the problem of constructing sub-grid-scale climate change scenarios for the area surrounding Kastela Bay, in Yugoslavia. Regression equations were developed to predict station temperature and precipitation anomalies from regionally-averaged climate anomalies. We proceeded to substitute GCM perturbed-run minus control-run values of temperature and precipitation in the regression equations to obtain a prediction of the change due to the greenhouse effect at each station. The results were scaled by the equilibrium temperature of each of the four GCMs and an average for the four models obtained. The procedure was repeated for every station in the data set, and the results contoured to produce a scenario for the Kastela Bay region.

Annual and seasonal scenarios for both temperature and precipitation change were produced. It was noted that the scenarios presented in the Final Report demonstrated a very pronounced gradient across the northern Mediterranean coast. This mean that the scenarios for the Kastela Bay region show large differences over relatively short distances and must be interpreted with care.

The temperature response at the annual level around Kastela Bay is indicated to be close to, and possibly slightly below, the global mean change i.e. less than 1°C. The annual precipitation change scenario indicates that there may be a slight increase in rainfall amounts around Kastela Bay due to the enhanced greenhouse effect.

In all seasons the temperature change around Kastela Bay is close to the global value (i.e. 1°C per degree global change). In winter and spring the predicted change is around, or slightly below, 0.9°C per degree global change. In summer and autumn the change is indicated to be slightly greater, but not more than the global sensitivity, i.e. not greater than 1°C per degree global change.

Precipitation shows an increase in all seasons except autumn. In winter, the change is predicted to be of the order of +2% per degree global temperature change. In spring an increase of 6%/°C is indicated. The greatest change is shown in summer: over 10%/°C. However, this is a season of very low rainfall amounts so that only a small absolute increase will be expressed as a very large percentage change. The model-predicted reduction in autumn rainfall is slight: between 0% and 2%/°C.

The confidence that we can place in regional scenarios of climate change due to the enhanced greenhouse effect is low, and this is particularly true for precipitation scenarios.

1. THE USE OF GCMS IN REGIONAL SCENARIO DEVELOPMENT

It is generally accepted that the results from General Circulation Models (GCMs) offer the best potential for the development of regional climate scenarios. They are the only source of detailed information on future climates which can extrapolate beyond the limit of conditions which have occurred in the past.

GCMs are complex, computer-based, models of the atmospheric circulation which have been developed by climatologists from numerical meteorological forecasting models. The standard approach is to run the model with a nominal "pre-industrial" atmospheric CO_2 concentration (the control run) and then to rerun the model with doubled (or sometimes quadrupled) CO_2 (the perturbed run). In both, the models are allowed to reach equilibrium before the results are recorded. This type of model application is therefore known as an equilibrium response prediction.

The fact that the GCMs are run in equilibrium mode must in itself be regarded as a potential source of inaccuracy in model predictions. It can be argued that the predicted regional patterns of climate change will differ from those that will occur in a real, transient response world. This is because equilibrium results ignore important oceanic processes, not least ocean current changes, differential thermal inertia effects between different parts of the oceans and between land and ocean, and changes in the oceanic thermohaline circulation. Transient response predictions, where the CO_2 concentration increases gradually through the perturbed run and where the oceans are modelled using ocean GCMs, and which therefore should provide a more realistic estimate, are becoming available. However, the complexity of the problem in relation to present-day computing capability casts doubt on the reliability of the results, and this is likely to remain the case over the next decade. The present study restricts itself, therefore, to the use of results from equilibrium GCM experiments.

The results from four GCMs developed for climate studies are used in this report. These four are from the following research institutions:

UK Meteorological Office (UKMO)
Goddard Institute of Space Studies (GISS)
Geophysical Fluid Dynamics Laboratory (GFDL)
Oregon State University (OSU)

The models vary in the way in which they handle the physical equations describing atmospheric behaviour. UKMO, GISS and OSU solve these in grid-point form whereas GFDL uses a spectral method. All models have a realistic land/ocean distribution and orography (within the constraints of model resolution); all have predicted sea ice and snow; clouds are calculated in each atmospheric layer in all models.

One problem with the application of GCMs to the study of climate impacts is the coarse resolution of the model grid. The grid scale of the four models listed above ranges from 4° latitude x 5° longitude (OSU) to 7.83° latitude x 10° longitude (GISS). GCMs, therefore, have a spatial resolution of several hundreds of kilometres, which is inadequate for many regional climate change studies, especially in areas of high relief. We present here a set of high resolution scenarios for the north-eastern Mediterranean, based on the statistical relationship between grid-point GCM data and observations from surface meteorological stations.

2. CONSTRUCTION OF SUB-GRID-SCALE SCENARIOS

Kim et al. (1984) looked at the statistical relationship between local and large-scale regionally-averaged values of two meteorological variables: temperature and precipitation. They then used these relationships, developed using principal component analysis techniques, to look at the response of local temperature and precipitation to the predicted change at GCM grid points. The area of study was Oregon State. Although the paper contains certain statistical flaws, the underlying idea of relating local and large-scale data statistically is sound. The method of Kim et al. has been extended and refined by Wigley et al. (1990) and by Wilks (1989).

The methods of Kim et al. and Wigley et al. have been modified for application in the Mediterranean region. In the model validation exercise carried out for the Mediterranean Project (see Final Report) it was established that no single GCM can be identified as being always the best at simulating current climate. This being the case, there is little merit in presenting scenarios based on only one model. Presentation of scenarios for each of the four models avoids the issue, since the task of deciding which model is 'best', and/or of synthesizing the information to obtain a best estimate, is left to the impact analyst. We have therefore combined the information from the four models into a single scenario for each variable, according to the method described below.

The problem with presenting the scenarios in this form is that the results may be biassed by the different equilibrium responses of the individual models. The global warming due to $2xCO_2$ for the four GCMs ranges between 2.8°C for the OSU model and 5.2°C for the UKMO model run. We would therefore expect that the warming indicated by the UKMO GCM for the Mediterranean Basin will be greater than that suggested by the OSU model, even though the sensitivity of the region to climate change when compared to the global sensitivity might be the same. The individual model perturbations have therefore been standardized by the equilibrium (global annual) temperature change for that model, prior to the calculation of the four-model average.

We required a generalized computer program that would be applicable throughout this geographically complex area, and could be used with meteorological records of variable length and density. After investigating a number of approaches to the problem, we adopted the procedure summarized below:

1. Data sets of monthly mean temperature and total precipitation have been compiled for the area surrounding the Mediterranean Basin. Stations used in this study of the Kastela Bay region are listed in Appendix 1. Where possible, each record should be complete for the period 1951-88. Any station with a record length less than 20 years in the period 1951-88 for over six months out of twelve was immediately discarded.

2. Then, for every valid station, the temperature and precipitation anomalies from the long-term (1951-88) mean were calculated. For this part of the work, which is the first step in the construction of the regression equations (the calibration stage), only the data for 1951-80 were used. The 1981-88 data were retained to test the performance of the regression models (the verification stage, see Final Report). For the calculation of the temperature anomaly At_{ij}, the simple difference was used:

$$At_{ij} = t_{ij} - T_j$$

where t_{ij} is the mean temperature of month j in year i, and T_j is the long-term mean for month j. The precipitation anomaly Ap_{ij} was expressed as a ratio of the long-term mean:

$$Ap_{ij} = (p_{ij} - P_j)/P_j$$

where p_{ij} is the monthly total precipitation in month j of year i, and P_j is the long-term mean for that month. If P_j is less than 1mm, then this equation is modified to:

$$Ap_{ij} = (p_{ij} - P_j)/1.0$$

3. The individual station anomalies are used to calculate regionally-averaged anomalies. The procedures described from here to the end of Point 6 are station-specific, and must be repeated for each station in the data set.

   A 5° latitude x 5° longitude square is centred over the station for which regression equations are to be developed (the predicted station). All the stations which fall within this square are used to calculate the regional averages. If the number of stations is less than three, for temperature, or four, for precipitation, the procedure is halted. For temperature, the anomalies from all stations in the 5° x 5° square are averaged month-by-month to produce an area-average time series. For precipitation, the substantial degree of spatial variability makes it advisable to area-weight the station anomalies before calculating the regional mean for each month. To do this, the 5° x 5° region is divided into 20 x 20 smaller squares. The precipitation anomaly value assigned to a particular square is that of the station nearest to it (with the restriction that the distance separating a square from its nearest station should be no greater than 1° - where the distance is greater the square is ignored). The area average is then the mean of the values in the 400 (or fewer, if any fail the minimum distance criterion) squares. This method is similar to the standard Thiessen polygon method.

4. Regression analyses were performed using station temperature and precipitation anomalies as the predictands. These analyses were carried out on an annual and seasonal basis: winter (December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October and November). By considering the monthly values as separate observations within each season, we were able to extend the number of observations and so preserve a high number of degrees of freedom. The predictor variables are the regionally-averaged anomalies of temperature and precipitation.

5. In order to determine the perturbation due to the greenhouse effect at each station, the results from GCMs were employed. It is assumed that a GCM grid-point temperature or precipitation value is equivalent to a regionally-averaged value derived from observational data. For each of the four GCMs (GFDL, GISS, OSU and UKMO), the perturbed run and control run grid-point temperature (t) and precipitation (p) values are interpolated to the station position. Then, we obtain, for temperature:

$$Atm_i = t_i(2 \times CO_2) - t_i(1 \times CO_2)$$

where Atm is the perturbation due to CO_2 or the 'temperature anomaly' for model i and, for precipitation:

$$Ptm_i = [p_i(2 \times CO_2) - p_i(1 \times CO_2)] \times 100/p_i(1 \times CO_2)$$

where Ptm is the standardized perturbation due to CO_2 or the 'precipitation anomaly'.

The values for Atm and Ptm for each GCM are then substituted in the regression equations to obtain a prediction for the station perturbation of temperature (°C) and precipitation (%) due to CO_2.

6. The predicted change in temperature and precipitation for each model is divided by the equilibrium (global mean) temperature change for that model. The results are then averaged across the four models to obtain a composite value.

7. The procedures from Points 3 to 6 is repeated for each station throughout the Mediterranean. The results can then be plotted and contoured to obtain a map of the expected patterns of temperature and precipitation change due to the greenhouse effect.

In order to arrive at this procedure, a rigorous investigation of the validity of the method has been carried out. In particular, we have looked at:

- the use of other predictor variables in the regression equations
- performance and verification of the regression equations
- autocorrelation in the data
- multicollinearity in the predictor variables

These aspects are discussed in detail in the Final Report.

3. CLIMATE CHANGE SCENARIOS FOR THE KASTELA BAY REGION

The sub-grid-scale scenarios, constructed according to the method outline in Section 2, are shown in Figs. 1-5. The temperature perturbations are presented as the model average change, in degrees Celsius, per °C global annual change. The precipitation perturbations are shown as the percentage change for each 1°C global annual change. This procedure is described in greater detail, and the approach justified, in Section 2.

The problem with expressing the scenarios in this form is then to scale the values up (or down) in relation to some realistic estimate of the temperature perturbation to be expected from the greenhouse effect. The IPCC Report (Houghton et al., 1990) provides one such family of estimates. For their Business-as-Usual scenario of emissions, the likely increase of global mean temperature by the year 2050 is predicted to be about 1°C above the present level. By the end of next century, the increase is estimated at 3°C above present-day. On this basis, the temperature and precipitation scenarios for the Kastela Bay region presented in this report can be related directly to changes between now and the year 2050.

The location of Kastela Bay, on the northern coast of the Mediterranean, must be taken into account in evaluating the sub-grid-scale scenarios presented here. It was found in the Final Report that this northern coast is a zone of very rapid transition, particularly noticeable in the scenarios for temperature. Under this circumstance, it would be unwise to regard the predictions for future climate trends as in any way exact: they can only be taken as a general guide to possible future conditions, as indicated by the results from GCMs.

The scenarios for changes at the annual level are presented in Fig. 1. The temperature response around Kastela Bay is indicated to be close to, and possibly slightly below, the global mean change i.e. less than 1°C. The precipitation scenario indicates that, at the annual level, there may be a slight increase in rainfall amounts around Kastela Bay.

The seasonal maps are presented in Figs. 2-5. In all seasons the temperature change around Kastela Bay is close to the global value (i.e. 1°C per degree global change). In winter (the months of December, January and February) and spring (March, April, May) the predicted change is around, or slightly below, 0.9°C per degree global change. In summer (June, July, August) and autumn (September, October, November) the change is indicated to be slightly greater, but not more than the global sensitivity, i.e. not greater than 1°C per degree global change.

Precipitation shows an increase in all seasons except autumn. In winter, the change is predicted to be of the order of +2% per degree global temperature change. In spring an increase of 6%/°C is indicated. The greatest change is shown in summer: over 10%/°C. However, this is a season of very low rainfall amounts so that only a small absolute increase will be expressed as a very large percentage change. The model-predicted reduction in autumn rainfall is slight: between 0% and 2%/°C.

Fig. 1 Regional climate scenarios for the Kastela Bay region: annual. Temperature in units of °C per degree global change; precipitation in units of % per degree global change.

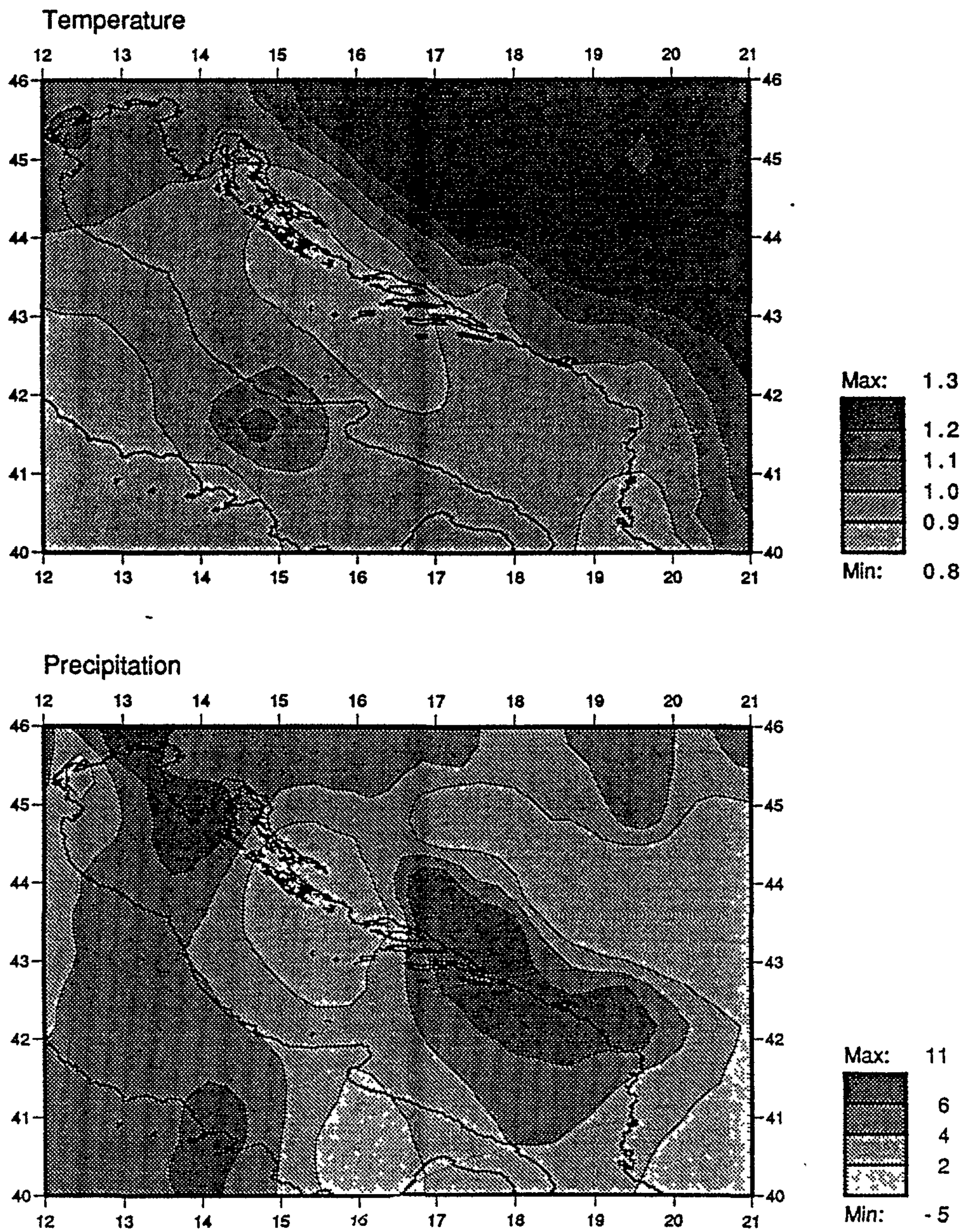


Fig. 2 Regional climate scenarios for the Kastela Bay region: winter. Temperature in units of °C per degree global change; precipitation in units of % per degree global change.

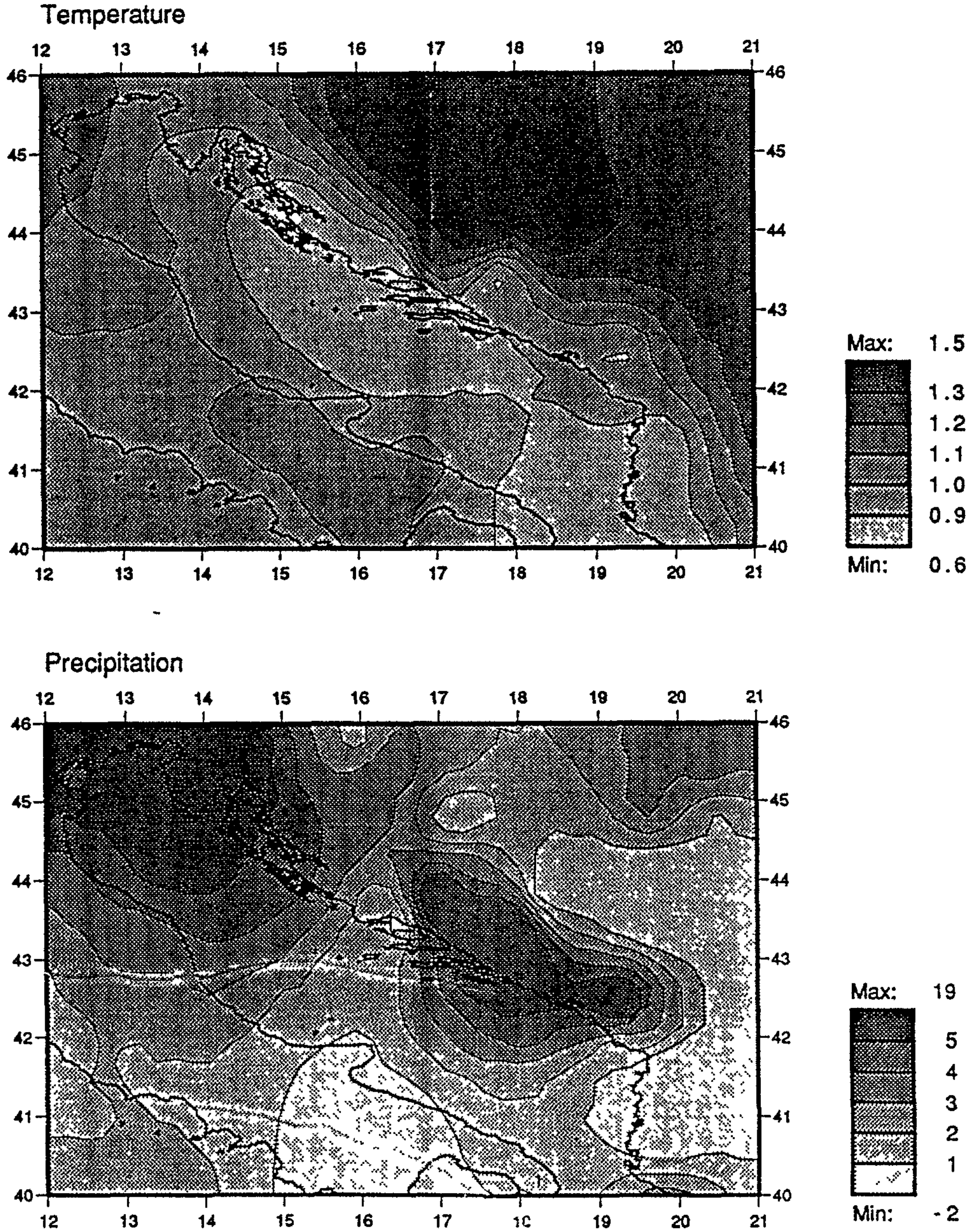
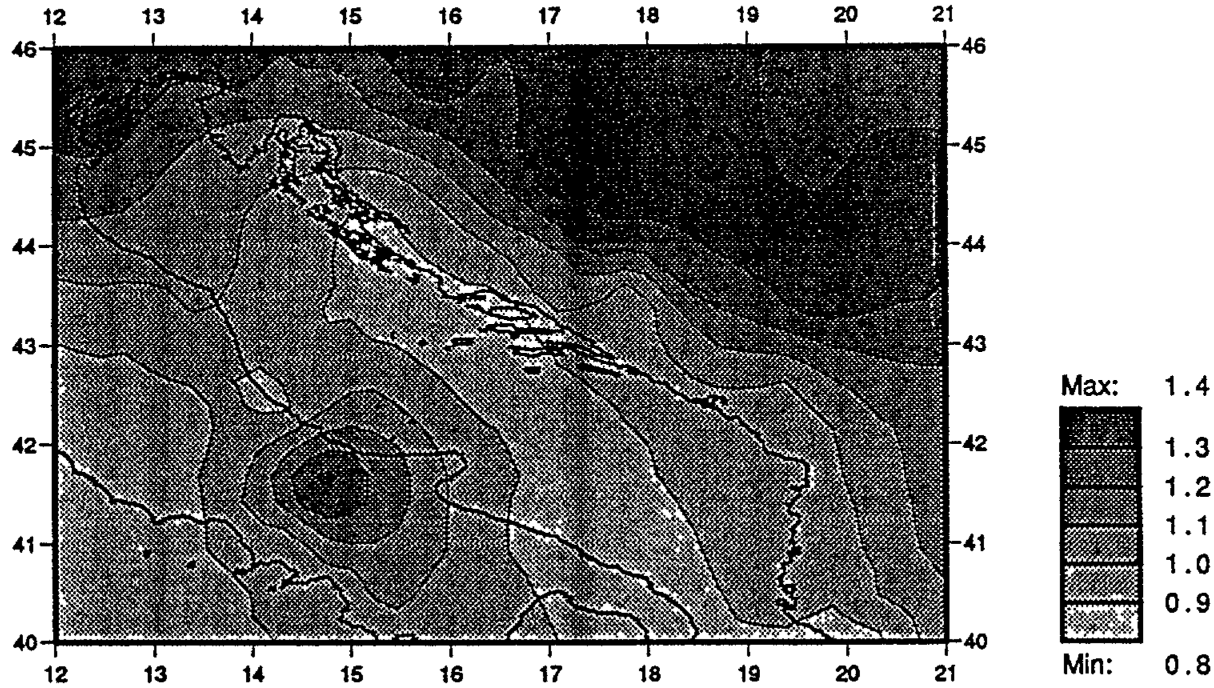


Fig. 3 Regional climate scenarios for the Kastela Bay region: spring. Temperature in units of °C per degree global change; precipitation in units of % per degree global change.



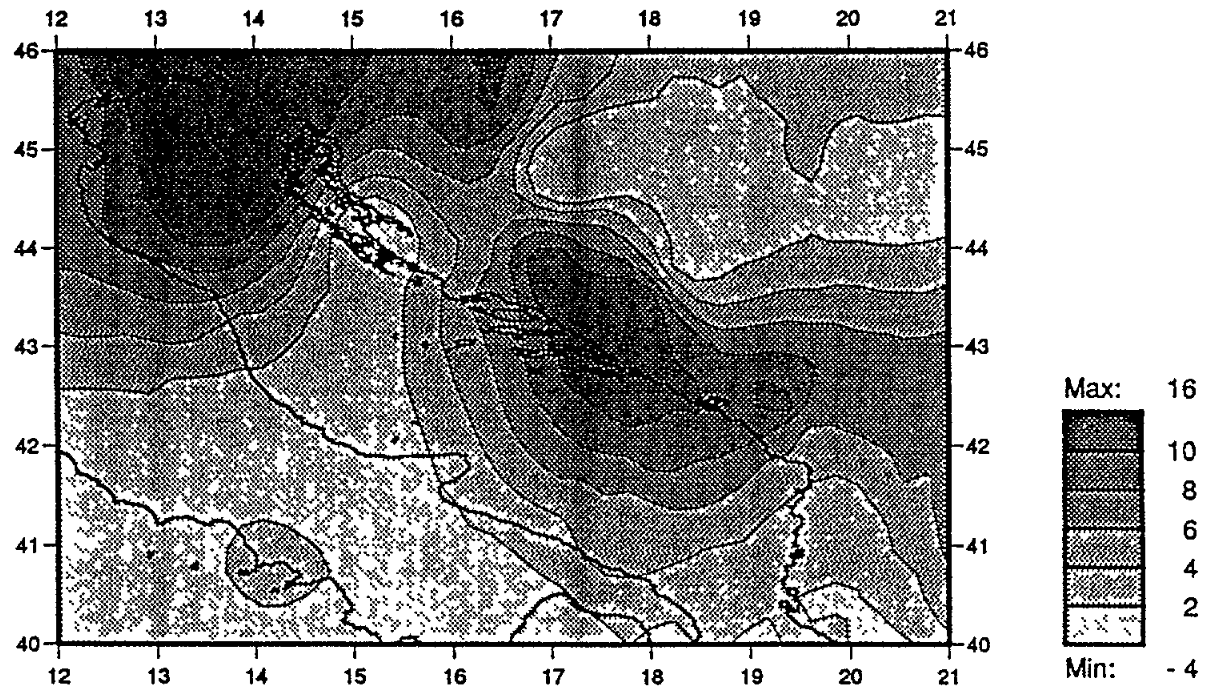
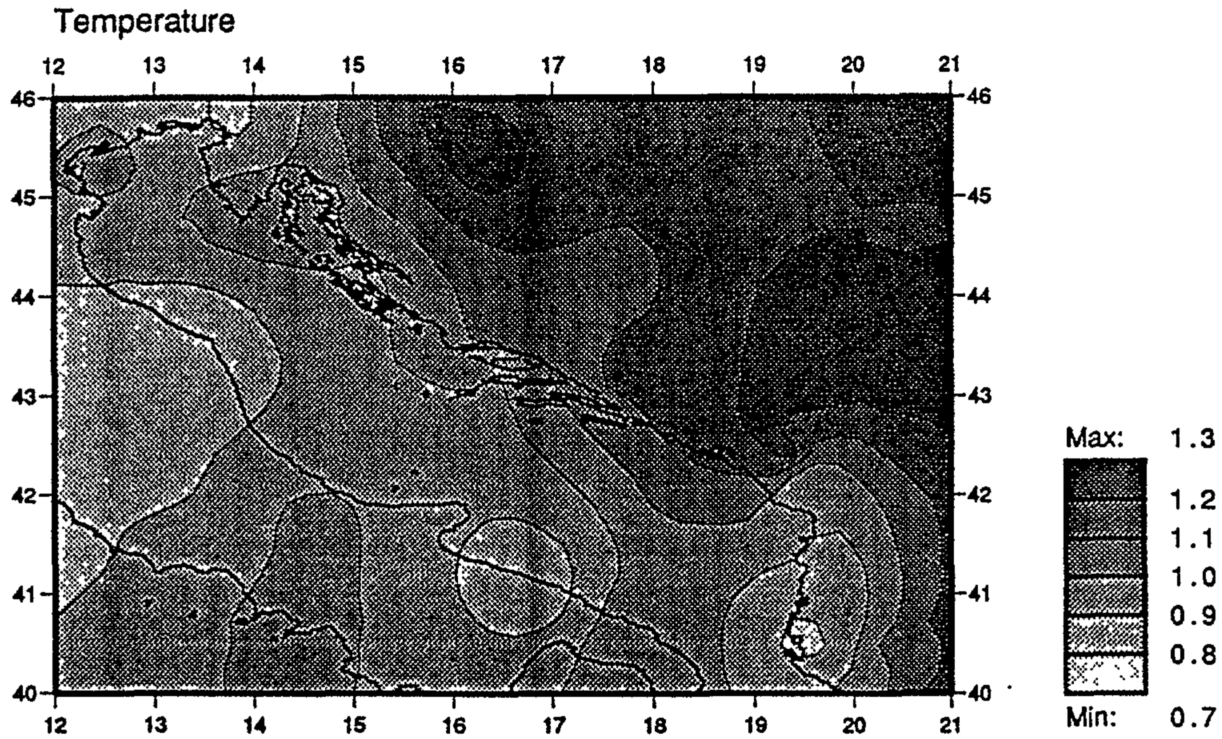


Fig. 4 Regional climate scenarios for the Kastela Bay region: summer. Temperature in units of °C per degree global change; precipitation in units of % per degree global change.



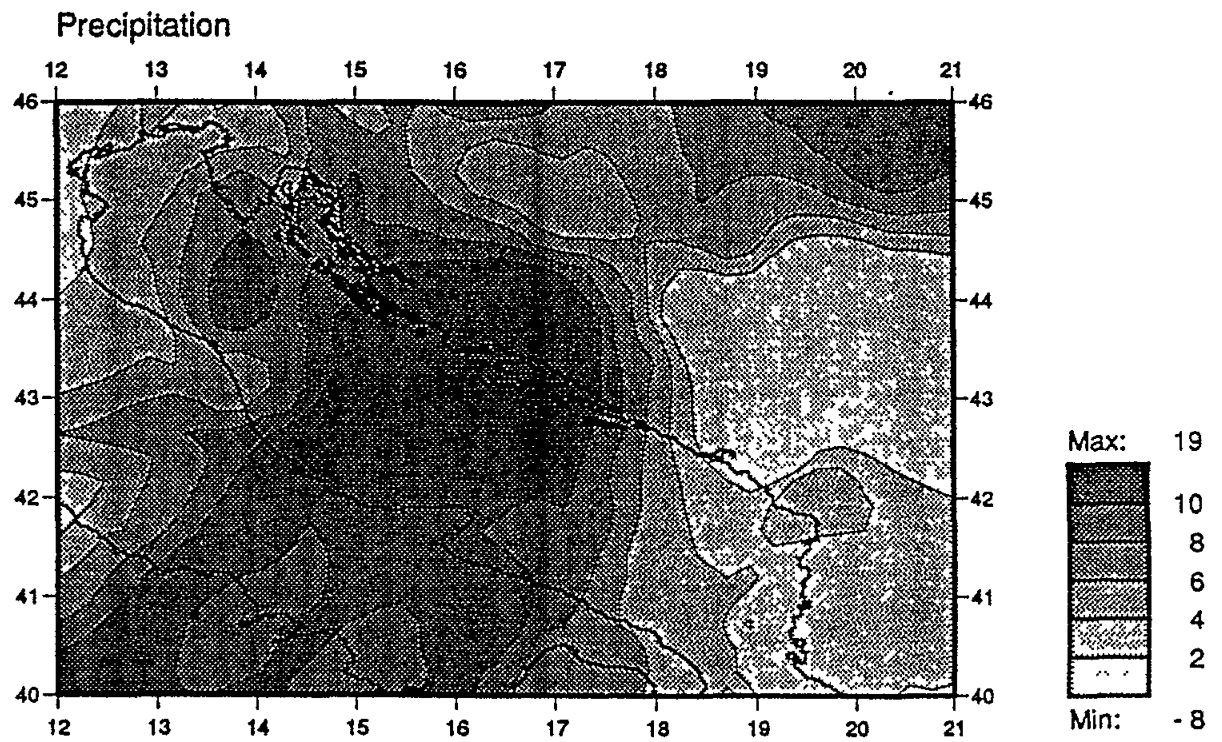
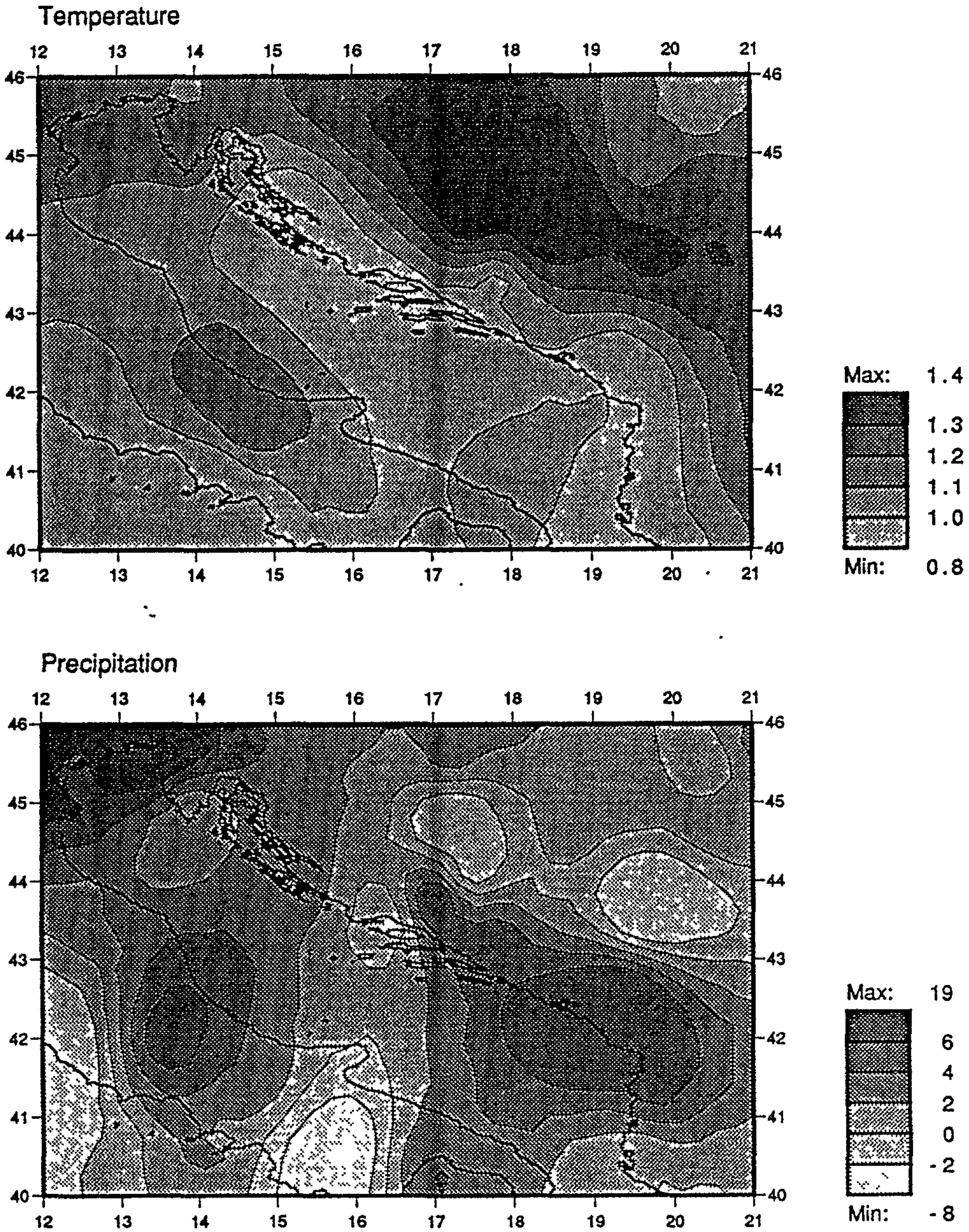


Fig. 5 Regional climate scenarios for the Kastela Bay region: autumn. Temperature in units of °C per degree global change; precipitation in units of % per degree global change.



4. CONCLUSIONS

We have applied the methods developed by Kim et al. (1984) and Wigley et al. (1989) to the problem of constructing sub-grid-scale climate change scenarios for the Kastela Bay region. Regression equations were developed to predict station temperature and precipitation anomalies from regionally-averaged climate anomalies. We proceeded to substitute GCM perturbed-run minus control-run values of temperature and precipitation in the regression equations to obtain a prediction of the change due to the greenhouse effect at each station. The results were scaled by the equilibrium temperature of each of the four GCMs and an average for the four models obtained. The procedure was repeated for every station in the data set, and the results contoured to produce a scenario.

Annual and seasonal scenarios for both temperature and precipitation change were produced. It was noted that the scenarios presented in the Final Report demonstrated a very pronounced gradient across the northern Mediterranean coast. This mean that the scenarios for the Kastela Bay region show large differences over relatively short distances and must be interpreted with care.

The temperature response at the annual level around Kastela Bay is indicated to be close to, and possibly slightly below, the global mean change i.e. less than 1°C. The annual precipitation change scenario indicates that there may be a slight increase in rainfall amounts around Kastela Bay due to the enhanced greenhouse effect.

In all seasons the temperature change around Kastela Bay is close to the global value (i.e. 1°C per degree global change). In winter and spring the predicted change is around, or slightly below, 0.9°C per degree global change. In summer and autumn the change is indicated to be slightly greater, but not more than the global sensitivity, i.e. not greater than 1°C per degree global change.

Precipitation shows an increase in all seasons except autumn. In winter, the change is predicted to be of the order of +2% per degree global temperature change. In spring an increase of 6%/°C is indicated. The greatest change is shown in summer: over 10%/°C. However, this is a season of very low rainfall amounts so that only a small absolute increase will be expressed as a very large percentage change. The model-predicted reduction in autumn rainfall is slight: between 0% and 2%/°C.

Regional scenarios of climate change due to the enhanced greenhouse effect can only be assigned a low level of probability, and this remark is particularly true for precipitation scenarios.

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APPENDIX 1

STATIONS AVAILABLE FOR USE IN SCENARIO CONSTRUCTION FOR THE KASTELA BAY REGION

Note that not all these stations will necessarily be used in the final scenario construction. They must first fulfill the criteria for acceptance laid down in Section 2 of this report, and in the Final Report.

ALBANIA

Station	E	N	HT	PRN	TEM	P%	T%
1. SHKODRA	19.5	42.1	43	1951-1970	1951-1970	100	100
2. TIRANA	19.8	41.3	89	1951-1970	1951-1970	100	100
3. VLORA	19.5	40.5	1	1951-1970	1951-1970	100	100

BULGARIA

Station	E	N	HT	PRN	TEM	P%	T%
4. VRATZA	23.5	43.2	360	1951-1970	1951-1970	92	92
5. LOM	23.2	43.8	33	1961-1989	1961-1979	43	41
6. SOFIA	23.3	42.7	564	1951-1989	1951-1979	67	72

FRANCE

Station	E	N	HT	PRN	TEM	P%	T%
7. BASTIA	9.4	42.7	n/a	1961-1985	1961-1985	100	100

GREECE

Station	E	N	HT	PRN	TEM	P%	T%
8. KERKYRA	19.9	39.6	2	1951-1989	1951-1988	96	96
9. YANENA	20.7	39.6	n/a	1956-1987	-	100	0
10. AGRINION	21.7	38.6	47	1956-1987	-	99	0
11. ARAXOS	21.4	38.2	23	1951-1987	1951-1970	99	100
12. ZAKYNTHOS	20.9	37.8	8	1951-1982	1951-1982	79	79
13. KOZANI	21.8	40.3	627	1955-1987	1955-1987	100	100
14. MIKRA	23.0	40.5	61	1951-1989	1951-1987	96	100
15. LARISSA	22.4	39.6	74	1951-1989	1951-1987	94	97
16. AGXIALO	22.8	39.0	n/a	1956-1987	1956-1987	100	98
17. TRIPOLIS	22.2	37.6	660	1957-1987	1957-1987	100	100
18. KALAMATA	22.1	37.0	5	1951-1989	1951-1988	94	95
19. TANAGRA	23.5	38.3	n/a	1957-1986	1957-1986	99	99
20. ATHENS	23.7	38.0	107	1951-1989	1951-1988	98	97
21. HELLENIKON	23.7	37.9	10	1951-1989	1951-1987	84	80

ITALY

Station	E	N	HT	PRN	TEM	P%	T%
22. TRENTO	11.1	46.1	312	1951-1976	-	100	0
23. UDINE	13.2	46.0	92	1967-1989	1967-1980	93	95
24. MILANO	9.2	45.5	103	1951-1987	1951-1986	95	99

25. VERONA	10.9	45.4	67	1961-1989	1961-1985	98	97
26. PADUA	12.0	45.4	13	1951-1974	-	100	0
27. VENEZIA	12.4	45.4	17	1951-1989	1951-1988	98	100
28. TRIESTE	13.8	45.7	20	1951-1989	1951-1988	98	100
29. PARMA	10.3	44.8	56	1951-1977	1951-1976	100	100
30. BOLOGNA	11.5	44.5	60	1951-1974	1961-1970	100	100
31. PISA	10.4	43.7	2	1961-1989	1961-1980	97	100
32. FLORENCE	11.3	43.8	75	1951-1977	1951-1970	100	100
33. ANCONA	13.5	43.6	104	1951-1978	1951-1978	98	98
34. PESCARA	14.2	42.4	9	1961-1989	1961-1980	97	100
35. ROME	12.2	41.8	2	1951-1989	1951-1988	98	99
36. NAPOLI	14.3	40.9	88	1961-1987	1961-1987	99	99
37. BRINDISI	18.0	40.7	15	1961-1989	1961-1980	98	100
38. MARINA	16.9	40.4	12	1967-1989	1967-1980	96	95
39. MESSINA	15.6	38.2	51	1961-1989	1961-1980	98	100
40. TRAPANI	12.5	37.9	79	1961-1989	1961-1980	98	100
41. CATANIA	15.1	37.5	65	1961-1987	1961-1987	98	99
42. CAGLIARI	9.1	39.3	18	1951-1989	1951-1988	98	99
43. AVEZZANO	13.6	42.0	n/a	1951-1970	-	100	0
44. BOLZANO	11.3	46.5	241	1961-1985	1961-1985	99	91
45. GROSSETO	11.1	42.8	5	1961-1985	1961-1985	99	100
46. PERUGIA	12.5	43.1	208	-	1961-1985	0	98
47. FALCONARA	13.4	43.6	12	-	1961-1985	0	97
48. CAMPOBASSO	14.7	41.6	793	1961-1985	1961-1985	99	99
49. BARI	16.8	41.1	34	-	1961-1985	0	99
50. POTENZA	15.8	40.6	823	1961-1985	1961-1973	99	96
51. CROTONE	17.1	39.0	155	-	1961-1985	0	99
52. PALERMO	13.1	38.2	21	-	1961-1985	0	99

RUMANIA

Station	E	N	HT	PRN	TEM	P%	T%
53. ORADEA	21.9	47.1	135	1951-1970	1951-1970	100	99
54. CLUJ	23.7	46.8	415	1951-1988	1951-1980	98	99
55. TIMISOARA	21.3	45.8	91	1951-1988	1951-1980	98	99

YUGOSLAVIA

Station	E	N	HT	PRN	TEM	P%	T%
56. PULA	13.9	44.9	30	1951-1980	1951-1980	100	100
57. ZADAR	15.2	44.1	1	1951-1980	1951-1980	100	100
58. HVAR	16.4	43.2	20	1951-1980	1951-1980	100	100
59. VARAZDIN	16.4	46.3	169	1951-1980	1951-1980	100	100
60. DARUVAR	17.2	45.6	161	1951-1980	1951-1980	100	100
61. BANJA-LUKA	17.2	44.8	160	1951-1980	1951-1980	100	100
62. BUGOJNO	17.5	44.1	562	1951-1980	1951-1980	100	100
63. MOSTAR	17.8	43.4	99	1951-1980	1951-1980	100	100
64. TUZLA	18.7	44.6	305	1951-1980	1951-1980	100	100
65. SREMSKA	19.6	45.0	81	1951-1980	1951-1980	100	100
66. ZRENJANIN	20.4	45.4	82	1951-1980	1951-1980	100	100
67. ZLATIBOR	19.7	43.7	1029	1951-1980	1951-1980	100	100
68. ULCINJ	19.2	41.9	30	1951-1980	1951-1980	100	100
69. NIS	21.9	43.3	196	1951-1980	1951-1980	100	100
70. PRILEP	21.6	41.3	661	1951-1980	1951-1980	100	100
71. ZAGREB	16.0	45.8	163	1951-1989	1951-1988	98	99

72. SISAK	16.4	45.5	98	1951-1970	1951-1970	100	100
73. BEOGRAD	20.5	44.8	132	1951-1989	1951-1988	98	97
74. SPLIT	16.4	43.5	129	1951-1989	1951-1988	98	99
75. LIVNO	17.0	43.8	730	1951-1970	1951-1970	100	100
76. SARAJEVO	18.4	43.9	637	1951-1989	1951-1988	97	99
77. TITOGRAD	19.3	42.4	33	1951-1989	1951-1988	97	98
78. SKOPJE	21.5	42.0	240	1951-1989	1951-1988	97	98

E - latitude
N - longitude
HT - height above sea level (m)
PRN - length of precipitation record
TEM - length of temperature record
P% - percentage of precipitation record present
T% - percentage of temperature record present